www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; SP-10(8): 667-673
© 2021 TPI
www.thepharmajournal.com
Received: 25-06-2021
Accepted: 27-07-2021

Kale PR
Ph.D. Research Scholar, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Pawar VS
Head, Department of Food Process Technology, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Shendge SN
Ph.D. Research Scholar, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Corresponding Author
Kale PR
Ph.D. Research Scholar, College of Food Technology, VNMKV, Parbhani, Maharashtra, India

Recent advances in stored grain pest management: A review

Kale PR, Pawar VS and Shendge SN

Abstract
The pest causes severe damage to stored food grains in many parts of the world. Though effective synthetic pesticides have a number of drawbacks including high cost, non-biodegradability and adverse effects on humans and the environment prompting farmers to seek out a more powerful and economically feasible alternative. There are several recent advances were developed for stored grain pest management which may involves the use of PVOC, nanotechnology, inert dusts, sands, silica aerogel and ionizing radiation. The control of insect pest is done by using different techniques such as by use of Insect Pheromones, Insect Growth Regulators (IGRs), Cultural Control and Microbial Control. Plant volatile organic compounds (PVOC) minimizes the application of synthetic insecticides in stored grains pest management and exhibit their effect on insects through their several charateristeics such as their toxic effect, repellency, fumigant, growth inhibitor, suppression of reproductive behavior, chemosterilants, antifeedant or feeding deterrent and reduction fertility. Nanotechnology offering active ingredients for stored grain pest management over the world. Nanoparticles have a larger surface area and circulate more freely in insects and making them unique harness chemicals. There are various nanoparticles such as essential oil nanoparticles, silver, aluminum and zinc oxide, diatomaceous earths, silicon dioxide and nanosilica (nanobiopesticides) used for stored grain pest management. These recent methods may provide a solution to the problems associated with health risks, availability, costs and resistance of synthetic pesticide and used for stored grain pest management.

Keywords: stored grain, pest, insect, plant volatile organic compounds (PVOC), nanoparticles, management

Introduction
Human beings have three essential needs such as food, water and shelter. With a global population growth rate of 1.5 percent delivering food grains to the people is the most pressing challenge. The production of cereals and other food grains at present is about 67-80 percent of the human food supply and faces the increased demand. Grain production has been continuously increasing as well. However, incorrect storage leads to significant grain loss. Grain losses due to storage are 10 to 20 percent of total production and caused by insufficient storage capacity, insect and pest infestations and other factors (Phillips and Throne, 2010) [27].
India loses 12- 16 million metric tonnes of food grains per year as per the world bank report. Grain is important for humans because it is ingested on a daily basis and it has a significant impact on the economy. As a result food grain production is a critical component of economic and social growth. For that reason grain scientists from several countries are attempting to develop sophisticated scientific grain storage techniques and facilities. A grain that has been properly kept is identical to a grain that has been produced. Every year, India produces roughly 259.32 million tonnes of food grains. Farmers store roughly 60-70 percent of food grains for their own usage. Farmers in India prefer to store food grains in traditional ways, using various storage structures created from locally available materials. While large farmers store food grains in government run storage facilities such as the Food Corporation of India (Mobolade *et al.*, 2019) [21].
Food and Agriculture Organization (FAO) predicted that the world may face a huge scarcity of food if the total world food production is not increased by 70 percent by the year 2050. Despite the fact that accessible land resources may be sufficient to feed the worlds future population, the FAO warns that the majority of this potential land is suited for only a few crops, not necessarily the most in demand and is concentrated in a few nations. Food grains and pulses are mostly consumed and stored food products, especially in the tropical and sub-tropical regions.

Unfortunately more than 70 percent of the produced grains are stored in villages by using traditional structures such as earthen pots, silos, gunny bags, steel drums and baskets, which leads to loss of food grains and pulses particularly in less developed countries (Mobolade *et al*., 2019; Kesavan and Swaminathan, 2008) [21, 16].

Postharvest losses of food grains and pulses are caused by a variety of reasons, with insect damage posing the greatest hazard. It has been reported that there are several losses of approximately 5–30 percent of the due to insect infestation of stored food grains out of worlds total agricultural production. This large range of estimates is due to a variety of factors, including geographical zones, climatic conditions and the principal crops farmed. In addition, there is no reliable way for calculating the losses. By directly devouring the kernels, insects can cause significant harm to grains and pulses. Insect accumulation can causes both qualitative and quantitative losses of food commodity and make the grain unfit for human consumption. Due to change in environment of the storage chamber by insect infestation which could provide favorable conditions for the growth of storage fungi that cause further losses (Prusky, 2011; Rajashekar, 2012) [28, 30].

Major primary stored grain pests include rice weevil (*Sitophilus oryzae*), granary weevil (*Sitophilus granaries*), lesser grain borer (*Rhyzopertha dominica*), Khapra beetle (*Trogoderma granarium*) and the pulse beetle (*Callosobruchus chinensis*). There are also many secondary pests that causes damage to stored grain such as rusty grain beetle, saw toothed grain beetle and mites (Rajashekar, 2012) [30].

