World Journal of Agricultural Sciences 7 (5): 527-549, 2011
ISSN 1817-3047

Management Strategies for Control of Stored Grain Insect Pests in Farmer Stores and Public Ware Houses

R.K. Upadhyay and S. Ahmad

Department of Zoology D D U Gorakhpur University, Gorakhpur 273009, U.P. India

Abstract: In the present review article various control methods for stored grain insects are discussed in detail and an emphasis was made to use non-chemical methods. Stored grain infestation is a very serious problem as various life stages of insects cause economic damage and deteriorates the quality of food grains and food products. There are number of stored grain insect pests that infest food grains in farmer stores and public ware houses and massively surge due to un-controlled environmental conditions and poor ware housing technology used. However, for suppression of multiplying insect population highly specific and more appropriate modern methods are to be used. Few important methods such as microwave and ionizing irradiation, pheromone baited traps, IGRs and use of entomopathogens are proved highly effective against stored grain insects. Over these methods, repellents and oviposition inhibitors isolated from various plant speices are considered as much safer in comparision to synthetic pesticides. These natural pesticides have no side effect and are biodegradable in natural environment. However, non-residual non-persistent and less toxic bio-organic pesticides should be used that may not affect the quality of food grains. Besides this, low pressure and low temperature treatments are proved much safer pest management tools that represent a potential alternative of fumigants to control coleopteran and lepidopteran insects. However, for an effective control of stored grain insects various parasitoids, predators, pathogens and other living organisms are employed in natural conditions to suppress the pest population. For better protection of stored grian control computer based decision support system should be used to predict damage and operation requirements for a timely control. In addition, both biological and non-biological factors and their effects must be evaluated to check the possible infestation during storage. Therefore, selected control strategies must be integrated for effective management of stored grain insects.

Key words: Stored grain insects · Microbial control · Cultural control · Chemical control · Pysical control

INTRODUCTION

Damage of stored food grains is very serious problem in South-East Asia and throughout the globe. Due to lack of proper ware housing facilities, stored grain insects largrly damage food grains in stores as well as during shipping and transportation. For better protection appropriate methods for disinfecting the food grains are required. Farmers, through a long history of battle against stored product pests, have learnt to exploit natural resources, or to implement accessible methods, that would lead to a degree of population suppression of pests.Traditional methods usually provide cheap and feasible ways of post-harvest handling of the crops, but they have many limitations. Basically, farmers should be fairly aware about hygienic practices which are essential for successful storing i.e. thorough cleaning of bins or granaries, avoidence of mixing infested grains with healthy ones, burning crop residues after-harvesting, sealing cracks and holes in muddy structures and another practices that ensure storage of food grains in a clean and uncantaminated environment. During storage, some traditional materials are often added to the product, which contribute to the reduction of pests' activity [1]. Inert dust, for example, is added in variable amounts into the stored product. Friction of dust particles with insect's cuticle leads to dessiccation and hampers the development of the pest [2]. Pre-treatment of *Vigna radiata* seeds with inert clay resulted in 100% adult motality of *Callosobruchus chinensis* within 24 h. It provides effective protection upto 12 months of storage under ambient conditions [3].

Corresponding Author: R.K. Upadhyay, Department of Zoology D D U Gorakhpur University, Gorakhpur 273009, U.P. India

The infestation is carried to the storehouses from the infested field crops with the food grains and spread rapidly. Further, damage is supported by environmental factors such as humidity, temperature and light. Females of stored grain insects enormously breed and multiplied the insect population in short span inside go downs in un-controlled conditions. Besides this, food grains are also infested in the field by a number of insect pests, but only few of them reach to store houses and cause severe grain infestation. Adults of stored grain insects choose wet place and begin their life cycle with the egg which are deposited on food grains and on the walls of store house by the female parent. Mainly grains deposited eggs, larvae and pupae are transported from field to go downs which start infestation. Mainly infesting stages are adults and larvae which inhabit inside grains and combinely resurse in a geometrical ratio if no control is being made. Both larvae and adult insects make heavy economic losses in the food grains reduced the quality of seeds and biological products. More than 70 insect pests have been identified which attack stored grains and cereal products in store houses. The overall damage caused by these insect pests, worldwide is estimated to be 10-40% annually. Therefore, there is an urgent need to maintain stored quality and its proper management.

Stored Grain Insects: Insect pests, which cause damage to stored grains are beetles (Coleoptera) and moths (Lepidoptera). Of these beetles are for more diversified and are highly distructive stored grain insects in comparision to moths. Both grubs and adult insects attack the stored food material while among the moth, only the caterpillars are harmful life stage that causes the damage. Besides, there are certain insect pests which do not bread in stored grain but their presence in the stores is harmful because they generate filth and nuisance. They do not cause large damage to food grains but creat noxious smelland debris. These insects are cockroaches, ants, crickets, silverfiches, pscolids and termites. Few mites also cause infestation in grain flour and other stored products. Few major stored grain pests are *Sitophilus oryzae* Linn. (Rice weevil), *Trogaderma granarium* (Kuapre beetle), *Rhizopertha dominica* (Fabr), *Tribolium castaneum* (Herbst) (Rust red flour beetle), *Sitotraga cerealella* (Olive), Grain and flour moth, *Bruchus chinensis* (Pulse beetle). All important stored grain pests are mentioned in Table 1. Among all stored grain pests bruchids mainly the pulse beetle, *Bruchus chinensis* is a serious pest of stored grains, cowpea, gram, arhar, soybean, moong, urd and moth. It damages food grains, occurs in storehouses and godowns and has a worldwide distribution (Table 1). The grubs eat the entire content of

Table 1: List of stored grain insects

Common name	Scientific name	Family	Order
Rice weevil	Sitophilous oryzae (L)	Curculionidae	Coleoptera
	Sitophilous granarius (L)	Curculionidae	Coleoptera
Khapra beelte	Trogoderm granarium (L)	Dermastidae	Coleoptera
	Trogoderma glabrum (Herbst)	Dermastidae	Coleoptera
Lesser grian borer	Rhizopertha dominica (Fabr)	Bostrichidae	Coleoptera
Rust red flour beetle	Tribolium castaneum (Herbst)	Tenebrionidae	Coleoptera
	Tribolium confusum	Tenebrionidae	Coleoptera
Pulse beetle	Pachymerus chinensis (Lin.)	Bruchidae	Coleoptera
	Bruchus analis (Fabr)	Bruchidae	Coleoptera
	Acanthoscelides obstectus	Bruchidae	Coleoptera
	Callosobruchus chinensis	Bruchidae	Coleoptera
	Callasobruchus maculatus	Bruchidae	Coleoptera
Angonmois grain moth	Sitotroga cerealella (Oliv.)	Gelechidae	Coleoptera
Rice moth	Corcyra cephalonica (Staint.)	Lariidae	
Almond moth	Ephestia cautella (Walker)	Pyralidae	Lepidoptera
Saw toothed	Oryzaephilus surinamensis (Linn.)	Grain beetle	Indian meal moth
	Plodia interpunctella (Hubner)	Pyralidae	Lepidoptera
Drug stone beetle	Stegobium paniceum (L.)		
Cigarette beetle	Lasioderma sericorne (F)		
	Anagasta kuehniella	Pyralidae	Lepidoptera
Psocids	Liposcelis bostrychophila	Liposcelididae	Psocoptera
	Liposcelis decotor (Pearman)	Liposcelididae	Psocoptera
	Cryptolestes ferrugineus	Cucujidae	Coleoptera
	Lasioderma serricorne (Fab)	Anobiidae	Coleoptera
	Zabrotes subfasciatus (Boh)	Chrysomalidae	Coleoptera
	Holotrichia serrata	Scarabaeidae	Coleoptera
	Eurygaster integriceps (Puton)	Scutelleridae	Hemiptera
Maize weevil	Sitophilus zeamais (Motsch)	Curculionidae	Coleoptera

the grain and leave the shell behind. Adult beetles also reside in the circular holes of the grains. From the researches, it has been proved that synthetic pesticides are highly toxic to non-tagret organisms and put adverse impacts on the environment. Hence, their use should be restricted to minimum. Thus, insect pests have developed resistance to many commercially available synthetic pesticides [4,5], Hence, new safe alternatives are being searched in form of bio-organic pesticides.

