Insect Pest Infestation During Storage of Cereal Grains, Pulses and Oilseeds

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Abstract Due to the increasing population day by day, the food security is the most global concern in order to fulfil the food demand for both developed and developing nations across the world. In developing countries, cereal grains are the staple food and nearly 70% of the population depends upon agriculture. In India the most challenging issue is the storage of these cereal grains. A number of insect pests deteriorate stored grains. Insect and pest infestations are major contributor to quality deterioration of stored food stuff such as cereals grains, pulses, and oil seeds. Tropical climate of India provides favourable condition for the continuous growth of insect/pests throughout the year. During storage, pests infest the grains and therefore, fulfil their food and shelter requirements by causing qualitative as well as quantitative losses of stored products. These insect pests impose the damage on stored products by direct feeding and affect the farmers because their infested grain may have a significant effect on the value of marketing, consumption, or planting. This chapter provides an overview of different types of stored grains and their infestation by major pests, and also describes various techniques for prevention of these infestations.

Keywords Stored products · Cereals · Pulses · Oilseeds · Loss · Pests

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Introduction

Insect and pests are major threat to quality deterioration of stored food stuff such as cereals grains, pulses, and oil seeds. In different parts of the world, a variety of insect species have been associated with stored products but a few are considered as significant pests (Srivastava and Subramanian 2016). Among them majority of storage grain pests are belong from order coleoptera and lepidoptera (Khare 1994). Loss of the nutritional and physical properties of stored food stuff due to infestation by weevils, bruchids and other insects and pests is very common. Deterioration of quality and quantity of the food stuff is greatly affected by physical, biological, chemical and engineering factors. “A grain saved is a grain produced” concept must be taken into concern from the time of harvest itself. Role of technologists and scientists to minimize the wastage of stored products at farm level is therefore, the need of the hour. Contamination sources of cereal grains are mostly insects and microbial sources which make it totally inedible. Infestation of insect pests also results in secondary contamination of moulds. Increased humidity without adequate ventilation, mould growth develops “caking” causing severe losses. Post-harvest losses are surveyed to be about 10–20% and sometimes it may be extent of 30% in storage which turns out to be huge taking in consideration the consumption level (Rajasri and Kavitha 2015). Cereal grains contribute to major food sources to humans as well as animals. Manual inspection at farm level is done by sieves, while industrial techniques include acoustic detection, uric acid measurement, carbon dioxide measurement, X-ray and IR spectroscopy methods. Industrial methods are more effective and less time consuming (Neethirajan et al. 2007).

Stored Products

After harvest surplus amount of produce which is to be stored for supply during off season, seed, preservation, export, marketing and processing.

Cereals

Cereal grains are plant fruits obtained from the grass family (Gramineae), include rice, wheat, corn, barley, oats and millets which serve as staple foods in most areas of world. Nearly 80% of the produce is cultivated in Asia, America, and Europe. India is the largest producer and exporter of cereals in the world. During 2015–2016, India produced 104.32 million tonnes rice, 21.8 million tonnes maize and 8.08 million tonnes bajra and exported of 8078.85 Million USD (Anonymous 2018a, b). Cereal are good source of CHO, protein, fat, fibre and micronutrients such as vitamins of group B, calcium and iron. It fulfils about half of the calorie intake of total energy requirement. Cereals are stored easily for a long time because of low moisture content, providing variety of acceptable products and also stored depending on market demand, size of production and the farmer's needs. Storage is the most important and critical post-harvest operation. Deterioration of the grain quality during storage can be due to improper storing conditions, which leads to contamination with fungi or insect infestation.

Common Insect Pests of Stored Cereals (Table 1)

Insects cause extensive damage to stored cereals and this may amount to 5–10% in the temperate geographical zone and 20–30% in the tropical zone (Chomchalow 2003). Therefore, there is a need for diverse kinds of safe control measures to prevent insect pests attack on food grains (Hikal et al. 2017). Quality of food grains is affected by insect infestation that represents severe and continuing problem at the grain and milling industry. Under the provisions of the Grain Standards Act, establishment of Federal standards for grain, is important for supervisors and inspectors to identify the various species of insects that cause damage to stored grains. There are five primary insect pests which attack stored grains namely Granary weevil, Rice weevil, Maize weevil, Grain borer. Angoumois grain moth spoils wheat and corn. Other insects that are found in stored grains are beetles, moths, and meal-worms.