Improper storage procedures could result in the worldwide loss of a large number of food grains and pulses. As a result, farmers are forced to sell their produce early after harvest with low profits in expectation of grain losses owing to pest infestation. Food grain losses are caused by a variety of variables, including environmental considerations, the type of storage structure utilized, length and purpose of storage, method of storing grains etc. The environmental factors may involve temperature, moisture content of grains, pH and humidity etc. The biological factors such as insects, pests, microorganisms and rodents may causes qualitative and quantitative losses during storage. So, there are various recent advances in stored grains insect and pest management were developed.

Losses due to stored grain pests

According to current estimates, insect pests cause a 25 percent loss in rice and maize, a 5% loss in wheat and a 15% loss in pulses in India. More than 20,000 species of field and storage pests are responsible for the destruction of almost one-third of the worlds food production worth more than $100 billion per year. India being a tropical country suffers around 20–30percent damage to stored grains and grain products due to insect pests which is only around 5–10percent in the temperate zone. Food grain production in India was reported to be 250 million tons in the year 2010-2011, in which nearly 20–25percent food grains are damaged by stored grain insect pests. According to a World Bank research, 12-16 million tonnes of food grains are lost owing to storage pests, which could feed one-third of the world population if prevented. Therefore, there is a need to develop effective, economical and environmentally sustainable methods for control and management of stored grain pest (Rajashekar *et al.,* 2010; Sharon *et al*., 2014) [31, 36].

Stored grain pest management approaches

Traditional practices

Traditional age-old practises include storage of red gram (*Cajanus cajan*) grains with common salt, which are then packed in jute gunny bags and then stored. This method gave protection for 6-8 months from insects. *Azadirachta indica* leaves are most commonly used in traditional storage practices all over India. Use of lime and camphor are also common in storage of paddy in gunny bags. The use of neem (*Azadirachta indica*) oil in the seed storage treatment employs mixing 20 ml oil of for 1 kg of pulse seeds and use of neem seed kernel extract for a dip treatment to the jute gunny bags with before storage is also employed. Storage of grains with sweet flag (*Acorus calamus*) powder prevented insect infestation for 6 months as the strong odour emitted from sweet flag acted as a repellant against all the storage pests (Karthikeyan *et al*., 2009) [13].

To safeguard stored grains from insect infestation, farmers may rely on a variety of indigenous traditional knowledge. Several crop-specific storage strategies have been developed around the world to preserve the quality and quantity of food until it is consumed or transported to another location. Farmers created a variety of traditional structures for storing food grains using locally available raw materials such as bamboo, straw, wooden planks, mud, bricks and cow dung. Plant components or plant extracts were also commonly used as natural pesticides (Suleiman and Rugumamu, 2017) [40].

Conventional practices

Postharvest technology have long been responsible for preventing insect pests from causing damage to food crops around the world. Synthetic pesticides were established as the most successful and reliable means of managing store insects over the world with the start of the chemical era. In many developing nations, synthetic fumigants are widely and solely utilised to successfully destroy all phases of insect pest growth within storage facilities (Isman, 2006; Fields & White, 2002) [12, 8].

Methyl bromide and phosphine were used as a chemical fumigants to protect stored grain pests all over the world. Methyl bromide, on the other hand, was discovered to be hazardous to the stratospheric ozone layer and was recognised as an ozone-depleting compound in 1993, after which it was phased out in accordance with the Montreal Protocol. It results in a paradigm shift in phosphine usage not only in terms of quantity but also in terms of its application to a wide range of stored products other than food grains including spices, cocoa beans, dried fruit, nuts and even fresh fruits. Synthetic pesticides on the other hand have a number of drawbacks including damage to humans, ozone depletion, toxicity to non-target organisms, product adulteration, unpredictable supplies and unavailability during important periods. Furthermore, the cost of insecticides often puts a strain on the finances of small-scale farmers. An alternate strategy that can effectively reduce the usage of chemical insecticides is urgently needed. In this context, some recent advancements in stored grain pest management have been established (Norman, 2005; Horn *et al.,* 2005) [24, 11].

Use of Plant volatile organic compounds (PVOC) in stored grain pest management

The plants may contain organic bioactive compounds provide an odor that is typically volatile in nature and hence termed as plant volatile organic compounds (PVOC). Farmers all over the world have traditionally utilised these substances against stored grain pests. Toxicity, repellency, antifeedant or feeding deterrent, fumigant, growth inhibitor and suppression of reproductive behaviour and loss of fecundity and fertility are only some of the ways phytochemicals affect insects. Plant volatile organic compounds are essential oils consist of alkanes, alcohols, aldehydes and terpenoids especially monoterpenoids and extracts from many plant (Rajashekar, 2012) [30].