Chemical Control

Fumigation: Stored grain pest infestation is controlled by various methods among them, fumigation is one of the most effective method in which insect pests are exposed to a poisonous gaseous environment, produced by applying a grain fumigant. It is applied for pest control in buildings, ware houses, small bags, soil, seed and stored products. Fumes generated by fumigants enter the body of insect through the spiracles and spread to trachea and tracheoles and bined to the hemolymph components. In the past, various synthetic fumigants were used to eliminate stored grain insect pests [6]. Few other fumigants such as sulphuryl fluoride, ethyl formate and carbonyl sulphite and ethane dinitrile are used to kill termites, cockroaches and mites. Ethylene dichloride and carbon tetrachloride mixture (3: 1 ratio) is used for fumigation of empty godowns to kill the eggs, larvae and adults of stored insect pests. It has no harmful effect on gain even if it is itended to use for seed purposes. Vapours of mixture are not toxic to man in ordinary concentrations but nassive fumes show anesthetic effects. Similarly another fumigant Grain-O-Cide is a mixture of carbon bisulphide and carbon tetrachloride (1: 4 ratio) that is used to fumigate godowns. Besides this, fumigation is also done by using HCN gas generated by metal phoshide preprations are used for fumigation of public store houses. Phosphine inhibits the development of eggs in stored product pest *Liposcelis bostrychophilia* (Psocoptera: Liposcelididae) [7]. Phosphine affects the hatching of coleopteran insect pests, *Cryptolestes ferrugineus, Lasioderma serricorne, Oryzaephilus surinamensis* [8]. Besides this, phosphorus hybrid polymers and phosphorus oxyacids used to generate phosphine gas during fumigations of stored products [9]. Similarly, Cyanogens also show toxicity against insects of stored grain [10]. Besides this, some of the most common fumigants are used to control stored grain insects are carbon disulphide, carbon tetra chloride, ethylene dichloride, ethylene oxide, methyl bromide, chloropicrin, trichloroethylene, sulphur dioxide, methyl format and trichloroacetonitrate. Fumigation with methyl bromide is more effective than Grain-O-Cide and Killoptera a mixture of ethyl dichloride and carbon tetra-cholride. Besides this, one of the most effective and safer fumigant is aluminium phosphide which is available in the marker in form of tablets. Similarly pyrethrum spray mixed in white oil was also found effective at the rate of 6-8 ounces per cubic feet before storage. Both methyl bromide and phosphine are used for fumigation purpose to protect legumes and cereals. Moreover, pirimiphos-methyl, spinosad and combination of pirimiphos-methyl and synergized pyrethrins are used to control *Corcyra cephalonica* [11]. Similarly, volatile natural and synthetic cyanohydrins show fumigant toxicity against stored product pests and also used for soil fumigation [12]. Acrolein vapours are used to control stored product insects and increase the seed viability [13]. Propylene oxide (PPO) at low is used to control all life stages of stored product insects, *Tribolium castaneum* (Herbst), *Plodia interpunctella* (Hubner), *Ephestia cautella* (Wlk.) and *Oryzaephilus surinamensis* (L.). This combination of PPO with low pressure can render the fumigant a potential alternative to methyl bromide for rapid disinfestation of commodities [14]. Ethiprole alone and combination with conventional insecticides are used for protection of stored wheat and stored corn [15]. Similarly d-Limonene shows contact and fumigant toxicity mainly ovicidal and feeding-deterrent activities against stored product beetles. It effectively suppresses stored grain pests population [16]. Few organophosphate insecticides such as azamethiphos, fenitrothion, chloropyrifos-methyl and pirimiphos-methyl show toxic effect on *Liposcelid psocid* [17]. It has showed that hydrophobic amorphous silica dusts resulted in efficient control of *Callosobruchus chinensis,* as no beetle survived after 48 h at a concentration of 0.1% [18]. A similar effect can also be achieved through treatment with wood ash, collected from burnt tree wood. Some farmers may also add fine sand and high proportion of quartz to cause damage to the sensitive cuticle of the newly hatched larvae. Similarly, acetic acid brine solution impeded the emergence of pupa and adult and also decrease their survival [19]. Diatomacious earth surface treatment significantly reduced adult survival, cause mortality and destroyed the future progeny of lesser grain borer [20]. Three diatomaceous earth (DE) formulations Protect-It, PyriSec and DEA-P was used to kill the larger grain borer, *Prostephanus truncatus* (Horn) (Coleptera: Bostrychidae) adults in stored maize, *Zea mays* L. at different temperature and relative humidity. These treatment also effect progeny production and hatching of larvae in stored grain insects. The efficacy of DEA-P continuously increases with the temperature and relative humidities that causes very high mortality in *Tribolium confusum* [21]. Besides this, diatomaceous earth formulations act as toxicant to cause mortality in *Sitophilus oryzae* [22], when mixed with natural pyrethrum these formulation show very high toxicity against *Tribolium confusum* [23]. Lesser grain borer infestation is reduced by treating seeds in different surface layers of hard winter wheat. However, combined treatments of spinosad and chloropyrifos-methyl were used for management of resistant psocid pests of stored grain [24], while synergized bifenthrin plus chloropyrifos-methyl was used for control of beetle and psocids in Sorghum [25]. Morespecially, imidacloprid is potentialy used to control four species of psocids that infest stored grains [26] while Thiamethoxam and imidacloprid is used for seed treatment to control European corn borer and Indian meal moth larvae [27]. Spinosad shows long-term persistence and efficacy against *Rhyzopertha dominica* (Coleoptera: Bostrychidae) in wheat. Dichlorvos used to control stored product insects in port ware houses [28]. Similarly few synthetic insecticides such as ethiprole [15], carbonyl sulphide [29], ethylene dibromide [30], cyanohydrins [12] and organophosphates [17] are potentally used to control stored grain pests. Spinosad shows long term persistence and efficacy to control *Rhyzopertha dominica* in wheat. It's residues in farm stored wheat act as toxicant to kill the stored product insects. Surface treated with spinosad cause knockdown and mortality in adults of stored product beetles [31].

Fumigation is not effective unless the storage to be treated is well sealed and the grain temperature is well above 50 degree F. Contact poisons like insecticides, (S)-hydroprene and cyfluthrin are used to control stored grain insects in ware houses. The insecticide cyfluthrin is more effective than hydroprene [32]. These pesticides much efficiently control all life stages of *Tribolium castaneum* (Herbst). Besides this, gas-propelled aerosols and micronized dusts are used for controlling stored product insects in aircraft at pilot scale [33]. Desiccant dusts synergize the effect of *Beauveria bassiana* (Hyphomycetes: Moniliales) on stored grain beetles to control these insect pests [34]. Allyl acetate is used as fumigant, which effectively control stored grain beetles [35]. Constituent of *Foeniculum vulgare* fruit work as contact poison and fumigant against three coleopteran qustored product insects [36]. Pyrethrum based formulations are used to control grain weevils [37] while Pyrethroid-Acarophenax lacunatus interaction was used to suppressing the beetle *Rhyzopertha dominica* in public ware houses [38]. Repelin act as surface protectant against pulse beetle *Callosobruchus chinensis* infesting cowpea [39]. Certain terpenes are used to increase the efficacy of microbial insecticides against cotton bollworms [40]. The cowpea bruchid was controlled by potential transgenic insecticidal compounds using an artificial seed system (1) CIP-PH-BT-J and recombinant egg white avidin and (2) avidin and wheat alpha amylase inhibitors. These combinations cause large scale larval mortality in cowpea bruchids [41]. Innert dusts are used to control stored insects. These are chemically unreactive and adhered on insect surface, dehydrate the body and kill them.

