DETECTION TECHNIQUES IN MONITORING OF STORED GRAIN INSECTS

Abstract

Stored grain insects (rice weevil, lesser grain borer, khapra beetle, red flour beetle, pulse beetle etc), rodents, and other pests like fungi and birds can infiltrate grain storage facilities, leading to significant losses. Pests feed on stored grains and contaminate them thereby making them unfit for consumption (FAO, 2015). Among different factors affecting food grain storability, stored grain pests can cause both qualitative and quantitative loss in food grains.

During storage, all forms of food grains, such as cereals, pulses, spices, oil seeds, and other stored food products, are vulnerable to insect pest attack. Following are the major pests of food grain commodities

Keywords: Detection Techniques, Stored grain insects, qualitative and quantitative

Authors

Pyla Jyothi
National Institute of Plant Health Management,
Hyderabad.

Alice R P Sujeetha
National Institute of Plant Health Management
Hyderabad.

C S Gupta
National Institute of Plant Health Management
Hyderabad.

Common Insect Pests of Stored products	
Scientific name	**Common name**
Cereals	
Trogoderma granarium	Khapra Beetle
Sitophilus oryzae	Rice weevil
Rhyzopertha dominica	Lesser grain borer
Tribolium castaneum	Red flour beetle
Oryzaephilus surinamensis	Saw-toothed grain beetle
Cryptolestes spp.	Rusty grain beetles
Sitotroga cerealella	Angoumois grain moth
Ephestia cautella	Tropical warehouse moth
Corcyra cephalonica	Rice Moth
Plodia interpunctella	Indian Meal Moth
Pulses	
Sitophilus oryzae	Rice weevil
Callosobruchus maculatus	Cowpea beetle
Callosobruchus analis	Cowpea beetle
Callosobruchus chinensis	Adzuki bean weevil
Oil seeds, oil cakes, meals	
Caryedon serratus	Groundnut bruchid
Oryzaephilus surinamensis	Saw-toothed grain beetle
Trogoderma granarium	Khapra Beetle
Corcyra cephalonica	Rice Moth
Plodia interpunctella	Indian Meal Moth
Ephestia cautella	Warehouse moth
Dry fruits and tree nuts	
Oryzaephilus surinamensis	Saw-toothed grain beetle
Lasioderma serricorne	Cigarette beetle
Tribolium spp.	Flour beetle
Trogoderma granarium	Khapra Beetle
Plodia interpunctella	Indian Meal Moth
Ephestia cautella	Warehouse moth
Stegobium paniceum	Drugstore beetle
Spices	
Lasioderma serricorne	Cigarette beetle
Stegobium paniceum	Drugstore beetle
Tribolium spp.	Flour beetle

The stored grain pests become small in size, average adult size being 3-5 mm and are cryptic andtherefore, they go unnoticed when present in low numbers. They are highly prolific in thatseveral generations occur in a year.

I. IMPORTANCE OF PEST DETECTION

The detection of insect presence in stored foodstuffs is critical to ensuring grain quality and shelf life. Inspecting for insect-damaged kernels is time-consuming, and many infested kernels may go undetected because the immatures has not emerged from the kernel. Grain inspectors at milling plants must be aware of the extent of hidden insect infestations so that cargoes with excessive infestations can be cleaned or redirected for other purposes. Detection methods alert about presence of infestation in the storage premises or grain consignment and helps in decision making (Quitco and Quindoza, 1986). Detection methods are useful in locating infestation, for early detection of low level infestations and to determine the success of fumigation or other control measures undertaken. Early detection also helps to avoid scheduled or calendar fumigations and spray treatments and thus, reduce pesticide use or contaminants (Ramzan *et al.* 1986; Merga and Haji, 2019).