- In stored grains most common insect pest are:
  - Rice weevil *Sitophilus oryzae* (L.)
  - Angoumois grain moth *Sitotroga cerealella* (Olivier)
  - Lesser grain borer *Rhyzopertha dominica* (Fab.)

Granary Weevil (*Sitophilus granarius* Linnaeus)

The granary weevil, *Sitophilus granarius* (Linnaeus) is small polished red brown to black beetle with no wing cover and well-marked thorax with oval pits (Gorham 1991). The head emends with a long pair of distinct snout of stow mandibles or jaw at the end; these two characteristics distinguish granary weevil to rice weevil and wheat weevil. It's long about 1/8″ to 1/4″. It is oldest insect pest which prefers a temperate climate and has been found all over the world. Adult is live about 7–8 week and during this period female lays about 50–250 eggs. Female weevil uses her strong mandibles to chew the grain kernel and make a small hole, and deposit eggs in the hole and cover it with gelatinous fluid. It takes about 5 weeks for development of egg to adult in warm weather while in cold weather it takes prolong periods. After few days the eggs hatch into a white, soft legless fleshy grub that feeds in the interior of the grain kernel. The grub develops to naked white pupa eventually into an adult beetle. Since the granary weevil cannot fly because it lacks

Table 1 Important insect pest of stored products (Chomchalow 2003)

Species	Common name	Classification	Stored products attacked
Acarus siro	Flour mite	Sarcoptiformes: Acaridae	Cereals, cereal products, dried fruits, tobacco
Acanthoscelides sp.	Pulse weevil	Coleoptera: Bruchidae	Many pulses including kidney bean
Callosobruchus chinensis	Pulse beetle	Coleoptera: Bruchidae	Many pulses including soybean except kidney bean
Callosobruchus maculatus	Pulse beetle	Coleoptera: Bruchidae	Many pulses except soybean except kidney bean
Carpophilus hemipterus	Dried fruit beetle	Coleoptera: Nitidulidae	Dried fruits, groundnut
Corcyra cephalonica	Rice moth	Lepidoptera: Galleridae	Rice, maize, soybean, groundnut, cacao, dried fruits, copra, flour
Cryptolestes ferrugineus	Rusty grain beetle	Coleoptera: Laemophloeidae	Maize, wheat
Cryptolestes pusillus	Flat grain beetle	Coleoptera: Laemophloeidae	Maize
Caedra cautella	Tropical warehouse moth	Lepidoptera: Phycitidae	Rice, maize, mung bean, soybean, groundnut, flour, dried fruits, copra
Latheticus oryzae	Long-headed flour beetle	Coleoptera: Tenebrionidae	Maize
Oryzaephilus mercator	Merchant grain beetle	Coleoptera: Silvanidae	Oilseeds, groundnut, maize, dried fruits
Oryzaephilus surinamensis	Saw-toothed grain beetle	Coleoptera: Sylvanidae	All cereals, pulses, spices, tobacco, dried fruits, flour
Plodia interpunctella	Indian meal moth	Lepidoptera: Phycitidae	Rice, wheat, maize, sorghum
Rhyzopertha dominica	Australian wheat borer	Coleoptera: Bostrichidae	Paddy, rice, maize, sorghum, root crops
Sitophilus granarius	Granary weevil	Coleoptera: Curculionidae	Rice, wheat, maize, sorghum
Sitophilus oryzae	Rice weevil	Coleoptera: Curculionidae	Rice, maize, wheat, sorghum, pulses
Sitophilus zeamais	Maize weevil	Coleoptera: Curculionidae	Maize, also other cereals
Sitotroga cerealella	Angoumois grain moth	Lepidoptera: Gelechiidae	Paddy, wheat, maize
Tribolium castaneum	Red flour beetle	Coleoptera: Tenebrionidae	All cereals, starch, pulses, oilseeds, spices, dried fruits
Tribolium confusum	Confused flour beetle	Coleoptera: Tenebrionidae	Flour, wheat, maize
Trogoderma granarium	Khapra beetle	Coleoptera: Dermestidae	All cereals