Physical Control Control by Temperature, Heat and Pressure: Temperature treatment of stored grains is a best physical method which successfully kills several life stages of insects at a time. Most of the stored product insects can not tolerate extreme temperature, heating and cooling and show heave mortality. Superheating of food grains provide extraprotection with out treating with any insecticide. Grain temperature raised upto 55-65°C and for 10 to 12 h can effectively kill all life satges of stored grain pest in ware houses. Similarly low temperature also provides long term effect on stored seed and keeps them free of insect infestation. Low temperature reduces insect development and kills large number of immature stages of stored grain insects. The insects become inactive and eventually die at a temperature below 12 °C. It is probably the most important single factor in making long term storage possible and economical. Supercooling point at low temperature causes very high mortality in stored grain insects. The relationship between mortality at low temperature after minimum exposure and supercooling point for different stages of development of moth shows different responses to low temperatures depending on stage of development and cold acclimation [42]. Low temperature also maintains seed viability. The key to insect growth, reproduction and activity lies in the fact that insects must rely on warm condition to remain active. Most insects are inactive below 55 °F. Temperature also affects reproductive performence of *Tribolium castaneum*. It also reduces the fecundity, egg to adult survival and adult progeny production significantly [43]. The rate of increase of stored product mite population get increased with increasing moderate temperature untill 25°C [44]. Thus a key to stored grain insect pest management is proper temperature management, so that the grain mass is evenly cooled and very slowly allowed to warm. Temperature maintenance is very sensitive due to the chance of moisture condensation in the grain mass due to the extreme temperature gradients within the mass. Most stored grain insects can not live on extremely dry grains; however it is impractical to reduce grain moisture much below minimum moisture levels necessary for long term storage. Insect activity and reproduction are favored by high grain moisture, especially during pre and post rainy season. For insect development most favorable grain moisture ranges from 12-15%. Moisture contents also hit insect survival and reproduction inside grain whose moisture content is below 9%. If the moisture level is reduced below 40% it massively effect in insect reproduction and development and help in contro of insects.

Low pressure is a pest management tool, represents a potential nonchemical alternative to fumigants as methyl bromide and phosphines for controling bruchids [45]. Time-mortality response of red flour beetle eggs, young larvae, old larvae, pupae and adult stages increased with increase in temperature and exposure time. Morespecifically, eggs and young larvae are most susceptible at high temperature than old larvae [46]. Adults of rusty grain beetle *Cryptolestes ferrugineus* (Coleoptera: Laemophloeidae) responded faster to higher temperature gradients than to lower temperature gradients. Low pressure creates a low oxygen controlled atmosphere that kill stored product insect, cowpea weevil, *Callosobruchus maculatus* (F.). Low temperatures and high pressure are not so effective to kill more number of eggs compared with high temperatures combined with low pressures in all flour stored grain insects [45]. Eggs, larvae and pupae of *Tribolium castaneum* (Herbst)*, Plodia interpunctella* (Hubner) and *Rhyzopertha dominica* (F) were exposed to high temperature and low pressure showed significant reduction in lethal time values. But eggs of each species found most tolerant to low pressure [47]. The movement and distribution of adults in grain provide important information for detection of insect pests and for simulations of their distribution in grain bins [48,49]. Hidden infestation of stored-product insect larvae is detected most rapidly by acoustic techniques, when the larvae are highly active. Larval activity is periodic and it tends to decrease after the larvae are cooled at a very low temeprature. Heat treatment increases the larval activity and improves the speed and reliability of acoustic detection under adverse condition. Food grain can be superheated under an infra-red microwave radiation. Fludized bed heating is used to generate high temperature to disinfest the grains. Larval detectability is enhanced if cooled grain samples are warmed and all samples are left undisturbed for 15-20 min before inspection [50].

Inert Dusts, Sands and Silica Aerogel: Inspection Inert dusts are also used to kill insects. Chemically these are unreactive and kill insects by physical contact. Insects coated with inert dusts show massive dehydration and die very soon. These kill insects by dessication and its effectiveness is increased with the decrease in relative humidity [51]. Sands and soil components were also used as traditional insecticides. Sands provide protective layer on top of stored seed [52]. Besides this, fossilizized remains of diatoms known as diatomaceous earth (DE) were also used to protect food grains. It is mainly composed of opaline silica which shows very toxicity to mammals [53]. Besides natural DE arttficially modified CaDE are also being made which have shown insecticidal repellent and ovicidal activity against *Callasobruchus maculates*. Similaly silica aerogel that contain sodium silicate is used as a non-hygroscopic powder to control field and store grain insects [54]. Besides this, rock phosphate and calcium oxide found in rocks is used to control insects [2].

Ionizing Radiation: This is an environmental friendly control of stored grain insects effective in sotre houses. Seeds are treated with both γ and β radiation to control stored garin insects. However, γ-radiation is generated by Cobalt 60 while β-radiation is generated electrically. Low ionizing radiation damage insects by causing the production of highly reactive free radicals or ions, while strong inonizing radiation (at a dose of 0.6 kGy) causes sterilization in stored grain insects [51]. Inrradiation 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 lure and trap flying insects by mass killing [51]. Besides this, 1MHz sound exposure for 5 minutes can kill all of stages of *S. granarius*. Ozone (O_3) is allotropic oxygen when is also used to sterilize and kill insects in food commodities. It is generated by atmospheric oxygen and is used for fumigation of stores. It is highly unstable and breaks down to molecular oxygen quickly. Ozonation is considered as a potential alternative to conventioal methods to control stored grain pests [55].

Behavioral Control by Using Insect Pheromones: Pheromones are used in behavioral control of insects either by applying male specific or female specific pheromonal substances. These are used for surveillance and detection of an infestation in stored grains. These are used to uphold communication disruption or mass trapping of insects by lures and attract. 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. Disruption of mating with pheromones provides wider suppression of insect population. Morespecifically, pheromones of *Trogoderma* and the black carpet beetle, *Attagenus megatoma* (F) are used either singly or in combination in bait traps to capture these insect pests in larger number. The primary component of the *Trogoderma* pheromone, 14- methyl 8 - hexadecenal is now used to capture and kill large numbers of *Trogoderma granarium*. Besides this, wheat germ oil combined with sex pheromone is used to attract and trap *Trogoderma* larvae. Similarly, male lesser grain borer, *Rhyzopertha dominica* (F.), produce an aggregation pheromone that attracts both sexes. Besides this, synthesized pheromones are used in baited traps, which were found effective in monitoring populations [56]. These traps can detect presence of stored grain insects in deep within grain bins. Pheromones are also used to capture grain moths in ware houses. For example, several species of stored-product Pyralidae respond to the synthesized sex pheromone (Z, E) - 9, 12-tetradecadien -1 - 01 acetate [57,58]. Pheromones of other grain-infesting beetles and weevils are also identified and are used for trapping *Tribolium* spp. *Sitophilus* spp. *Stegobium paniceum* (L.) (drugstore beetle) and *Lasioderma serricorne* (F) (cigarette beetle) in ware houses. Artificial selection was conducted to reduce the behavioural responsiveness of female bruchid beetles *Callosobruchus chinensis,* to the oviposition deterring pheromone excreted by conspecific females. Significant responses to selection were observed after two generations of selection. These indicate that this pheromone communication system has significant additive genetic variance needed for its evolution [59]. Besides this, for more effective manipulation and suppression of stored product insects pheromones are used with entomopathogens. It is more feasible method in which is 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. Uses of pheromones in lures and trap devices that contain insect pathogens were found more successful against insect pests in stored products than simple devices. In such methods the insects can be exposed to the pathogen by using an effective pheromone baited device. When an infected insect with a pathogen move and expose the normal population of insects it may cause more lethality in insects. Further, spore transfer to the subsequent generations, increases the intesinty to kill more number of larvae and adults contaminated by contact. That is why it is a promising method for long-term control of insect pests of stored products. The combinations of pheromone with pathogens are used to suppress the population of dermestid beetles (Coleoptera: Dermestidae) and *Trogoderma glabrum* Herbst. For an effective control of the beetles a pheromone (14 - methyl - 8 hexadecenal) is mixed with a protozoon pathogen, *Mattesoa trogodermae* Canning (Neogregarininda: Ophoryocystidae). It substantially suppresses subsequent generations of *T. glabrum* by a single time exposure of *M. trogodermal* spores into high density (32 adults/m²) population of adult males. Further, spore transfer and pathogen transfer in natural environment is enhanced by contaminated flying adult insects. Therefore, a very high lethality was observed in moths (*Plodia interpunetella*) in maize storage facilities when insects were exposed to *Bacillus thuringiensis* However, spores and crystals of *B. thuringiensis* adults are capable of rapidly killing larvae that feed on them. Similarly prevention of infestations of Indian meal moths*, P. interpunctella* and almond moths, *Ephestia cautella* by using *B. thuringiensis* [60]. Contrary to this, it was found less effective in controlling the Angoumois grain moth, *Sitotroga cerealella* (Olivier).