Quality requirements for grains have been set in the majority of countries to please customers, who are becoming more conscious of the importance of clean grain and its products. With consumers seeking high-quality food, contaminants such as insects, rat droppings, and ergot (a deadly fungus body) in post-harvest grains must be reduced. Grain buyers are increasingly demanding zero-tolerance for these impurities. Canada, for example, has a constitutionally mandated zero tolerance for stored-grain insects (Canada Grain Act, 1975). Any delay in detection may cause pest outbreak or heavy population build-up, initiating severe contamination besides quantitative loss. Detection of stored grain insects using appropriate techniques is considered as the main step in pest management. Quality maintenance and contaminant reduction to meet the International Standard Organization (ISO) and hazard analysis critical control points (HACCP) are important for marketing the produce.

II. DETECTION METHODS

Accurate information about insect infestation can only be obtained by thorough and regular inspection and sampling procedures. This is imperative in formulating sound management decisions involving the adoption of any remedial action against these bio-deteriorating agents or the disposal of grain with due cognizance to the condition of both the commodity and the storage facility. Regular inspection will help in maintaining a good storage environment which is favourable to good grain quality by monitoring any significant build-up in pest populations, graintemperature, moisture migration, and grain residues. Exact and reliable detection and monitoring of storage insects in grain bulks is an essential part of commercial trading and research for pest management (Rajendran S, 2005).

Detection of hidden infestation in whole kernels can be done by several methods. It can be detected by staining of kernels to identify entrance holes for eggs, floatation, trapping, radiographic techniques, acoustic techniques, uric-acid measurement, nuclear magnetic resonance imaging and immunoassays. The major techniques commonly practiced for detection of the infestation caused by insects are as follows -

1. **Visual Inspection:** Normal visual inspection of storage facilities and stored grain is subjective in nature, and therefore any results can only be recorded in a descriptive way. Based on visual inspection, many observations can be made on the grain or stored

products to find out whether the sample is infested or not. The exit holes on grains, eggs on grain surface, webbing or silken strands present, pupal cases sticking to shells and gunny bags can be observed visually.

Symptoms caused by various stored grain pests		
Symptoms	**Commodity**	**Causal agent**
Exit Holes	Cereals	*Rhyzopertha dominica, Sitophilus* spp.
	Paddy	*Sitotroga cereallela*
	Pulses (whole)	*Callosobruchus* spp. , Other Bruchids
	Groundnut in Shell	*Caryedon serratus*
	Whole spices	*Stegobium paniceum*
	Cassava	*Lasioderma serricorne*
Eggs on grain surface	Pulses	Bruchid infestation, *Callosobruchus* spp.
Webbing and silken strandspresent	Cereals (whole and milled), oilseeds, oilcakes/meal s	*Corcyra cephalonica, Ephestiacautella, Plodia interpunctella*
Pupal cases sticking shells and gunny bags	Peanut in shell	*Caryedon serratus*
Exuviae or moulted cuticle /skin casts	Cereals	*Trogoderma granarium*

2. **Sampling and Sieving Method:** These are the ancient and most popular and widely practiced methods. The aim of drawing random samples of the commodity is to determine the mean value and the variability of the level of infestation or contamination (% discoloured kernels) in any given situation. The method simply involves drawing grain samples 0.5-1.0 kg using trier or spear sampler from the consignment and bag stacks. The accuracy depends on the samples drawn and quantity of each sample and insect population density in the grain (Jones *et al*., 2011).

   "Hand held sieves" are particularly useful in assessing the dust content and live insects from small samples. Different-sized mesh openings can be used for different particle size, or a combination of appropriate sizes can be used for mixed commodities varying in particle size.

   "Sack sieves" are used to sample an entire sack; the time taken can be between 5-15 minutes. The recovery of insects is dependent on insect species, time of sieving, slope ofthe oscillating sieve mesh and mesh size. However, one demerit of sampling and sieving methods is that they do not indicate the level of hidden (internal) infestation.

3. **Specific Gravity Method:** In hidden infestation, the larva inside the grain feeds on the endosperm and creates a cavity and thus reduces the density of the grain. When a mixture of uninfested and infested grains is immersed in a salt solution of appropriate density for

about 10 minute the uninfested grains sink to the bottom, while the infested grains float. The specific gravity method is suitable for detection of internal infestation in whole grains. It is quick and requires very simple laboratory facilities but does not indicate the species or the specific life stage present inside the grains. Grains infested with egg and immatures do not float and therefore, cannot be detected. Hence, it underestimates the actual infestation level. This method is reported to be not suitable for hulled seeds such as barley, oats and rice and for large seeded grains like corn.