meta-thoracic flight wings which are well developed in *S. zeamais* and *S. oryzae*., it is mostly found in storage (Mason and McDonough 2012; Egbon and Ayertey 2009).

Rice Weevil (*Sitophilus oryzae*)

In Rice, insects cause economic losses because of ability to adverse effects of milled rice, paddy and the by-products of milling material. Rice weevil is a most destructive insect pest of cereals in the world which affects crops including wheat, rice, and maize. Adult rice weevil is around 2 mm long with a long snout and almost brown to black in colour. The wings usually cover four orange/red spots. Rice weevils have the ability to fly but are similar to granary weevil in the form however having different colour and wings. Rice weevils are known to be the worst pests for stored grain since ancient times and found all over the world. It's particularly abundant in warm weather country and breeds incessantly and damage the quality and quantity of unprotected stored grain. The life of adult rice weevil has average 4–5 months and during this period female lays around 300–400 eggs (Mason and McDonough 2012). Its early life stage is similar to granary weevil, the egg, larva and pupal stages passes to 26 days at hot weather and this is prolonged in cold weather. For killing of rice weevils in all stages of development freezing infected food below 17.7 °C (0 °F) for a period of 3 days or heating to 60 °C (140 °F) for a period of 15 min (Catsberg and Kempen-van Dommelen 2013).

Maize Weevil (*Sitophilus zeamais*)

The maize weevil (*Sitophilus zeamais*) is a species of the family Curculionidae (Cowley et al. 1980). It attacks standing crops and stored cereal products, such as rice, wheat, barley, sorghum, oats, buckwheat, rye, cottonseed and peas. Maize weevils are as similar appearance to rice weevil except they are 3–3.5 mm length, darker (reddish brown) with long snout and have reddish spot on the elytra defined clearly (Hidayat et al. 1996; CABI 2018). The maize weevil's thorax is densely and uniformly pitted with round punctures. Adults can fly from the granaries to the field and start infestations after harvest and destruct the storage grain. It reduces the kernels to dry powder and hulls. The life cycle of maize weevil is similar to rice weevil, 3–6 months and more (Devi et al. 2017; Ojo and Omoloye 2016). Adult females lay eggs in hole of the grain and sealing with mucus plug. The development rate is slower and requires minimum 30 days for development from egg to pupal stages (Clutton-Brock 1991). The maize weevil and rice weevil have similar look, but maize weevil is found in corn and is larger and darker as compare to rice weevil. *Sitophilus zeamais* is more resistant to starvation than *S. oryzae* (Maceljski and Korunić 1973).

The *Sitophilus* spp. are distributed throughout the world in temperate and tropical counties. These are internal feeders, both grubs and adults known to produce damage. Pupation also takes place inside grain and the adult exit by making a large irregular hole. It is estimated about 5–10% loss in market value due to infestation by only *Sitophilus* spp. (Kumar and Kalita 2017).

Lesser Grain Borer (*Rhyzopertha dominica* F)

Lesser grain borer (*Rhyzopertha dominica* F.) is thought to be native of Indian subcontinent but now cosmopolitan. It is smallest around (2 mm), dark- brown to black coloured, slender cylindrical beetle, reported to major pest of wheat, rice and corn in storage and also found on olive trees in Sicily (Flinn et al. 2004; Buonocore et al. 2017). Both larva and adult bores into the grain and cause damage (Kargbo 2013). The female can lay 200–500 eggs on outside kernel, and after hatching larva bores into the grain. At 34 °C, incubation period is 2 days, the larval lasts about 17 days, and the takes 3 days to complete development. It takes 25 days to complete the life cycle from eggs to adult. The adults are strong flier and fly to spread infestation (Mason and McDonough 2012). In India, it is reported to cause up to 12% of post-harvest losses (Ajaykumara 2015).