Insect growth, development and metamorphosis are all known to be influenced by phytochemicals. These have an irreversible effect on the insect physiology and behaviour, resulting in weight loss in larvae, pupae and adults as well as longer larval and pupal periods. Following larval treatment, various plant extracts inhibited percentage pupation. Plant-derived botanicals were also discovered to stop eggs and immature stages from developing inside grain kernels. Aqueous extracts of common cocklebur *Xanthium strumarium* (L.) (*Asteraceae*) leaf was also reported to show several insecticidal properties including repellency, inhibition of fecundity and adult emergence of the insects, toxic effect and grains protection against *C. chinensis* (Roy *et al*., 2014; Tatun *et al.*, 2014) [32, 42].

PVOC may act as a growth inhibitors, oviposition deterrents, antifeedants or feeding deterrents, repellents and chemosterilants against the stored grain pest. Oviposition deterrents means chemicals which prevent or avoid insect from egg laying. Oviposition deterrents have a lot of potential for preventing insect infestations and can be used as a first line of defence against pest insects. PVOC has been implicated in the prevention of egg laying and the development of several insect pest families from laid eggs on stored grains, according to many specialists. The oviposition rate of numerous insects was discovered to be affected by 1, 8 cineole, which was extracted from essential oils and their volatile component of diverse *Lamiaceae* plants. Use of garlic oil as an oviposition deterrent is also common against the stored grain pest management (Sousa *et al.,* 2015; Subramanyam *et al.*, 2012) [37, 39].

Antifeedants often known as "feeding deterrents," are chemical chemicals that interfere with an insect's feeding habit by rendering the treated meal unpleasant or unpalatable. Antifeedant is a type of insecticide that aims to eradicate insects without disrupting the natural balance of the environment. Antifeedants don't kill the target insect; instead they make them available to their natural predators. It's possible that the negative consequences will be acted upon. The discovery of azadirachtin and neem seed extracts as effective feeding deterrents opens the door to natural pesticides (Casida, 2012) [6].

Repellents are chemical that protect plants or stored grain products from insect damage by making them unappealing, unpalatable or unpleasant to insect pests. The ar-turmerone isolated from *Curcuma longa* (*Zingiberaceae*) rhizomes were reported to show effective repellent activity against *S. zeamais*. Chemosterilants are chemical compounds that prevent insects from reproducing. It has proven to be an important aspect of integrated pest management programs. The asarone isolated from the rhizomes of *A. calamus* and 1, 3, 7-trimethylxanthine isolate from seed extract possessed insect chemosterilant properties (Tavares *et al.,* 2013) [43].

Many plant volatiles may have ovicidal property means that potential to kill eggs especially the eggs of insects and mites etc. This property of plants helps in the management of insect-pests at every stages of their life cycle and preventing the damage caused by other stages. L-menthol is an active component extracted from the essential oil of *Mentha arvensi* L. (*Lamiaceae*) and the essential oil of cardamom (*Elletaria cardamomum*) L. (*Zingiberaceae*), *Cinnamomum zeylanicum Blume* (*Lauraceae*), *Sygium aromaticum* L. (*Myrtaceae*), *Eucalyptus spp.* and *Azadirectica indica A. juss* (*Meliaceae)* found to have ovicidal effect on the eggs of *T. castaneum* (Hong *et al.*, 2018; Mondal *et al*., 2009) [10, 22].

Use of Nanotechnology for stored grain pest management

In last years consumer awareness of the health hazard from residual toxicity and insect resistance to the pesticides has led the researchers to look for alternative approaches. From these alternatives the inert dusts such as clay, rock phosphate, sand, ashes, diatomaceous earth as well as synthetic silica have been used as insecticides in modern storages. Insects normally used a range of lipids on their cuticle to protect the water barrier on their body and avoid death due to dehydration. A mechanism used by the nanoparticles that becomes absorbed into the cuticle lipids by physisorption thus causing insect death exclusively by physical ways (Barik *et al*., 2008) [4]. Nanoemulsions are type emulsions in which size of particle is uniform and extremely small ranges from 20-200 nm. Nanopesticides would be a modern way to control insect pests and also decreasing the negative effects of synthetic insecticides on the environment. PVA (polyvinyl alcohol) is a water-soluble polymer derived from petroleum that has distinctive qualities such transparency, gloss, antielectrostatic properties, chemical resistance and toughness. Because of its water solubility, reactivity and fast biodegradability, it can be used in agricultural and water treatment applications. This strategy will be useful to control the stored product insects in the storages **(**Kitherian, 2017; Wakeil *et al*., 2017) [17, 45].

Types of nanoformulations

There are many forms of nanoparticles used against stored grain pests silver nanoparticles like $AgNO_3$, silica like diatomaceous earth, synthetic silica (SiO_2), sands, Silica Aerogel Aluminium oxide (Al_2O_3), Zinc oxide (ZnO), Copper oxide (Cu_2O), Titanium dioxide (TiO_2). The metal nanoparticles are utilized for making such formulations and these can be used as insecticides. Chemical techniques are used to fabricate nanostructured materials oftenly. The scanning tunneling microscope (STM) is used to know about target nanoparticles and this is very important. The unique type nanomaterial is prepared from silica is nanosilica. In recent projects, it is used as a catalyst and nanopesticide. Nanoparticles could be used in novel insecticide compositions to combat a variety of insect species (Barik *et al*., 2008; Zahir *et al*., 2012; Yousef *et al*., 2019) [4, 48, 47].