4. **Insect Fragment Count:** In this method, insect fragments such as insect heads, cast skins and head capsules arising from live and dead insects are isolated from processed foods directly and from whole grains after grading /sorting and then counted. It is an accepted method in India (BIS, 1971).

   Whole grains are ground to a particle size of 1.5 mm so as to expose the internal infesters. After digesting the grain materials, the insect parts or fragments are trapped in a system consisting of an oil phase (mineral oil) and an aqueous phase (water). The oil globules extract and concentrate the light insect fragments. The trapped insect fragments in the oil phase are then removed by filtration and collected on a filter paper for microscopic examination.

5. **X-ray Technique (X-ray radiography):** Soft X- ray is the only non-destructive direct method that can detect insect infestation in grain kernels. Hidden Infestation caused by Bruchids and rice weevil is significantly detected. Both living and dead insects can be detected by this method. This approach, however, is insensitive to egg and early larval instars. The main requirement for this procedure is a costly machine to generate the X-rays, films for exposure/automatic computer-enabled software system, and an expert to interpret the radiographs. The exposure and voltage depend on the commodity as well as the degree of penetration and contrast required. greater moisture grains necessitate a greater voltage for X-ray penetration. In mango fruits, the X-ray technique has also been used to detect the mango stone weevil *Sternochetus mangiferae*.

X-ray Image of Large, Medium, and Immatures in Wheat Grains (left to right)

6. **NMR and NIR Technique:** NIR spectroscopy has evolved as a quick, dependable, precise, and cost-effective tool for grain compositional characterization. This method is applicable to both qualitative and quantitative analysis. The NIR is based on electromagnetic wavelength absorption in the 700-2500 nm region. Classical absorption spectroscopy can be used to determine the amounts of substances such as water, protein, fat, and carbohydrate. Near-infrared spectroscopy (NIRS) can detect the presence of

hidden insect larvae or external adult insects quickly and automatically. Because each insect species' cuticle may have a varied chemical makeup, NIRS can identify between them based on their absorbance properties. This unique chemical composition causes molecules to vibrate at unique frequencies and absorb NIR energy corresponding to these frequencies and overtones of these fundamental frequencies (Panjama Cheewapramong, 2007)

7. **ELISA Test:** Enzyme linked immunosorbant assay (ELISA) is also one of the detection method used for detection insect pest contamination in grains. This is a straightforward but extremely sensitive approach for detecting trace amounts of particular insect protein in grain and milled grain. Myosin, a muscle protein, is found in all life stages except insect eggs. The muscle protein myosin is easily extractable from infested grains. Myosin is not found in food grains and processed food. In this method, the mass of insect material (myosin content) present is correlated to the number of insects in the infested grains (Dunn *et al.,* 2008).

   First and foremeost, the antibodies to insect myosin are developed. In the ELISA plate, insect protein isolated from the sample is allowed to bind with antibodies conjugated to an enzyme. The development of colour, which is proportionate to the quantity of myosin, is measured in colorimetric ELISA reader at 414 nm. The assay is generally linear and can find one weevil / 50 g grain. To carry out the test, it needs a moderately equipped laboratory and normally the test takes 2 h for 20 samples approximately.

8. **Uric Acid Analysis:** Measurement of the uric acid contents in infested grains will give an indication of the past insect infestations that are concealed during processing. The method is only useful when insect density is high, in which case they were visibly obvious anyway. The quantity of uric acid excreted by insects varies between species and life stages. Uric acid can be determined by colorimetric, flurometric, GLC, TLC, HPLC and enzymatic methods.