Grain Moths

Grain moths are belonging from order lepidoptera known to cause enormous loss in storage of agricultural crops by destroying unbroken kernels and milled products. Immature larva is damaging stage which is known as caterpillar. Among four, two (Angoumois moth and Almond moth) are internal feeder and rest two (Indian meal moth and Rice moth) are external feeders. They are:

Angoumois Grain Moth: *Sitotroga cerealella* (Olivier)

The Angoumois grain moth *Sitotroga cerealella* (*Olivier*), is small in size about 1/8″ long. It is buff or yellowish in color, fully developed larvae is usually yellowish-white with a yellowish brown head (Beshir 2011). Grains infested with this insect have unpleasant smell by larvae. It affects cereal grains all over the worlds and attacks in field and stored grains. The ovipositional period, incubation period, larval period, pre-pupal period and pupal period are reported for 3.67 days, 5.5 days, 25.2 days, 3.0 days and 5 days, respectively. Male lives for 8 days where female longevity is lasts up to 10 days. The eggs are glued to the kernel. When the eggs are laid, they are white subsequently change to reddish colour (Akter et al. 2013). After hatching, larva crawls to grains kernel and spin into a cocoon that assists it in penetrating the hard kernel however, inside the grain larvae continues to feed the endosperm or the germ until maturation. When mature, eats outside of the seed channel and forms a weak fastened flap at the exit by cutting the shell of one-half to three-fourths of the circumference of a circle (Ignjatović et al. 2018). After that larva spun into a silken reddish-brown cocoon and pupate within the kernel, adult moth pushes the flap back on the kernels.

Management

Preventive Methods

- Maintain sanitation and ventilation at field and storage
- Clean and disinfect storage structure, gunny bags, bins followed by fumigation to avoid carry forward of infestations
- Filling of cracks, crevices and burrows
- Drying of grains at minimum moisture (<8%)

Physical Methods

- Sieving or physical exclusion
- Vacuum sealing or controlled atmosphere conditions: lower oxygen level (1–2%) and increase CO_2 at room temperature
- Temperature control and cooling: 0 °F for 4 days usually kills most of the species
- Use of diatomaceous earth (DE, silicon dioxide): penetrates pest's cuticle, resulting in death by dehydration (Barbercheck 2018)

Pheromones: can be implicated for mass trapping in IPM:

- Male of *S. orzyae* produce an aggregation pheromone ((4S,5R)-5-Hydroxy-4-methylheptan-3-one)
- Hexane extracts of Tenax®-trapped volatiles from males held on wheat were attractive to both sexes (Faustini et al. 1982)
- For *Rhyzopertha dominica*: Dominicalure-1 (D1) and Dominicalure-2 (D2), (Bashir et al. 2003)
- For Angoumois Grain Moth:(Z,E)-7,11-Hexadecadienyl acetate (9) (Z,E)-7,11-Hexadecadienal (1)
- For Indian meal moth: (Z,E)-9,12-Tetradecadienyl acetate (1) (Z,E)-9,12-Tetradecadien-1-ol (1)
- For Almond moth: (Z,E)-9,12-Tetradecadienyl acetate (7) Z)-9-Tetradecenyl acetate (1)
- For Rice moth: 6,10,14-Trimethylpentadecan-1-ol (F) E,E-Farnesal (M), (Swords and Van Ryckeghem 2010).