Control by Using Insect Growth Regulatiors: Besides synthetic pesticides, insect hormones and their analogues (IGRs) are used to control insects. These insect growth hormones are used in closed environment and found relatively more successful against several stored-product moths and beetles [61-63]. IGRs disrupt oviposition behavior in insects and cause impairment of reproduction. Two IGRs methoprene and hydropene are applied to prevented emergence of pupae in *Tribolium castaneum* (Herbs) and in *Tribolium confusum* [64]. Methoprene also shows inhibition of emergence of adult *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. Similarly, both compounds reduced the populations of adult progeny of *Sitophilus oryzae* (L.) and *Lasioderma serricrne* (F) [65]. However, for more effective control IGRs could be added to attractant impregnated baits instead of directly to food. After a moderate exposure of IGRs, the insects might cease to develop or behave properly. Moreover, juvenile hormone antagonist methoprene and pyriproxylen and the ecdysone agonists RH-5849 and tebufenocide susceptible and actellic-resistant strains of *Tribolium castaneum, Rhyzopertha dominica* and *Sitophilus oryzae* [66].

Microbial Control: One of the effective alternatives of synthetic pesticide is microbial control in which microbial insecticides in form of spores and toxins are used. It is much safer and highly specific toxins. Most effective strains is Bt toxins produced by *Bacillus thuringensis*, is used against stored grain insects. Besides this, many entomopathogens are used for the control of stored garin pests [67]. For more effective control certain botanicals are also mixed with *B. thuringensis*. It shows significant enhancement in killing power of pathogens and causes massive mortality in stored garin insects [68]. Similarly, mustard oil with *Paecilomyces formosoroseus* or *Normuraea rileyi* fungi causes significant reduction in oviposition and adult emergence in *Bruchidius incarnates*. For control of Indian meal moth four fungal species, *Beauveria bassiana, Lecanicillium lecanii, Metarhizium anisopliae* and *Paecilomyces farinosus* are used [69]. However, for effective control of Saw toothed grain beetles (Coleoptera: Silvanidae) an entomopathogenic fungus *Beauvesia bassiana* is used [70]. Similarly, for effective control of Indian meal moth, *Plodia interpunctella* granulosis virus (GV) is used [71], while *B. thuringienesis* protein Cry IC is used to kill diamond backmoth [72]. It is mutant enterotoxins also show insecticidal activity against Lepidopteran insects [73,73].

Cultural Control: Food grains store houses must be clean all around, dirt; egg shells and dead larvae should be removed. Broken infested grains are removed and burnt before new garins are stored before storage these should be properly fumigated and closed till the new haevest 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 riase the tempreture of the room to about 150 °F. During temperature treatment the doors should be tightly closed for 48 h alfter which godowns should be allowed to cool and cleaned before storage. Sulphur can be used to keep it on on burning charcoal to fumigate the godowns. Quarantine should be applied before export and import of food grains. Before supplying de-infestation of food grain is highly essential. For ware housing proper storage method are adopted. Dusting the walls, floors and ceiling of empty store with 5% BHC or 10% DDT dust at the 6 to 8 ounces per 100 cubic feet of space. Commercial smoke generators of BHC or DDT may also be used to disinfect the godown if they can be made reasonably air tight. Splitting of stock should therefore be avoided. Mixing of inert dusts with stored grain, prevent infestation. This measure can be adopted where small quantities of grains are to be stored [75].

Biological Control: Different biological agents are used for suppression of population of stored grain insects. It becomes an acceptable strategy to control stored grain insects. Various living organisms or their products are used to reduce populations of insects. However, for very effective control of stored grain insects various parasitoids, predators, pathogens and other living organisms are employed in natural conditions to suppress the population (Table 2). Most commonly hymenoptera parasitoids are used to reduce infestation and damage done by stored grain insects. Besides this, insect pathogens are alo employed as biological control agents [68]. Few predators such as hemimpteran bug, *Xylocoris flavipes* (Reuter) and several other anthocorid bugs of the sub-family Lyctocorinae are more frequently apply to control insect pests in store houses. These hemipteran bugs are promising agents for suppression of both Coleoptera and Lepidoptera insects in ware houses. They prey on most stages of many of these species. This predator has a high capacity to increase its numbers so as to reduce the population when prey is scarce. But there is one demerit that *X. flavipes* although found effective against many unprotected insects which are incapable of penetrating hard materials like seeds but is found ineffective against weevils that infest grain and pulse. It is especially used to suppress bruchids population in stored legumes [76]. Parasitoids are those insect which rely on other parasites help to maintain the low population level of stored grain insects. Two common parasitoids that in stored products are *Bracon hebetor* Say (Braconidae) and *Venturia canescens* (Gravenhorst, Ichneumonidae) and used to suppress *E. cautella* populations. *Laeluis pedatus* (Say) (Bethylidae) is another parasitoid which successfully controls dermestid larvae. However, a problem was noted that *Anthrenus flaviceps* Le Conte (furniture Carpet beetle) possesses a

Table 2: Name of parasites used to control certain stored grain pest

Name of parasite	Family	Order	Used against stored insect
Bracon hebetor Say	Braconidae	Hymenoptera	Oryzaephilus surinamensis L.
Venturia canescens (Gravenhorst)	Ichneumonidae	Hymenoptera	Oryzaephilus surinamensis L.
Lariophagus distinguendus Förster	Ptermalidae	Hymenoptera	Sitophilus granarius L.
Venturia canescens	Pyralidae	Lepidoptera	Plodia interpunctella (Hubner)
Anisopteromalus clandrae (Howard))	Pteromalidae	Hymenoptera	Oryzaephilus surinamensis L.
Anisopteromalus calandrae (Howard)	Pteromalidae	Hymenoptera	Cephalonomia waterstoni
Peregrinator biannulipes (Montrouzier)	Reduviidae	Hemiptera	Sitophilus granarius L.
Xylocris flavipes (Reuter)	Anthocoridae	Hemiptera	Plodia interpunctella (Hubner)
Lyctocoris spp	Anthocoridae	Hemiptera	S. oryzae
Amphibolus wenator (Klug)	Reduviidae	Hemiptera	S. oryzae
Scenopinus fenetralis (L)	Scenopinidae	Diptera	Cephalonomia waterstoni
Ventura canescens (Gravenhost)	Ichneumonidae	Hymenoptera	S. oryzae
Bracon hebetor Say	Braconidae	Hymenoptera	S. oryzae
Antrocephalus spp	Chalcididae	Hymenoptera	S. oryzae

supra - anal organ that serves as a defense mechanism against this parasitoid. Similarly, another parasitoid bethylid, *Cephalonmia tarsalis* (Ashmead) is used to suppress the population of *Oryzaephilus surinamensis* L. (sawtoothed grain beetle). There are several promising pteromid (Hymenoptera; Pteromolidae) parasitoids of grain and pulse weevils. One example is *Anisopteromalus colandrae* (Howard) effectively control grain weevils and a number of other stored-product pests [77]. *Lariophagus distinguendus* (Forst) and *Choetospila elegans* (Westwood) are other cosmopolitan parasitoids of grain weevils (Table 2).