Using nanoparticles against major stored grain insect pests

Nanotechnology is a gaining importance for formulation and delivery of insecticide active components as well as increasing and offering new active ingredients for controlling many of stored grain insect pests throughout the world.

Essential oils-nanoparticles

Nanoemulsions were found to be useful for the formulations of pesticides. Nanoparticles may reduces the expected volume of application and slow down the quick release kinetics. Using nanoparticles for coating the imidacloprid (IMI) increases its toxic effect. Their results showed that both nanoparticles (silica and silver) were effective on larvae and adults up to 100 percent mortality. Amorphous silica nano particles have 100 percent mortality against *T. castaneum.* Its adult activity of insecticidal polyethylene glycol-covered nanoparticles loaded with garlic essential oil was examined. *T. castaneum* mortality was found to be 80percent, almost certainly due to the slow and steady release of dynamic components from nanoparticles (Zahir *et al*., 2012; Sahayaraj *et al*., 2016; Debnath *et al.,* 2012) [48, 34, 7].

Silver nanoparticles

Silver nanoparticles (Ag NPs) were prepared by using various natural products like *Azadirachta indica*, *Glycine max* and *Camellia sinensis*. The ethanolic leaf extract of Annona squamosa was examined against *S. oryzae*. Silver nanoparticles (Ag NPs) were tested for their entomotoxic effects on *S. oryzae.* The insecticidal effect of nanostructured alumina against S. oryzae and R. dominicae in stores who said that after 3 days of continuous exposure to nanostructured alumina-treated wheat, a considerable mortality was documented. *S. oryzae* could be controlled using aqueous extracts of E. prostrate leaves that generated Ag NPs (Tripathi *et al*., 2009; Stadler *et al*., 2010) [44, 38].

Aluminum and zinc oxides

In the laboratory two nanomaterials such as aluminum and zinc oxides were tested against adults of *S. oryzae.* Their result shows that aluminum nanoparticles (Al_2O_3) were more effective than zinc nanoparticles (ZnO) against *S. oryzae.* By increasing the time of exposure and concentration, the mortality (percent) will be increased. They found that aluminium oxide nanoparticles were highly efficient against S. oryzae, reducing insect loss and having a significant oviposition deterrent impact. They also found that zinc oxide (ZnO) nanoparticles were highly effective in reducing S. oryzae infestation. Mortality of *S. oryzae* reached to 86 percent by using Aluminium nanoparticles as well as to 65 percent of S. oryzae by applying Zinc nanoparticals. When compared to nanoparticles of Titanium oxide, Al_2O_3 had the strongest deterrent impact on S. oryzae and S. zeamais (TiO_2) (Keratum *et al*., 2015; Salem *et al*., 2015) [15, 35].

Diatomaceous earths

DE is the byproduct of microscopic plants (diatoms) that once flourished in the oceans. DE's insecticidal activity is attributed to the diatom remnants' razor sharp edges. DEs with smaller particle sizes are more hazardous than DEs with bigger particle sizes. Other factors affecting DEs insecticidal efficiency included active surface and oil adsorption ability, SiO2 content, moisture content and so on. The DE comes into contact with the insects as they crawl through the treated grain and dustbins and the sharp edges puncture the insects exoskeleton. The body fluids were absorbed by the powdery DE causing death from dehydration. Several diatomaceous earth formulations have been tested against a variety of stored-product insects with positive results. If it has a high amorphous silica concentration and a consistent size distribution, it plays an important role. It caused 100 percent mortality by spraying amorphous silica nanoparticles on *Corcyra cephalonica*. Nano-DE powerfully killed the eggs of *T. confusum* more than *T. castaneum* after 120 storage days. The efficiency of Nano-DE on infestation (percent) of *T. confusum* were more efficient than on *T. castaneum* (Sabbour *et al*., 2015; Athanassiou *et al*., 2004) [33, 2].

Silicon dioxide nanoparticles

The use of nanoparticles for insect control has grown in popularity. Surface functionalized silica nanoparticles were shown to be extremely harmful to S. oryzae adults. Amorphous SNP was discovered to be quite beneficial, producing S. oryzae mortality of over 90%. Two silicon dioxide nanoparticles of Aerosil and Nanosav caused more mortality and toxicity to *R. dominica* and *T. confusum* adults. The *T. confusum* was more tolerant than *R. dominica* (Ziaee and Ganji, 2016) [49].