9. **Analysis of CO_2 production:** Insect produces CO_2 during the respiration. The CO_2 produced in grains due to respiration of insects in 24 h has been considered to detect the presenceof internal infestation in grains. The expected CO_2 level in un-infested dry grain of <14% moisture content is less than 0.25%. In a 24 h incubation period at 35^0C, if the intergranular air contains beyond 0.3% CO_2, it indicates that the grain is infested. The CO_2 concentration is determined by instrumental methods using a gas chromatograph with TCD detector, interference refracto-meter or infra-red gas analyser.

   Demerit of this method is that, it is time consuming, less sensitive at low level infestation and is not applicable for grains with moisture content exceeding 14%. At higher moisture levels, grain alone evolves more CO_2. If the grain is infested only with eggs or early larval stages, detection is not possible because of their low respiratory activity.

III. STAINING TECHNIQUES

1. **Egg-Plug Staining:** Weevils (*Sitophilus* spp.) attacking cereals will deposit their eggs inside the grain and plug the holes by their mucilaginous saliva. The egg-plugs can be

identified after staining the grains with suitable chemicals. The egg-plugs are stained cherry red by a 0.5% acid fuchsin solution or plurple colour by 1% gentian violet solution.

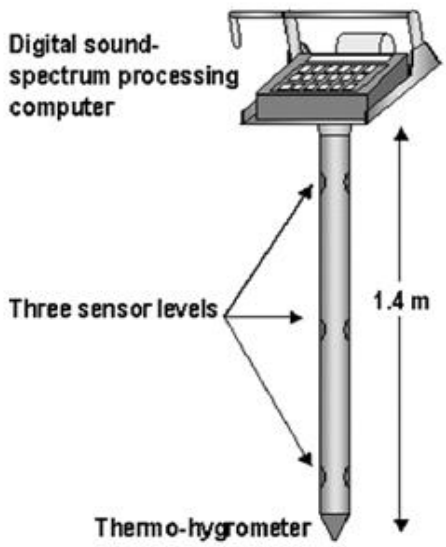
Soaking grains for a minute in 20 ppm aqueous solution of berberin sulphate, selectively stains eggs. The stained grains fluoresces greenish yellow, when observed under UV light of 366 nm wavelength. The intensity of infestation can be estimated by the number of egg-plugs observed (Obeng-Ofori, 2012).

2. **Ninhydrin Method** –It is very useful for the hidden infestation detection. When the insect body fluid (haemolymph) comes in contact with a paper impregnated with ninhydrin (triketohydrindene hydrate), an orange dye, purple colour spots appear due to the reaction of freeamino and keto acids in haemolymph with the dye.

The indicator paper is impregnated with 0.3% ninhydrin in acetone. The grain sample is allowed to be crushed on the paper to facilitate contact of insect haemolymph with the dye in the paper. Following the reaction, the purple colour spots develop in less than one hour at 20-25^{0}C. The numbers of marked spots are counted and the infestation level can be taken as the number of hidden insects/kg of grain.

In situ Detection and Monitoring Methods: The various methods applicable for detecting and monitoring insect infestation in grain stored in silos and elevators and food processing industries are as follows –

- **Acoustic Method -** Insects produce mechanical vibrations during their movement in stored grains. They also produce sound during feeding inside the grain (larvae) and outside the grains (adults and larvae) (Njoroge *et al*. 2014). Insects developing inside food grains are also known to emit ultrasonic signals. These mechanical vibrations, feeding noises and ultrasonic signals can be identified by using appropriate sensors. Storage insect make sounds by their feeding activity. Apart from feeding activity, adult of lesser grain borer make noise by their grain boring activity and adult females of rice weevil probe the grains for insertingtheir eggs inside the grains.



The frequency of the sound produced in a definite period is considered for the level of pest activity in the grain. The sound signal transmitted by each sensors on probe is directly pre-amplified by an electronic amplifier housed in the tube of the shaft behind each sensor level. Then, the analogic signal is transmitted to the processing unit at the head of the shaft. In this method, grain sample is taken in a sound proof box having an acoustic vibration sensor, which is connected to an amplifier and the noise produced from the feeding activity is transmitted for recording. Now acoustic detection of insects has concentrated on methods of analysing the sound spectrum of insect noises and developing computer based analysis programmes that will detect the insect species through their sound spectrum (Fleurat-Lessard *et al*., 2006).