For control of Indian meal moth*, Plodia interpunctella* (Hubner) egg parasitoids, *Trichogramma deion* Riley (Hymenoptera: Trichogrammatidae) and larval parasitoid, *Habrobracon hebetor* (Say) (Hymenoptera: Braconidae) were used for preventing infestations. It significantly suppresses the *P. Interpunctella* adults' population [78]. Similarly, a parasitoid *Apanteles flavipes* (Cam) is used for control of bean-weevil (*Bruchus chinensis* L.). Ity completes its whole life cycle inside the body of the host by completing a number of generations in a year and it successfully parasitizes *Bruchus chinensis* up to 45% in field population and 83% under laboratory conditions. Similarly, *Venturia canescens,* a hymenopteran parasitoid used to parasitize the Mediterranean flour moth (Lepidoptera: Pyralidae) [79], while for controlling sawtoothed grain beetles (Coleoptera: Silvanidae) in stored oats, an entomopathogenic fungus is used in conjuction with seed resistance. Besides this, spatiotemporal clustering and association of *Ephestia kuchniella* (Lepidoptera: Pyralidae) and two of its parasitoids are used to control stored grain pests in bulk [77]. Chemical cues are a major source of information used by insects for this purpose. Primary infestation of stored grain by stored product pests often favors the intense growth of mold. Volatiles of wheat infested by *Aspergillus sydowii* and *A.versicolor* repelled females of *Lariophagus distinguendus,* a parasitoid of beetle larvae in an olfactometer [80]. Successful parasitization requires commonly series recognition of host habitat and its location [81]. Stored product insects natural enemies also survive in spinosad treated wheat [82]. For control of cowpea weevil entomopatogenic *Beauveria bassiana* is used to control cowpea weevil, *Callosobruchus chinensis* exoskeleton [83], while *Bacillus thuringiensis* strains are used to control Coleopteran pests of stored wheat [84], while *Eupelmus vuilleti* (Hymenoptera: Eupelmidae) control cowpea [85]. The parasitoid *Anisopteromalus calandra* (Hymenoptera: Pteromalidae) parasitize and develop on late instars of five diferent stored product insects that typically complete their development inside seeds of grain or legume species or other dry commodity. Parasitoid adults were significantly larger and heavier when they developed on cowpea weevil irrespective of parasitoid population [77]. *Lariophagus distinguendus* Forster (Hymenoptera: Pteromalidae) is used as a biological control agent against the granary weevil, *Sitophilus granarius* (L), in grain stores. Similarly for effective control parasitoid wasp, *Theocolax elegans*, used to reduce the population of *Rhyzopertha dominica* on wheat [86]. Parasitism decreased the larval host size and development time. Similarly, larvae of the next generation also had reduced developmental period. Effect of low temperature prevailing in grain stores is necessary to be able to predict the potential of this parasitoid against *S. granarius* in temperate region, where grain is cooled with ambient air to achieve safe storage conditions [87]. The oviposition perference of insects should correlate with host suitability for offspring development. Therefore, insect females have to be able to assess not only the quality of a given host but also the environmental conditions of the respective host habitat. The egg parasitoid *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae) responded to synomones emitted by leguminous plants induced by feeding and oviposition activity of the bug *Nezara viridula* (L.) (Heteroptera: Pentatomidae). Broad bean leaves (*Vicia faba* L.) damaged by feeding activity of *N.viridula* and on which host egg mass had laid produced synomones which attracted *T. basalis* [88]. The fungi *Beauveria bassiana, Metarhaizum anisopliae* and *Verticillium lecanii* act as bioinsecticides to control broad bean beetle. *Nigella* and mustard oils acted not only as oviposition deterrants but also adversely influence the fecundity. In field, *Beauveria bassiana* and *Metarhaizum anisopliae* fungi gave the highest protection to broad bean against *Bruchus rufimanus* infestation. The treatments with bioinsecticides had a significantly lower percent of grain damage and lower seed weight loss. Enhanced efficacy of *Beaveria bassiana* for red flour beetle with reduced moisture. Red flour beetle, is a major pest of stored and processed grains that is tolerant of *Beaveria bassiana* (Balsamo) Vuillemin under most conditions. The desiccating conditions improved the efficacy of the fungus [32]. Besides this, for suppression of stored product mites *Phaseolus vulgaris* is used [89].

Control by Natural Plant Products: For control of stored grain insects, various methods have been applied to protect stored grains and other agricultural products from insect infestation. During last few decades, various synthetic pesticides have been applied to protect stored grains and other agricultural products from insect infestation, but their massive use has imposed so many detrimental effects on the environment and cause intoxication of non-targeting organisms [90-93]. However, these chemicals are declared ecologically unsafe because these persist for longer period in the environment and enter in to the food chain. It has been reported that certain insect pests have acquired resistance against most of the insecticides [4]. Thus it is necessary to develop certain new safe alternatives of these synthetic pesticides, which might have no adverse effect on the environment and non-target animals. Thus it is necessary to develop certain new alternatives that have no adverse effects on environment and other non-target animals. In this connection, it has already been established that many plant products have shown cidal properties to different stages of life against field crop [94]. Many botanicals such as plant essential oils and their chemical constituents are reported for their developmental inhibitory activities against insect pests [95,96]. The essential oils of many plant speices are known to have repellent and insecticidal activities [97,98]. Besides crude oils, toxic effect of oil constituents like d-limonene, linalool and terpenols was also observed on many insect pests (Table 3) [99,100]. Morespecifically, natural products show limited undesirable effects on the environment and non-target organisms and continuously evaluated for their pesticidal effects botanical resources [97] to resolve the pesticide dilemma [101].

The essential oils of *Artemisia annua* (L.) shows toxic, repellent and development inhibitory activities against two economically harmful stored product insects, *Tribolium castaneum* (Herbst.) and *Callosobruchus maculatus* (L.) (Table 4). Adult beetles of *T. castaneum* were repelled significantly by oils of *A. annua* at 1% concentration. Dose-response relationship revealed a significant negative correlation between larval survival, pupal survival and adult emmergence of *T. castaneum* [102]. Bruchid beetles attack legume seeds and cause severe damage in the quality and quantity of the crop. They attack broad bean before or during harvest as well as in storage. *Bruchus rufimanus* (Boh) is a univoltine species start infestation on broad bean pods in the field. After harvest the infested seeds were transmitted to stores, where development of beetle completed [103,104]. There after the beetle move to bean fields from trash beans left in sacks or harvesters and planters equipments. Beetles usually migrate from store house to broad bean field in the mid to late march, but this insect is not a storage problem. Feeding starts on pollen and petals, mating takes place wherever and eggs are deposited on green buds.