Nanosilica (nanobiopesticide)

Amorphous nanosilica is one of the potential new compounds that could help store product insects be managed effectively and safely. These nanosilicas may be absorbed into the cuticular lipid stuffs by physisorption, resulting in the complete death of the insects. To protect humans surface charged modified hydrophobic nanosilica (3-5 nm) could be used to successfully to manage a range of insect infestations. Nanoparticles have a larger surface area and circulate easily in lepidopteran insects, hence they are classified unique harness compounds that will be expelled from the insect body within 24 hours. In the insect hemolymph, particles smaller than the micron order would be less harmful. Using hydrophobic silica nanoparticles significantly reduced the seed damage potential of *C. maculatus* as compared to the control. The insecticidal efficiency of silica is expected to improve if the particles are finely separated (Lawry, 2001; Arumugam *et al*., 2016) [19, 1].

Mode of action of nanoparticles

The method is based on the fact that insects utilise a variety of cuticular lipids to maintain their water barrier intact and hence avoid death due to dehydration. Several research have shown that nanomaterials like nanosilica or silver nanoparticles as well as aluminium nanoparticles, could be used as pesticides in insect management programmes. Physisorptio absorbs nano-silica into the cuticular lipids of insects. If nanoencapsulation is released, the following stages would be followed by diffusion, biodegradation, dissolution and osmotic pressure with an exact pH. Insect control operations that use nanoparticles must be focused toward the launch of speedier and environmentally friendly insecticides in the next years. Manufacturers are focused on nanoscale insecticide formulations for injecting into the target host through nanoencapsulation (Bhattacharyya, 2009; Patil, 2009) [5, 26].

Inert dusts, sands and silica aerogel

Inspection by using inert grains dusts are also used to kill insects. These are not reacting chemically and kill insects by physical contact. Insect coated with inert dusts shows loss of water and death occurs very quickly. These insects are killed by dessication and with the decrease in relative humidity its effectiveness is increased. Traditional pesticides included sands and soil components. Sands create a protective layer on top of the seed that has been preserved. Diatomaceous earth (DE), which is made up of fossilised diatom remnants was also employed to safeguard food grains. It is mainly composed of opaline silica which shows very toxicity mammals. Besides natural DE arttficially modified CaDE are also being made which have shown insecticidal, repellent and ovicidal activity against *Callasobruchus maculates*. Similarly, a non-hygroscopic powder containing sodium silicate is used to suppress field and store grain insects. Insecticides made from rock phosphate and calcium oxide are also used to control insects (Banks and Field, 1995; Quarles, 1992) [3, 29].

Ionizing Radiation

This is an environmental friendly control of stored grain insects effective in store houses. Seeds are treated with both and radiation to control stored grain insects. However radiation is generated by Cobalt 60 while radiation is generated electrically. Strong ionizing radiation (at a dose of 0.6 kGy) bring about sterilization in stored grain insects and low of ionizing radiation damage insects by producing highly reactive free radicals or ions. Irradiation done in closed chamber can effectively kill all life stages of insects and nutritional value of food grains remains unaffected. Colorized light and sound also control stored grain insect. Light is used to catch flying insects by mass killing. All the stages of *S. granaries* will be killed 1MHz sound exposure for 5 minutes. Ozone for (O_3) is allotropic oxygen when is also used to sterilize and kill insects in food commodities. It is generated by is atmospheric oxygen and is used for fumigation of stores. It is exceedingly unstable and soon degrades to molecular oxygen. To manage stored grain pests, ozonation is being studied as a possible alternative to traditional treatments (Kells *et al.*, 2001; Banks and Field, 1995) [14, 3].

Behavioral Control by Using Insect Pheromones

Pheromones applying male specific or female specific pheromonal substances for behavioral control of insects. These are used for surveillance and detection of an infestation in stored grains. Pheromones are used in minute quantities in traps which can be placed in warehouses at a considerable distance. The traps treated with pheromones caught significantly more number of target insects than untreated traps. Pheromones control depends on the efficacy of traps in capturing the attracted populations and suppression methods used. The presence of stored grain insects in grain bins can be detected using these traps. In ware houses, pheromones are also employed to catch grain moths. The pheromones are also identified and utilised to trap *Tribolium spp*., *Sitophilus spp*., *Stegobium paniceum* (L.) (Drugstore beetle) and *Lasioderma serricorne* (*F*) (Cigarette beetle). After two generations of selection significant responses were observed. Besides this, for more effective manipulation and suppression of stored product insects pheromones are used with entomopathogens. It is more feasible method in which pheromone - baited or light-baited device is used with an open reservoir containing a pathogen such as *Bacillus thuringiensis*. It helps to distribute a pathogen among stored-product insects (Tanaka and Takeda, 1993) [41].