- **Physical Traps:** Insects will move around and fly in stored grains or storage premises in response to volatiles emitted by grains/food commodities, pheromones secreted by the adults and they also wander at random due to their innate behaviour of dispersal. This dispersal activity of insects has been exploited to detect and monitor the insects using appropriate devices known as insect traps. Traps help to avoid repeated sampling, which is labour intensive and time consuming (Mutungi *et al*. 2014).. Following traps is used for the earlydetection of stored grain pests -

  - **Pitfall Traps:** Pitfall trap consists of a plastic jar with a mesh screen over the top. The traps can be fixed inside the grains lot on the surface layer of bulk storage. Insects such assaw toothed beetle crawling across the grain slip through the mesh into the trap and unable to escape.

  - **Probe Traps:** Probe trap consists of a plastic cylinder perforated with approximately 2.8 mm holes that are angled down into the body of the traps where a funnel directs the captured insects into a collecting tube. The probe trap is vertically inserted into the body of the traps where a funnel directs the captured insects into a collecting tube. The probe trap need to be inserted vertically into the grain mass and left for a week or more. Insects in the deep layer of the grains crawl into the holes and fall into the collecting tube. They remain trapped inside, till the trap is taken out of the grain bulk and inspected. The probetraps are sensitive to Rusty grain beetle, red flour beetle and saw toothed beetle.

Recent Advances: Normally the traps are left inside the grain for a week or more and then takenout to examine the trapped insects to assess the infestation level. In the improved system whichis known as Electric Grain Probe Insect counter (EGPIC), an infrared beam sensor has been installed in the probe, which identifies and records the insects, as they drop into the trap. The sensor output signals are continuously recorded in a computer and the data analysed.

  - **Pitfall Cone Traps**: Pitfall cone (PC) trap is the combination of pitfall and probe trap, to trap the insects which are active at surface level and in the deep layers of the grain bulk.

Thus, the trapping methods are applicable only for the insect stages that are active and mobile.



Pitfall Trap **Probe Trap** **Pitfall Cone Trap**

- **Multiple Funnel Trap:** Multiple funnel trap consists a series of funnels fitted vertically one above the other without any food bait. It is useful to detecting/trapping beetle and moth pests showing flight activity. Stored grain insects in cereal warehouses and moth pests in flour mill can be trapped efficiently (Adams *et al*. 1978).

- **Sticky Traps:** Adhesive and sticky traps have the surface, treated with sticky substances like petroleum jelly and polybutane gel. Sticky traps can be used for detecting and trapping flying insects including *Rhyzopertha*, Rice moth, Angoumois meal moth, almond moth, Indian meal moth etc (Mboya *et al*., 2013).

  Sticky traps in conjunction of food bait/attractants are highly efficient in locating andmonitoring insect infestation in warehouses and other traditional storages.

- **Attractant Traps:** Stored grain pests (adults) are attracted by light of wavelength between 280 and 600 nm. Long wavelengths UV light (365 nm) and green light (500-560nm) is particularly attractive. A light trap consist a suitable light source and a container orsticky surface to catch and retain insects.

- **Traps Using Food Lures:** Insect pests are attracted by volatile, deriving from stored commodities. This behavioural response has been taken advantage of, for detecting and monitoring insect pests, particularly beetles. The food attractant traps are useful and low cost material in detecting and monitoring both larvae and adults and are cheaper as locally available (Baoua *et al*., 2012).

Two Types of Food Lures are used in the Traps

- **Broken Grains:** The broken grains of one or mixed type are used in cloth, jute or plastic bags. These baited bags are distributed around grain stacks and on the floor in warehouses. After a period of 1-2 weeks, the bags can be retrieved and insects trapped need to be counted. The bait bags need replacement once in 2 weeks, as they lose their attractiveness in due course. An important advantage of these baited bags is that they attract multiple species and the attracted insects remain inside bags for a considerable period. Rolled barley, wheat, corn has tested as food baits. It is also proved that brown rice alone and a mixture of wheat, peanuts and locust beans are the most attractive food baits (Kumar and Kalita, 2017).