Volatile Action of Plant Essential Oils: Besides plant extracts, essential oils have shown insecticidal activity against field crop pests [105] and household insect pests [106]. Many of these oils have also shown high oviposition and growth inhibitory activity [107]. Similarly, volatile constituents, methyl salycylate from *Securidacalonga pedunculata* exhibited repellent and toxic properties against *Sitophilus zeamais* and *Rhizopertha dominica* [108]. Volatile compound diallyl disulphid isolated from neem have shown potent toxic, fumigant and feeding deterrent activity against stored

Table 3: Major components of essential oils isolated from various plant species

S. No	Essential oil	Components	Percentages
1	Black cumin	Thymoquinone	45.3
		p-cymene	15.53
		Longifolene	7.2
		Carvacrol	7.2
		4-terpineol	3.1
		t-anethole	1.97
		Longipinene	1.37
		Limonene	1.12
		a-pinene	0.85
		b-pinene	0.52
2	Cumin	Cuminaldehyde	21.0
		b-pinene	21.0
		p-mentha-1,3-dien-7-al	11.0
		p-cymene	9.7
		p-mentha-1,4 -dien-7-al	8.9
		a-phellandrene	1.4
		a-thujene	1.1
		Myrcene	1.2
		1,8-cineole	0.8
		Limonene	0.7
3	Dill	Carvone	53.30
		Limonene	35.8
		Cis-dihydro carvone	3.71
		trans- dihydro carvone	1.78
		Dihydrocarveol	1.37
		a-phellandrene	1.04
		b-phellandrene	0.02
		Cis dihydro carvone	3.71
		Trans dihydro carvone	1.78
		Dihydrocarveol	1.37
		P-cymene	0.32
4	Saunf	Anethole	68.02
		Limonene	11.09
		a-phellandrene	3.54
		Anisealdehyde	2.68
		p-anisic acid	2.16
		Eugneool	1.10
		Geraniol	0.99
		Ocimene	0.78
		a-pinene	0.63
		b-pinene	0.40
5	Ajwain	p-cymene	15.57
		Limonene	2.08
		g-terpinene	11.86
		Terpinene-4-ol	1.13
		Thymol	61.31
		Carvocrol	0.63
		b-pinene	3.31
		Myrecene	0.56
		b-phellandrene	0.18
		a-thujene	0.02
6	Black pepper	Sabinene	19.0
		Limonene	19.0
		d-carene	16.0
		b-pinene	12.0
		b-caryophyllene	10.0
		a-pinene	8.2
		a-phellandrene	1.3
		Myrcene	1.2
		a-thujene	0.8
		b-biasabolene	0.6

Table 3: Continued

S. No	Essential oil	Components	Percentages
7	Mace	Sabinene	49.09
		a-pinene	13.19
		a-phellandrene	6.72
		terpinene-4-ol	6.43
		p-cymene	3.09
		b-pinene	2.2
		Myristicin	1.85
		cis-sabinen hydrate	1.62
		Safrol	1.34
		b-asaron	1.1
8	Star anise	Cineole	18.1
		Linalool	10.1
		Sesquiterpene hydrocarbon	7.2
		Methyleugeenol	9.8
		Safrole	6.6
		a-terpineyl acetate	6.8
		Terpinen-4-ol	3.9
		a-terpinol	3.3

Table 4:Essential oils and their action against stored grain pest

Essential oil	Scientific name	Action	Activity	Insect pest
Ajwain	Carum copticum	Fumigant	1,8-cineol	Eggs, larvae and adult of S. oryzae
Thymus	Thymus percicus	Fumigant	Cinnamaldehyde	Callosobruchus maculates, Tribolium astaneum and S. oryzae
Dhania	Coriandrum sativum	Fumigant and		Tribolium castaneum repellent
	Vitex pseudonegundo	Fumigant		Egg, larvae and adult of Callosobruchus maculates
	Laurus nobilus	Fumigant		All life stages of Tribolium castaneum
Rosemarry	Rosmarinus	Fumigant		Egg larvae and adult of Tribolium officinalis castaneum
Garlic	Allium sativum	Fumigant	Diallyl sulphate	Adult Tribolium castaneum
	Aillanthus altissima	Fumigant and Repellent		Adult of S. oryzae, O. surinamensis, T. castaneum
	Schinus molle	Fumingant	Limonin α-Phellandree Elemol Comphene	Adult of S. oryzae
	Mentha longifolia	Fumingant and		All life stages of Sitophilus zeamais repellent
Eucalyptus	Eucalyptus nicholii	Fumigant	Cineole	Adult of T. castaneum and Rhizopertha
dominicaCimmanon	Cardamom sp	Fumigant	Callosobruchus maculates	
		Fumigant		All life stages of Callosobruchus maculates and T. castaneum
Neem	Azadirachta indica	Fumigant		Adult of S. oryzae and Rhizopertha Dominica
Ground nut	Elletaria cardamomum	Fumigant		Ovipositin inhibition of Callosobruchus
maculatesClove	Syzigium aromaticum	Fumigant		larvve of Corcyra cephalonica and T. Castaneum

grain pests, *Sitophilus oryzae* (L) and *Tribolium castaneum* (Herbst) [109]. The active components from leaves of *Artimisia princepi* and seeds of *Cinnamomum camphora* (L) have been shown repellent and insecticidal activity against *Sitophilus oryzae* and *Bruchus rugimanus* [110]. Thus, plant products show enormous toxicity against several stored product pests and provide prolonged protection to the seeds, which may be due to a high mortality of adult insects, besides reduced oviposition and low hatching [111]. Foam sprayed with clove oil and placed between sacks caused the highest mortality of *Callosobruchus maculatus* (Table 4) [112].

Plant volatile aldehydes are used as natural insecticides to control stored product beetles [80]. Methyl allyl disulfide and diallyl trisulfide obtained from essential oils of garlic, used to control stored product pests [11]. Volatile constituent, di-n-propyl disulfide extracted from seeds of neem, *Azadirachta indica* is toxic, when applied as a fumigant to *Tribolium castaneum* adults and larvae and *Sitophilus oryzae* adults. Di-n-propyl disulfide significantly decreased the growth rate and dietary utilization with moderate inhibition of food consumption in both insects (Table 3). This component is a potent toxic, fumigant and that also act as feeding deterrent to stored grain pests [112]. Essential oil extracted from the leaves of turmeric, *Curcuma longa* L. showed contact and fumigant toxicity, antifeedent and affects the progeny production. It reduced oviposition and egg hatching in stored grain insects [113]. The constituents of *Foeniculum valgare* fruit show contact and fumigant activity against coleopteran stored product insects [36]. The Japanese mint (*Mentha arvensis*) oil was found effective as fumigant against *Sitophilus oryzae* in sorghum *(Sorghum bicolor)* [114]. Two alpha amylase inhibitors, called alpha AI-1 and alpha AI-2, isolated from common bean (*Phaseolus valgaris*) provides complete protection from Pea weevil. Amylase inhibitors are used to bring about protection of crops from insect pests and to decrease insect pest population below the economic injury level. Natural fungicide developed against aflatoxigenic fungi protect stored rice when mixed wirh lemon grass essential oil Methyl salicylate as the principal volatile component in the methanol extract of root bark of *Securidaca longepedunculata* protecting stored grains against insect pests [115]. *Bauhinia monandra* leaf lectin (BmoLL) shows insecticidal action against *Anagasta kuehniella, Zabrotes subfasciatus* and *C. maculates* [116]. N-acetylglucosamine-binding lactin obtained from *Koelreutaria paniculata* seeds affects the larval development of *Callosobruchus maculates* and *Anagasta kuehnilla* larvae [117].

Essential oils possess attractive or repellent effects and showed an insecticidal action against many stored grain insectss. Essential oils isolated from plants that consist of cyclic and monocyclic mono-terpenes were found more effective repellents against insects. Filter paper strips treated with *Acorus calamus* oil significantly repelled more number of *Tribolium castaneum* adults [118]. Similarly, the oils of *Nigella*, *Frankincense* and *Pumpkin* act as repellent, oviposition deterrent and protectant against the bean bruchids, *Bruchus incarnate* beetles [119]. Repellent and insecticidal activities of essential oils extracted from leaves of *Artemisia princeps* pamp and seeds of *Cinnamomum comphora* against storage pests [120]. 1,8-Cineole from *Artemisia annua* shows toxicity and feeding deterrence activity against *Tribolium castaneum.* It also affects the progeny production in flour beetle [107]. In combination, avidin and alpha AI did not increase mortality, but they cause a significant increase in developmental time of cowpea bruchids [41]. Legume seeds contain a wide range of allelochemicals with toxic and deterrent effects against insect pests [121].