Control by Using Insect Growth Regulators (IGRs)

Besides synthetic pesticides, insect hormones and their analogues (IGRs) are used to control insects. These insect growth hormones have been demonstrated to be more effective against a variety of stored-product moths and beetles when administered in a closed setting. IGRs induce reproduction problems in insects by disrupting oviposition behaviour. Two IGRs methoprene and hydropene are applied to prevent pupae in *Tribolium castaneum* (Herbs) and in *Tribolium confusum*. Methoprene also inhibit *Oryzaephilus mercator* and *O. surinamensis* at 1 mg/kg while hydrophene shows complete inhibition of adult progeny in *Sitophilis granarius* (L.) at a dose of 10-20 mg/kg. However, for more effective control IGRs could be added to attractant impregnated baits insteated of directely to food (Williams and Amos, 1974; Loshiavo, 1976) [46, 20].

Microbial Control

Microbial control which uses microbial insecticides in the form of spores and toxins, is one of the most effective synthetic pesticide alternatives. It is safe and target specific toxins. *Bt* toxins, produced by *Bacillus thuringiensis*, are the most efficient strains against stored grain insects. Aside from that, a variety of entomopathogens are employed to control stored grain pest. For more effective control certain botanicals are also mixed with *B. thuringensis*. It demonstrates a considerable increase in pathogen killing ability and causes massive mortality in stored garin insects (Lacey, 2001) [18].

Cultural Control

Food grains store houses should be cleaned in asuch way that all dirt, egg shells and dead larvae be removed. Broken infested grains are removed and burnt before new grains are stored before storage these should be properly fumigated and closed till the new harvest comes. All cracks and crevices made in the flour walls and ceiling of the store should fill up with cement and labled. Stores should be white washed or painted by repellent paint. For painting purpose coal-tar is used. For better disinfestation, godowns should be superheated with burninig charcoal at the rate of 8 kg per cubic feet space so as to raise the tempreture of the room to about 150 °F. During temperature treatment the doors should be tightly closed for 48 h after which godowns should be allowed to cool and cleaned before storage for stored grain pest management. Dusting the walls, floors and ceiling of empty store with 5 percent BHC or 10 percent DDT dust at the 6 to 8 ounces per 100 cubic feet of space. If the godown can be made relatively airtight, commercial smoke generators of BHC or DDT can also be employed to disinfect it. Stock splitting should therefore be avoided. Infestation can be avoided by mixing inert dusts with stored grain. When only a tiny amount of grain needs to be kept, this method might be used (Parkin, 1955) [25].

Biological Control

To control the population of stored grain insects, various biological treatments are employed. Controlling stored grain insects has become an accepted method. Insect populations are controlled by using various living creatures or their products. However, numerous parasitoids, predators, diseases and other living organisms are used in natural situations to suppress the population of stored grain insects. Hymenoptera parasitoids are most typically utilised to minimise infestation and damage caused by stored grain insects. Insect pathogens on the other hand are used as biological control agents. Parasitoids are insects that rely on other parasites to keep stored grain insects at a low population level. *Bracon hebetor Say* (*Braconidae*) and *Venturia canescens* (*Graven horst, Ichneumonidae*) are two parasitoids found in preserved products that are employed to control *E. cautella* numbers. Another parasitoid that successfully controls dermestids is *Laeluis pedatus* (*Say*) (*Bethylidae*). However a problem was noted that *Anthrenus flaviceps Le Conte* (furniture Carpet beetle) possesses a supra - anal organ that serves as a defense mechanism against this parasitoid (Lacey, 2001; Ghimire and Phillips, 2007) [18, 9].

Spinosad as a natural grain protectant

Spinosad is a low-risk pesticide made by fermenting *Saccharopolyspora spinosa*, a soil actinomycete. Spinosad is becoming more popular as a grain protectant, pending ultimate adoption of international residue tolerances by key grain importing and exporting countries. Spinosad is a pesticide that efficiently eliminates economically important beetle and moth pests found in stored grain. Spinosad is effective against certain psocid species as well as economically important beetle and moth pests associated with stored grain (Nayak *et al*., 2005) [23].

Conclusion

Stored grain infestation is a serious issue as it may causes economic losses and damage the quality of food grains. There are number of stored grain insect pests in farmers storage houses and public ware houses that causes damage to food grains due to un-controlled environmental conditions and lack of knowledge about ware housing technology used. However, for suppression of multiplying these insect pest above discussed recent advances are used. These are highly specific and more appropriate for the stored grain pest management. Plant volatile organic compounds possess insecticidal properties and used as botanicals in stored grain pest management. Indeed, many nanotechnology enabled products have previously been on the market and nanoparticles in eco-friendly insecticides are likely to be adopted for use in the near future due to their biodegradable nature, systemicity after application, ability to alter the behaviour of target pests and favourable safety profile. So, it is recommended that the silica nanoparticles could be used effectively in a stored grain pest management. Other methods described here are also effective and efficient against many insect pest.