- **Oil & Distillates:** Cereal (wheat germ oil), sesame oil, vegetable oils and distillates of locust bean deployed as a lures in the traps. Oat and corn oils has ability to attract the adults of *S. oryzae* and rice, soybean, wheat germ and corn oil are attractive to the adults of red flour beetle. Sesame oil and pumpkin seed are found more attractive in case of Khapra beetle larvae. These attractants are only fatty acids, which can be incorporated with pheromone traps and in physical traps for improved detection and monitoring.

  - **Corrugated Paper Traps:** Traps that contain corrugated cardboard are particularly effectiveat attracting wandering moth larvae. Corrugated paper acts as a refuge or hiding site for manyof the crawling beetle pests and for the late larvae of *Ephestia* spp. which are about to pupate.The refuge seeking behaviour has been exploited in refuge traps. The trap efficiency gets boosted, when grain oils and /or pheromones were used as lures in these traps.

Corrugated Paper Traps

  - **Pheromone traps -** Pheromones are chemical molecules secreted by insects as part of their communication mechanism. Mainly two types of pheromones are known to secrete by the insects:

    - **Sex pheromones**
    - **Aggregation pheromones**

All the moth pests and some of the beetles such as *Stegobium paniceum* and *Trogoderma* spp. release sex pheromones. However, most of the beetle pests, the males release aggregationpheromones, which attracts both males and females of the same species. Commercial traps baited with pheromones include (Z, E)-7, 11-hexadecadien-1-ol acetate (or HAD) for *Sitotroga cerealella*, (Z, E) - 9, 12-tetradecadien-1-ol-acetate (or TDA) for the pyralidslike *Ephestia* spp. and *Plodia interrpunctella*, dominicalure for *Rhyzopertha dominica*, 1, 8 dimethyldecanal for *Tribolium* spp., serricornin for *Lasioderma serricorne* and stegobinone for *Stegobium paniceum*. The traps are used at an optimum height of 2-3 meters for every 14 metre for monitoring moth pests. The required trap density varies according to the pests to be detected and monitored. The use of traps and subsequent interpretation of insect captures for monitoring and population estimation are the most efficient and cost effective tools available so far. Data generated using traps and interpretation provides the best pest management decision support.

IV. MANAGEMENT OF STORED GRAIN INSECTS

Detection and management of insects are intrinsically intertwined processes. Detection serves as the initial trigger for effective management. By accurately identifying the presence, type, and extent of insect infestations, one can make informed decisions about the most suitable management strategies. Early detection is particularly critical, as it enables timely intervention and prevents infestations from spiraling out of control. Detection techniques and management of stored grain pests are essential for preserving the quality and safety of stored grains, which are susceptible to infestations by various insect pests and rodents. The management of stored grain pests involves a combination of preventive and control measures. Preventive measures include proper sanitation, maintaining appropriate temperature and moisture levels, and using quality storage facilities. Numerous techniques and strategies have been developed to ensure the safe and long-term storage of food grains, thereby reducing post-harvest losses and maintaining the quality of stored products. Drying is a fundamental method that reduces moisture content, preventing mold growth and insect infestations. Airtight containers, such as silos or hermetic storage bags, create a barrier against external factors, pests and preserving the integrity of the grains (Navarro *et al.,* 2017). According to Omondi *et al.* (2011) and Vales *et al.* (2014), seeds stored in triple layer plastic bags retained up to 85% of their germination percentage after 9 months when compared to traditionally used storage gunny bags, which lost 76% and 14% within three months. Similarly, Waongo *et al*. (2019) reported that germination rates of sorghum grains stored in polypropylene bags reduced dramatically, with no differences seen when compared to early germination in grains stored in PICS bags. Black gram stored in polypropylene and gunny bags was infested with pulse beetle by the third month of the storage period. But black gram stored in bags with hermetic ba g as inner layer was not infested up to 12 months and could retain the grain quality (R. Meenatchi *et al*., 2018).