Potential ingradients isolated form various plant speices shown toxic and growth inhibitory activity against stored grain insects. Besides this, both cinnamaldehyde and cinnamyl acetate have shown excellent inhibitory activity agains stored grain insects [122], while *Artimisia princeps* and *Cinnamomum camphora* (L) oils have shown repellent and insecticidal activity against *Sitophilus oryzae* and *Bruchus rugimanus* (B.) [93]. Beside this, volatile oils isolated from leaves and flowers of *Lantana camara* (L), *Callistemon lanceolatus*, *Cymbopogon winterianus*, *Eucalyptus* sp, *Nerium deander*, *Ocimum bacillicum, Ocimum sanctum* and *Vitex negundo, Satureja hortensis*, *Thymus serphyllum* and *Origanum* have shown insecticidal, antifeedant and growth inhibitory activities against insect pests. Similarly biopesticides from *Chenopodium* have shown toxic effect against *Orius insidosius* (Say) and *Aphidius colemni* [123]. *Eugenia caryophyllata* bud and leaf oil compounds show ovicidal effects in *Pediculus capitis* [124]. Plant essential oils have shown very high repellent and toxic action against stored grain insects at very low LC_{50} value [125]. Few important essential oils such as Cumin, black pepper, ajwain, dill oil and staranise oil have shown very high toxicity and low LC_{50} ranging between 1.05 -1.25µl. most of the essential oils isolated from common spices have shownvery high insecticidal and oviposition inhibition potential against a stored grain pests. These essential oils significantly suppressed the survival of larvae and pupae and havily cut down the adult emergence [125]. Percent repellency noted in different essential oils was maximum in clove 55±1.30 at 0.05µl concentration and minimum in citronelle oil 33.3±1.80 at the same concentration (Table 5)

The essential oils isolated from *Salvodora oleoides* and *Cedrus deodara* have shown significant oviposition deterrence against *Phthorimaea operculella* [126] while essential oils isolated from *Anethum sowa* and *Artemisia annua* have been reported for their repellent, toxic and developmental inhibitory activity against *Tribolium castaeneum*. *Artemisia annua* oil also affects viability of *Callosobruchus maculatus* eggs [102,107]. Verma et al. [105] has reported the toxic and developmental inhibitory activities of *Lippa alba* oil against *Callosobruchus maculatus* and *Tribolium castaneum.* Similarly, Black pepper deter oviposition in *Tribolium castaneum* significanlly at 1.5µl concentration [125] while essential oils isolated from black cumin, clove Cassia, neem, almond bavachi and cleome has shown moderate oviposition

Table 5: Percent repellency of different oils against the pulse beetle Bruchus chinensis

Essential oil tested	Dose*	Repellency (in percent)** (Mean±SE)	F-value
Cumin	0.50 µl	35±1.50	72.21
	1.00 µl	38.8±1.80	
	2.00 µl	70±1.20	
	4.00 µl	86.60±1.80	
Black pepper	0.50 µl	53.3±1.20	134.28
	1.00 µl	66.6±1.80	
	2.00 µl	83.3±1.20	
	4.00 µl	95±1.30	
Ajwain	0.40 µl	43±1.10	132.16
	0.80 µl	55.8±.0.70	
	1.60 µl	72.0±1.20	
	3.20 µl	94±0.86	
Staranise	0.50 µl	45±1.70	92.88
	1.00 µl	56.6±1.80	
	2.00 µl	78±1.20	
	4.00 µl	90±1.40	
Dill	0.50 µl	50±0.90	122.21
	1.00 µl	61.6±1.10	
	2.00 µl	71.6±1.60	
	4.00 µl	95±1.30	
Saunf	0.50 µl	55±1.60	106.92
	1.00 µl	68.3±1.20	
	2.00 µl	83.3±1.80	
	4.00 µl	93.3±1.20	
Black cumin	0.50 µl	48.3±1.10	111.68
	1.00 µl	56.6±1.20	
	2.00 µl	73.3±1.60	
	4.00 µl	90±1.40	
Clove	0.05 µl	55±1.30	96.29
	0.25 µl	65±0.80	
	0.50 µl	78.30±1.10	
	1.00 µl	96.60±0.08	
Cassia	0.50 µl	50±0.80	276.46
	1.00 µl	55±0.80	
	2.00 µl	71.6±1.10	
	4.00 µl	96.6±0.80	
Neem oil	0.50 µl	53±1.20	96.29
	1.00 µl	65±0.80	
	2.00 µl	73±1.20	
	4.00 µl	96.6±0.80	
Almond oil	0.40 µl	45±1.60	147.9
	0.80 µl	55±0.80	
	1.60 µl	70±1.40	
	3.20 µl	95±0.80	
Bowchi oil	0.50 µl	53±1.20	261.1
	1.00 µl	65±0.80	
	2.00 µl	75±0.80	
	4.00 µl	96.6±0.80	
Citronelle	0.50 µl	33.3±1.80	184.14
	1.00 µl	56.6±0.80	
	2.00 µl	73.3±0.80	
	4.00 µl	96.6±0.80	
Cleome oil	0.50 µl	53.3±1.20	214.31
	1.00 µl	65±0.80	
	2.00 µl	71.6±1.10	
	4.00 µl	96.6±0.80	

* Two choice repellency bioassay was performed for each essential oil.

Repellency for each essential oil was tested four times for each concentration

Table 6: Effect of different essential oils on oviposition behaviour of Bruchus chinensis

		Mean No. of eggs laid per insect	% Eggs laid per insect	
Essential oila	Dose applied (ml)	Mean ± SE	Mean ± SE	%ODI[b]
Cumin	20% of LC_{50}	2.15±0.122	52.52±3.062	45.45
	40% of LC_{50}	1.88±0.076	47.08±1.902	50.94
	60% of LC_{50}	0.88±0.015	22.08±0.380	58.10
Black pepper	20% of LC_{50}	0.80±0.033	44.44±1.853	31.14
	40% of LC_{50}	0.78±0.049	43.51±2.753	36.05
	60% of LC_{50}	0.76±0.038	42.59±2.139	63.93
Ajwain	20% of LC_{50}	0.68±0.068	45.55±4.559	38.46
	40% of LC_{50}	0.65±0.065	43.33±4.375	39.53
	60% of LC_{50}	0.53±0.084	35.55±5.593	40.62
Staranise	20% of LC_{50}	2.12±0.059	52.92±1.493	37.61
	40% of LC_{50}	1.53±0.099	38.33±2.477	39.53
	60% of LC_{50}	0.85±0.020	21.25±0.510	47.78
Dill	20% of LC_{50}	0.83±0.065	41.66±2.805	30.8
	40% of LC_{50}	0.73±0.056	36.66±2.805	44.66
	60% of LC_{50}	0.67±0.050	33.33±0.962	64.94
Saunf	20% of LC_{50}	1.51±0.055	68.93±2.493	41.34
	40% of LC_{50}	0.98±0.076	44.62±3.459	46.52
	60% of LC_{50}	0.52±0.055	23.48±2.493	49.81
Black cumin	20% of LC_{50}	1.61±0.064	62.16±2.463	18.59
	40% of LC_{50}	1.15±0.055	37.82±2.110	38.36
	60% of LC_{50}	0.63±0.038	24.35±1.481	61.76
Clove	20% of LC_{50}	3.97+0.13	56.66+1.81	28.87
	40% of LC_{50}	3.13+0.03	44.76+0.44	36.59
	60% of LC_{50}	2.43+0.08	37.14+1.23	47.81
Cassia	20% of LC_{50}	10.41+0.57	88.64+5.35	8.75
	40% of LC_{50}	8.97+0.34	74.88+3.16	15.47
	60% of LC_{50}	8.47+0.31	72.05+2.69	17.18
Neem	20% of LC_{50}	10.40+0.17	93.86+1.09	3.28
	40% of LC_{50}	6.36+0.20	57.46+2.02	27.61
	60% of LC_{50}	2.43+0.08	26.93+0.85	57.78
Almond	20% of LC_{50}	7.33+0.13	82.32+1.59	9.84
	40% of LC_{50}	6.72+0.16	75.55+2.02	14.38
	60% of LC_{50}	4.55+0.16	51.37+2.04	32.85
Bowchi	20% of LC_{50}	8.32+0.14	85.62+1.76	7.96
	40% of LC_{50}	6.80+0.12	80.02+1.50	13.73
	60% of LC_{50}	5.88+0.14	65.96+1.67	20.87
Citronelle	20% of LC_{50}	9.38+0.29	81.17+2.57	7.11
	40% of LC_{50}	5.15+0.17	44.54+1.61	38.88
	60% of LC_{50}	1.97+0.09	17.02+0.91	70.95
Cleome	20% of LC_{50}	12.13+0.45	91.10+3.74	5.96
	40% of LC_{50}	11.08+0.54	83.20+4.52	11.08
	60% of LC_{50}	9.70+0.42	74.32+3.52	17.23

[a]The chemical stimulus in form of essential oil was coated on the Whatmann filterpaper strip(1Cm2) in oviposition inhibition test

[b]The %ODI was calculated as 100(A-B)/(A+B), with A and B being the number of eggs laid in the control and in test respectively.