References

1. Arumugam G, Velayutham V, Shanmugavel S, Sundaram J. Efficacy of nanostructured silica as a stored pulse protector against the infestation of bruchid beetle, *Callosobruchus maculatus* (Coleoptera: Bruchidae). Applied Nanoscience 2016;6:445-450.
2. Athanassiou CG, Kavallieratos NG, Andris NS. Insecticidal effect of three diatomaceous earth formulations against adults of *Sitophilus oryzae* (Coleoptera: Curculionidae) and *Tribolium confusum* (Coleoptera: Tenebrionidae) on oat, rye and triticale. Journal of economic entomology 2004;97:2160-2167.
3. Banks HJ, Field JB. Physical methods for insect control in stored-grain ecosystem. In Stored grain ecosystem, eds. Jayas DS. N.D.G. White and B. Subramanyam. Marcel Dekker: New York 1995, 353-409.
4. Barik TK, Sahu B, Swain V. Nanosilica-from medicine to pest control. Parasitol. Research 2008;103:253-258.
5. Bhattacharyya A. Nanoparticles-from drug delivery to insect pest control. Akshar 2009;1:1-7.
6. Casida J (Ed.), Pyrethrum: the Natural Insecticide, Elsevier 2012.
7. Debnath N, Das S, Patra P, Mitra S, Goswami A. Toxicological evaluation of entomotoxic silica nanoparticle. Toxicological and Environmantal Chemistry 2012;94:944-951.
8. Fields PG, White ND. Alternatives to methyl bromide treatments for stored product and quarantine insects. Annual review of entomology 2002;47:331-359.
9. Ghimire MN, Phillips TW. Suitability of Five Species of Stored-Product Insects as Hosts for Development and Reproduction of the Parasitoid *Anisopteromalus calandrae* (*Hymenoptera: Pteromalidae*). Journal of Economic Entomology 2007;100(5):1732-1739.
10. Hong TK, Perumalsamy H, Jang KH, Na ES, Ahn YJ. Ovicidal and larvicidal activity and possible mode of action of phenylpropanoids and ketone identified in *Syzygium aromaticum* bud against *Bradysia procera*. Pesticide Biochemistry and Physiology 2018;145:29-38.
11. Horn F, Horn P, Sullivan J. Current practice in fresh fruit fumigation with phosphine in Chile. Annual Research Conference on Methyl Bromide Alternatives and Emissions Reductions 2005;48:31-34.
12. Isman MB. Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. Annual Review of Entomology 2006;51:45-66.
13. Karthikeyan C, Veeraragavathatham D, Karpagam D, Firdouse SA. Traditional storage practices 2009;8:564-568.
14. Kells S, Mason LJ, Maier DE, Woloshuk CP. Efficacy and fumigation characteristics of ozone in stored maize. Journal of Stored Products Research 2001;37:371-282.
15. Keratum AY, Abo Arab RB, Ismail AA, Nasr GM. Impact of nanoparticle zinc oxide and aluminum oxide against rice weevil *Sitophilus oryzae* (Coleoptera: Curculionidae) under laboratory conditions. Egyptian Journal of Plant Protection Research 2015;3:30-38.
16. Kesavan PS, Swaminathan MS. Strategies and models for agricultural sustainability in developing Asian countries. Philosophical Transactions of the Royal 2008;363:877-891.
17. Kitherian S. Nano and bio-nanoparticles for insect control. Research Journal of Nanoscience and Nanotechnology 2017;7:1-9.
18. Lacey L. Insect Pathogens as Biological Control Agents. Biological Control 2001;21(3):230-248.
19. Lawry JV. Insects separate diffusing particles in parallel. Nanotechnology Model Simulation Microsystem 2001;1:254-257.
20. Loshiavo SR. Effect of the synthetic regulators methoprene and hydropene on survival, development or reproduction of six species of stored-product insects. Journal of Economical Entomology 1976;60:395-99.
21. Mobolade AJ, Bunindro N, Sahoo D, Rajashekar Y. Traditional methods of food grains preservation and storage in Nigeria and India. Annals of Agricultural Science 2019;64(2):196-205.
22. Mondal M, Khalequzzaman M. Ovicidal activity of essential oils against red flour beetle, *Tribolium castaneum* (Coleoptera: Tenebrionidae). Journal of Bioscience 2009;17:57-62.
23. Nayak MK, Daglish GJ, Byrne VS. Effectiveness of spinosad as a grain protectant against resistant beetle and psocid pests of stored grain in Australia. Journal of Stored Products Research 2005;41(4):455-467.
24. Norman CS. Potential impacts of imposing methyl bromide phaseout on US strawberry growers: a case study of a nomination for a critical use exemption under the Montreal Protocol. Journal of Environmantal Management 2005;75:167-176.
25. Parkin EA. Progress in the control of insects infesting stored foodstuffs. Annals of Applied Biology 1955;42(1):104-111.