Insecticide Control

- Spray storage surface with *Bacillus thuringiensis* (*Bt*) to control lepidopterous pests
- Treat the storage with pyrethrum

- Use insecticides viz., malathion (5% @250 g/quintal), dichlorvos and deltamethrin
- Place aluminium phosphide (celphos 3 tabs/tonnes of grain) in storage
- Treatment of grains with 2 ppm of Spinosad

Pulses

Pulses belong to legume family which is dried edible seeds of certain plants having rich source of protein and fibre and low fat content. Pulses are valuable sources of minerals such as iron, zinc, phosphorus; folate and vitamin B (Vaughan and Geissler 2009). According to the nutritional profile it helps in improving health, especially in developing countries and the main characteristics of pulses are less expensive proteins as compared to animal proteins. Protein content in soybean is 36%, soy chunk 52%, lentil 9%, moong bean 26%, Bengal gram 20% and peas 26%. Pulses are referred to as "poor man's crops", as "poor man's protein", or as marginal products of marginal lands. A survey reveals that about 68% people in India are lacking in protein. Consumption of pulses as whole or split can help to reduce this malnutrition. Fresh beans or peas are not included in pulses. Soybeans and peanuts are classified as oilseeds because of their higher content of fat (Singh 1997). The total production of India in 2018 was 24.51 million tonnes and require import to meet the domestic consumption of 29.92 million tonnes (Anonymous 2018a, b).

In Asia a broad characterization of the current situation has following observation:

- India is the largest consumer, and also has moved from an import to in an import/export regime.
- Second largest consumer is China, and has moved to a two-way trade regime. (Ortega et al. 2011)
- Myanmar and Australia, characterized by inter seasonality of supply, moved to export regimes.
- Thailand moved from an export regime to a two-way trade regime.
- There are signs that pulses moved from negative income elasticity to positive income elasticity in India and Pakistan (Deaton and Drèze 2009).

Oil Seeds

Oilseed crops are an important and economically grown world widely for extraction of edibles oils. In Europe, oilseed crops are being attacked by six bugs that frequently require control by cultivators to ensure seed yield, are: the cabbage stem bug creepy crawly, dust bug, cabbage seed weevil, cabbage stem weevil and brassica case midge. These damage the product progressively at different development stages and harm diverse parts of the plant. They are on the whole far reaching yet their relative significance differs with nation and year. Push-pull (attractant-repellent) systems are being produced that utilization have plant inclinations and conduct reactions to semiochemicals to impact bug and regular adversary appropriations on the product (Verma 2000). There is likewise potential for common pest protection through change of inside field trim farming practices just as, on the scene scale, through territory and ecological control to support vegetational decent variety of the agro-ecosystem consolidating hedgerows, cover crops, blossoming preservation headlands and field edges to give shelter, sustenance, overwintering locales and elective prey or has for characteristic enemies. Now a day's demand of oilseeds is increased because of their health benefits such as healthy vegetable oils, pharmaceutical properties, livestock feeds, biofuels and other oleo chemical industrial uses. In last 30 years according to increasing interest of oilseed, there is an 82% expansion of oilseed crop in cultivation areas and around a 240% increment in total world production (Deininger and Byerlee 2011). Fulfilling the increasing demand of oilseeds over the world, sustainable oil production, through the classic breeding with biotechnological approach expands oil yield per unit area. Genetic engineering of oilseeds improves sustainable production of crops and also improves nutritional quality as well as enhancement of quality for industrial purpose. High grade yielding edible oil producing oilseed crops are sunflower, soybean, safflower, groundnut, sesame, castor and linseed are included in non-edible oil-producing species (Murphy 2007). For limit of infestation, insect pest management and possible control techniques are important for quality and quantity of the products. Varieties of pest attack oilseeds and significant losses of farms and storage products. These insect pests show significant effect on the economics of oilseed production. Pest Management is done by different types of preventive methods such as cultural control, physical control, biological control; host plant resistance and chemical control.

Storage Pests of Pulses and Oilseeds

Pulses are annual and seasonal crops which are stored for several months hence it has higher risk of damage due to insect pests which can cause post-harvest losses up to 25–50%. These losses occur due to insufficient and poor storage facilities, lack of proper knowledge of advanced technology in post-harvest pulse management and harsh climate in developing country like India. During storage, pulse beetles; *Callosobruchus chinensis* Linn and *Callosobruchus maculatus* Fab that causes about 5–10% loss of pulses during storage (Ngamo et al. 2007). Infestation of this pest leads to the loss of germinative ability and nutritive value of the seed (Sharma 1984). *C. chinensis* is the most primary and destructive pest found in India. Infestation of the pulses starts from the field and continues up to storage. The month July to October has recorded to have maximum damages of stored products. Pulse beetle not only causes qualitative but also nutritive loss that makes the pulse grains unfit for marketing and also less nutritious for human consumption.