Triple layer bags act as hermetic storage, which works on the principle of creating airtight conditions in which oxygen levels are depleted from the initially trapped air through insect, fungal, and seed respiration while maintaining seed quality parameters by reducing their growth and development (Quezada *et al.* 2006; Murdock *et al*. 2012). Irradiation of storage insect pests and related areas are more appropriate in the current era for global trade and safe storage. Pulses infested with pulse beetle was exposed to gamma radiation at different dosages viz., 400 Gy, 650 Gy and 850 Gy. Complete mortality of egg, larva, pupa and sterility of adult was noticed in all the doses even the results showed that lower dose of 400 Gy were found to be effective against all life stages of pulse beetle (Alice Sujeetha R P *et al.,* 2020). Temperature control is also a crucial aspect where cooler temperatures slow down insect activity and microbial growth and controlled atmosphere storages (CAS) with carbon dioxide, nitrogen, ozone etc as fumigants may acts as alternatives to conventional fumigants. Heat treatment can also be done using exposure to electromagnetic radiations, such as RF and MW. Chemical control methods, such as the application of approved pesticides, can be used when infestations occur, but they should be used judiciously and in accordance with safety guidelines. Integrated pest management (IPM) strategies, which combine various control methods, are gaining popularity for their effectiveness and sustainability. Biological control, through the introduction of natural enemies of pests, is also an environmentally friendly approach to managing stored grain pests.

The indiscriminate usage of pesticides created many hazards such as the development of resistance, residues on food crops, and contamination of the environment (Dhanapal *et al*. 2022). The 18 effectiveness of several strains was tested by using aqueous suspension s with different concentrations either by immersing the adults or immature stages of insects in these suspensions or by spraying the inner surfaces of grain containers before introduction of grains and insects (Dhanapal *et al*. 2022). P. Jyothi *et al*., 2014a studied the compatibility of entomopathogenic fungi with edible oils against the progeny build up of lesser grain borer recorded at 180 DAT was found to be less with Beauveria + Groundnut oil (118.33) followed by Metarhizium + Groundnut oil (121.33) compared to oils alone, sunflower (307.67) and groundnut (252.33) but were significantly different from control (517.00). Interaction studies of entomopathogenic fungi and in combination with edible oils (*Beauveria, Metarrhizium* and *Lecanicillium*) were evaluated against lesser grain borer on stored paddy as bag and grain treatments and recorded good results (P. Jyothi *et al*., 2014b, P. Jyothi *et al*., 2014c, P. Jyothi *et al*., 2014d) This paves the way for the entry of biological control concepts that utilize predators (Dhanapal *et al*. 2019; Murugasridevi *et al*. 2022), parasitoids, and entomopathogens (Dhanapal *et al*. 2019; Dhanapal *et al*. 2020; Velavan *et al*. 2022). The overall results, based on the relevant literature, indicate that the tested strains of EF have shown variable degree of effectiveness according to insect species, virulence of EF strains and the method of treatment or application (Ajaykumar *et al.* 2023). Although many of these strains have caused a moderate to high level of mortality to the target insects, there is a requirement for formulation of the applied strains to enhance their efficacy. Few investigators have tested the efficacy of isolated strains of EF against certain species of stored-grain insects using certain types of formulations to achieve a constant and higher control efficacy.

Important Storage Insect Pests

***Trogoderma granarium* – Khapra Beetle**

Khapra Beetle- Larva

***Sitophilus oryzae* – Rice Weevil**

***Rhyzopertha dominica* – Lesser Grain Borer**

***Tribolium castaneum* – Red flour beetle**

***Stegobium paniceum* –Drug Store Beetle**

***Lasioderma serricorne* – Cigarette beetle**

***Caryedon serratus* – Peanut Bruchid**

***Callosobruchus maculatus* – Pulse Beetle**

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