26. Patil SA. Economics of Agri Poverty: Nano-Bio Solutions. Indian Agricultural Research Institute, New Delhi, Indian 2009.
27. Phillips TW, Throne JE. Biorational approaches to managing stored-product insects. Annual Review of Entomology 2010;55:375-397.
28. Prusky D. Reduction of the incidence of postharvest quality losses, and future prospects, Food Security 2011;3:463-474.
29. Quarles W. Silica gel for pest control. IPM Practitioner 1992;14:1-11.
30. Rajashekar Y, Bakthavatsalam N, Shivanandappa T. Botanicals as grain protectants and Psyche. Journal of Entomology 2012, 640-648.
31. Rajashekar Y, Gunasekaran N, Shivanandappa T. Insecticidal activity of the root extract of Decalepis hamiltonii against stored-product insect pests and its application in grain protection. Journal of food science and technology 2010;47:310-314.
32. Roy B, Amin MR, Jalal S, Kwon YJ, Suh SJ. Evaluation of common cocklebur *Xanthium strumarium* leaf extract as post-harvest grain protectant of black gram against pulse beetle *Callosobruchus chinensis* (Coleoptera: Bruchidae) and isolation of crude compound. Entomology of Research 2014;44:254-261.
33. Sabbour MM, El-Sayed Abd-El-Aziz S. Efficacy of some nano-diatomaceous earths against red flour beetle *Tribolium castaneum* and confused flour beetle, *Tribolium confusum* (Coleoptera: Tenebrionidae) under laboratory and store conditions. Bulletin of Environment pharmacology and life sciences 2015;4:54-59.
34. Sahayaraj K, Madasamy M, Radhika SA. Insecticidal activity of bio-silver and gold nanoparticles against *Pericallia ricini* Fab. (Lepidaptera: Archidae). Jouranl of Biopesticide 2016;9:63-72.
35. Salem AA, Hamzah AM, El-Taweelah NM. Aluminum and zinc oxides nanoparticles as a new method for controlling *Tribolium castaneum* compared to malathion insecticides. Journal of Plant Protection Pathology 2015;6:129-137.
36. Sharon M, Abirami CV, Alagusundaram K. Grain storage management in India. Journal of Post-Harvest Technology 2014;2(1):12-24.
37. Sousa RMO, Rosa JS, Oliveira L, Cunha AM. Fernandes-Ferreira, Activities of *Apiaceae* essential oils and volatile compounds on hatchability, development, reproduction and nutrition of *Pseudaletia unipuncta* (*Lepidoptera: Noctuidae*). Indian Crop Production 2015;63:226-237.
38. Stadler T, Buteler M, Weaver DK. Novel use of nanostructured alumina as an insecticide. Pest Management Science 2010;66:577-579.
39. Subramanyam B, Hartzer M, Boina DR. Performance of pre-commercial release formulations of spinosad against five stored-product insect species on four stored commodities, Journal of Pest Science 2012;85:331-339.
40. Suleiman M, Rugumamu CP. Management of insect pests of stored sorghum using botanicals in Nigerian traditional stores. Journal of Stored Product Postharvest Research 2017;8:93-102.
41. Tanaka Y, Takeda S. Ecdysone and 20- hydroxyecdysone supplements to the diet affect larval development in the silkworm, *Bombyx mori*, differently. Journal of Insect Physiology 1993;39:805-809.
42. Tatun N, Vajarasathira B, Tungjitwityakul J, Sakurai S. Inhibitory effects of plant extracts on growth, development and [alpha]-amylase activity in the red flour beetle *Tribolium castaneum* (Coleoptera: Tenebrionidae). European Journal of Entomology 2014;111:181-186.
43. Tavares SW, Sousa Freitas S, Grazziotti GH, Parente LML, Li~ao LM, Zanuncio JC. Ar-turmerone from *Curcuma longa* (*Zingiberaceae*) rhizomes and effects on *Sitophilus zeamais* (Coleoptera: Curculionidae) and *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Indian Crop Production 2013;46:158-164.
44. Tripathi A, Chandrasekaran N, Raichur AM, Mukherjee A. Antibacterial applications of silver nanoparticles synthesized by aqueous extract of *Azadirachta indica* (Neem) leaves. Journal of Biomed Nanotechnology 2009;5:93-98.
45. Wakeil EIN, Alkahtani S, Gaafar N. Nanotechnology a Promising Field for Insect Pest Control in IPM Programs 2017, 273-309.
46. Williams P, Amos TG. Some effects of synthetic juvenile hormones and hormone analogues on *Tribolium castaneum*. Australian Journal of Zoology 1974;22:147-153.
47. Yousef DA, Bayoumi AE, Dimetry NZ, Amin AH, Hoballah EM. Evaluation of peppermint oil and its nano-formulations and their effects on bionomics and enzymatic activies against Spodoptera littoralies. Journal of Union Arab University 2019, 33-42.
48. Zahir AA, Bagavan A, Kamaraj C, Elango G, Rahuman AA. Efficacy of plant-mediated synthesized silver nanoparticles against *Sitophilus oryzae*. Journal of Biopestcide 2012;5:95-102.
49. Ziaee M, Ganji Z. Insecticidal efficacy of silica nanoparticles against *Rhyzopertha dominica* F. and *Tribolium confusum* Jacquelin du Val. Journal of Plant Protection Research 2016;56:250-256.