***Callosobruchus chinensis* Linnaeus**

It is commonly known as Chinese bruchid, Adzuki bean weevil, and pulse beetle found in world wide. *C. chinensis* has major pest in chick-peas (Pandey and Singh 1997), lentils, green gram, broad beans, soybean (Srinivasacharyulu and Yadav 1997).

Life Cycle

C. chinensis adults are about 2.0–3.5 mm long. The elytra are red brown with yellow marking, antennae and yellow legs. The antennae are serrate in female and pectinate in the male. Larva is about 5 mm long yellowish-white with brown head and reduced legs. This pest is raised annually seven to eight generations. Female lays about 50–100 eggs on smooth legumes pods, and larva immediately enter into the pods to feed. Several larvae occur within the same seed. Several weeks are required for full developments (Mulatu and Gebremedhin 2000).

Prevention and Control

- Intercropping with cereals and before pest attack, early harvest of the legumes. They should be stored in hygienic condition.
- Seeds are heated at 50 °C for 1 h which kills the eggs and larvae.
- Some legumes varieties with thick and hairy walls are resistant to beetle infestation
- Many plants extracts and oils are used for prevention of oviposition deterrents and for beetle control such as Organophosphates and neem compounds
- Certain parasitoids of the families Braconidae and Pteromalidae are used to attack
- *C. chinensis* in various parts of the world. The mite *Pyemotes* is also used as a parasite of the pest (Mulatu and Gebremedhin 2000).

***Callosobruchus maculatus* (Fabricius)**

Callosobruchus maculatus is commonly known as cowpea weevil and important pest of pulses throughout the world. It attacks leguminous grains, such as cowpeas, black gram, green gram, and lentils (Raja et al. 2000). Infestations of this pest starts in the field and continue to the storage, sometimes it can cause the total destruction of the seeds even within a period of 3–4 months (Barde et al. 2013).

C. maculatus adult body is 3 mm to 4.5 mm length, reddish brown, with block spots on the elytra and prothorax. The antennae of both male and female are slightly serrate. The last segment of abdomen extends out from under the short elytra, on black spots. The males are sometime shorter and lighter than females. It has two forms, one is flying form and other is flightless form (Raja et al. 2000).

Life Cycle

The female lays up to 200 eggs on the seed coat in the field and storage. The larvae burrowed inside the seed where the development is complete for the expense of grain endosperm and embryo, that's are responsible for cowpea damage. Larvae cannot move among seeds they are restricted to a particular seed that is chosen by their mother for them. It requires 14 °C for threshold development and 435 days are required for generation completion. It takes 4–5 week for completion of life cycle and overlapping six to seven annual generations. These beetles mostly live for 1–2 weeks. In India, the insects mostly breed from March to November and hibernate in the larvae stage in winters. Maximum damages were estimated during February to August due overall developmental stages that exist simultaneously. Infestation level in storage is influenced by the type of storage structure employed and seed variety (Ojimelukwe et al. 1999). Moisture content of seeds and temperature of storage influence the infestation level in local stores (Singh 1997).

Prevention

- Hygienic stores play an important role for limiting the infestation by these insect species.
- Harvesting crops early and intercropping maize with cowpeas is also effective.
- Storage area of freezing for 6–24 h at −18 °C will kill both adults and larvae
- Solarization (sun drying and heating) is also useful for control from infestations without affecting seed germination (Mohemed and Ismail 1996).
- Prevention from infestation through insect legume pods with hairy and thick walls is very effective.
- Several plant extracts such as neem, together called botanical biological pest control agents that are used against the pest control.
- Various *Hymenopterous parasitoids* include *Anisopteromalus calandrae*, *Uscana mukerjii* and *Dinarmus* spp. specifically targeted to *Callosobruchus* species.
- *Dinarmusbasalis* attacks small larvae and also limits their damage, even their presence still makes the beans unfit for sowing and human consumption. *Uscana mukerjii* is used as an egg parasite which prevents egg hatching.