Table 7: LC_{50} values of different essential oils against Bruchus chinensis.

Essential oil tested	LC_{50} (ml)	UCL[a] Upper Limit (µl)	LCL[a] Lower Limit (µl)	Slope function (S)
Cumin	1.05	1.139	0.968	1.346
Black pepper	1.25	1.365	1.145	1.355
Ajwain	1.05	1.140	0.966	1.319
Staranise	1.10	1.182	1.023	1.324
Dill oil	1.15	1.251	1.056	1.365
Saunf	0.90	0.965	0.839	1.317
Black cumin	0.85	0.880	0.820	1.104
Cardamom	0.346	0.582	0.206	1.102
Clove	0.42	0.45	0.39	1.29
Cassia	8.60	9.91	7.45	1.88
Neem	10.60	12.57	8.94	1.94
Almond	7.80	9.12	6.66	2.08
Bowchi	16.00	17.18	14.89	1.47
Citronelle	6.00	7.07	5.09	2.06
Cleome	5.50	4.52	6.69	2.05
Cinnmaom	0.050	0.084	0.030	1.002

UCL[a] = Upper Confidence Limit, LCL[a] = Lower Confidence Limit

deterrence [125]. (Table 4) Different essential oils cumin, ajwain, staranise and saunf have effectively inhibited the oviposition in *Bruchus chinensis* as their percent ODI noted was at 20% of LC_{50} value 45.45, 38.4, 37.61and 41.34, respectively (Table 6). Besides this, black cumin and clove have shown very low LD_{50} (Table 7), moderate percent ODI, i.e. 18.59/ 8.87±1.39 at 20% of LC_{50} value while cassia, neem, almond, bowchi, citronelle and cleome have shown very low percent of oviposition inhibition i.e. 8.75, 3.28, 9.84, 7.96, 7.11 and 5.96 respectively (Table 4). Volatile oil of *Calendula micrantha* plant showed insecticidal activity and inhibited reproductive potential of Mediterranean fruit fly *Ceratitis capitata* Wied [127]. *Calendula micrantha* plant extract has shown suppressive effect on reproductive potential of Mediterranean fruit fly *Ceratitis capitata* [127]. Beside essential oils, insecticidal potential of certain plant extracts such as *Piper nigrum,* (L) [128], *Anethum graveoleons,* [129], *Allium sativum* [130], *Vitex negundo, Polygonum hydropiper* [131] and *Myristica fragrans* [132] has been established against stored grain pests [133]. Vegetable oils acts as a grain protectent against beetles in storage of pigeon pea and show repellent action and decrease the adult emergence [134]. Extracted oils such as coconut, maize or ground nut oil have been recognised as toxicants or growth inhibitors. The azadirachtine-based insecticide, Neem Azal used as toxicant against adults of *Tribolium castaneum, Rhyzopertha dominica* (F)*, Sitophilus oryzae* (L.) in rye and oats) [135].

Oviposition Inhibition: The oviposition responses in insects may be influenced by type of chemical, functional group, volatility and scent. In stored condition some volatile oils elicit negative responses in stored grain pests. Therefore, insects shift towards peripheral areas as observed during experiments. Further, volatile repellents after evaporation in the medium deter insects from feeding and cause lethality in insects. Besides its volatile compounds also impose negative orientation responses in insects and inhibit the egg deposition on the surface. Similarly, corn leaf essential oils inhibit oiposition behavior in *Sesamia nonagrioides* females [136]. Contrary to this, few chemicals such as n-alkenes isolated from *Ostrinia nubilalis* (Hubner) [137] induce oviposition, but pentane extracts deter females from oviposition [138]. The difference in mortality and egg laying capacity between the control and test insects may be due to the volatile components of the essential oils. Furthermore, phytochemicals can be potentially used for disruption of oviposition in stored grain pest especially against *Bruchus chinensis* for successful reduction of beetle population in go downs.

Extracts of *Capparis deciduas* stem and flower shows insecticidal and oviposition inhibitory activities against *Bruchus chinensis* [138]. The essential oils isolated from *Salvodora oleoides* and *Cedrus deodara* has shown significant oviposition deterrence against *Phthorimea operculella* [121]. Phenyl butanoid extractedfrom *Zingiber purpurem* act as oviposition inhibitor [139]. Similarly, fungal volatiles are also used to control stored grain insects [80].

CONCLUSION

Store grain pests seriously damage food grains. Over the years, there were utter failures in control and management of which provide chances to stiored grain insects to cause more economic lossess every year. For protection of grain damage and quality of food grains, various methods are used. Synthetic pesticides were used as promising control, agents, but they have shown adverse effects on environment and persist for longer period in form of residues and entered in the food chain after utilization of products by organisms. Hence, use of synthetic chemicals is minimized and banned. To replace these chemicals safer methods were evolved for insect control. Therefore, for protection of environment, expenditure incurred on pesticides non-chemical methods such as pheromonal, microbial, biological and cultural control was practiced. However, specific and selected control methods are to be applied. Few natural prodcust such as volatile oils and their constituents were used to control stored grian insects. Further, volatile repellents after evaporation in the medium deter insects from feeding and cause very high lethality in insects. Morespecifically, volatile compounds impose negative orientation responses in insects and inhibit the egg deposition on the surface. Similarly plant leaves also contain highly volatile organic chemicals that show repellent and insecticidal activity against stored grain insects. Hence, pheromones are used in behavioral control of insects either by applying male specific or female specific pheromonal substances which uphold disrupt communication and help in mass trapping of insects by lures and attraction. Pheromones are used in minute quantities and at considerable distances. Further more, *Beauveria bassiana* and *Metarhaizum anisopliae* fungi gave the highest protection to food grains against *Bruchus infestation*. The treatments with bioinsecticides had a significantly lower percent of grain damage and lower seed weight loss. Further, desiccating conditions improved the efficacy of the fungus for suppression of stored product insects. Besides this, different biological agents are also emplyed for suppression of population of stored grain insects. These biological agents are various living organisms such as parasitoids, predators, pathogens or their products which are used in natural to reduce insect population. Most commonly hymenopteran parasitoids are used to reduce infestation and damage done by stored grain insects. Besides this, insect pathogens are also employed as biological control agents. Besides this, resitatnt varities also help in reduction of use of harmful and highly toxic chemicals. Further, genetic conrol can cut down the use of harmful persistant chemicals and improve the performance of natural biological agents. Food grains store in houses must be clean all around, dirt; egg shells and dead larvae and infested broken grains are removed and burnt before new garins are stored before storage. Storehouses should be properly fumigated and sealed with parpanlin till the new harvest comes. For better protection of stored grian environmental conduction must be evaluated. For much better control computer based decision support system should be used to predict damage and operation requirements at right time. Hence, both biological and non-biological factors and their effects must be evaluated to check the possible infestation during storage. Therefore, selected control strategies are developed for integrated and highly effective pest management of stored grains.

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