Indian Meal Moth: *Plodia interpunctella*

Host range: Maize, cereals, dry fruits, groundnuts and cereal products and milled products.

The Indian meal moth received its title from the US where it was reported to feed on meal made of "Indian corn". Adults 12.7 mm long with wing span of 16–20 mm. Distinctive bicoloured wings—dark reddish brown with a copper cluster on rear half of the wing and whitish grey on the inner body ends. Larvae have four pairs of legs, in which three pairs are true legs and fourth one is abdominal leg.

Life Cycle

Each female moth lays up to 400 eggs singly or in groups on food stuff. Hatched larva is small about half an inch long and varying in colour dirty white, greenish and pinkish. It creates webbing as they feed on the grain podium, dried fruits and nuts. The larva spins a silken cocoon and transforms into a light-brown pupa, from which the adult emerges later. At 18–35 °C, the Indian meal moth may complete all stages in 6–8 weeks. Mechanism of action—firstly larvae enter into kernel and releases massive amounts of silk over the grain surface. Webbing which happens by moth disrupt the air movement, which can cause grain heating leads to mould growth. It decreases the fumigation effectiveness (Fasulo and Knox 2015).

Cigarette Beetle (Tobacco Beetle) *Lasioderma serricorne* (Fab)

Family: Anobiidae; Coleoptera.

Hosts: Cigarettes of tobacco, Cocoa beans, groundnut, peas, cottonseed and beans, many stored grains, flours and foodstuffs (alternative). Adult Cigarette beetle is small, stout, oval, reddish-yellow or brownish red beetle of about 2.5 mm length. Head is projected downwards with concealed antennae that appears hump. Beetle founds in subtropical regions, infesting the tobacco and some others storage grains (Bhargava et al. 2007).

Life Cycle

A single female can lay about 100 eggs in folds and crevices of food material. Eggs are elliptical, ovoid, whitish that become opaque and dull in colour just before hatching. It occurs in 5–6 days. Larval stages last for 25 days followed by 5–7 days of pupal periods. Newly develop larvae is about 1 and less mm in length and cover with fine hairs and antenna is serrate. Larval head is yellowish with a semi-transparent and whitish body. After larval period, it constructs a smooth lined cell in which it pupates. Newly pupa formed is glossy white in appearance and later changes to reddish brown colour. Males are slightly shorter than female. It mostly prefers higher temperature and attacks the wide range of food stuffs. It can be controlled by temperature and humidity below 19 °C and 30% RH ceases development (Srivastava and Subramanian 2016).

Khapra Beetle (*Trogoderma granarium*)

It is a significant storage pest of wheat and groundnut (main), jowar, rice, maize, sorghum, oilseeds and pulses. The Khapra name of this beetle has given of its habit of congregation in cracks and crevices of bricks, masonry and wood storage. This beetle found in hot and dry and tropical/subtropical regions. It prefers low humidity and high temperature. Adult Khapra beetle has oval in shape and grey and pale brown markings. Head is essentially hidden beneath hood like pronotum.

Life Cycle

Adult female lays about 100–120 eggs on grain surface or crevices. Growth and development of beetle depends upon the temperature and humidity and requires 4–6 days incubation period at 35 °C (Bhargava et al. 2007). Larvae have brownish white colour, body cover with bundle of long, brownish red movable and erectile hair on the posterior segments and form a sort of tail in the posterior end. In the first stage larvae feeds on broken grains and debris resulting from the feeding of old larvae as its do not attack the whole grains. Developmental period from egg to adult is ranged 39–45 days at 30 °C and maximum 220 days at 21 °C (EPPO 2013; Athanassiou et al. 2019). These are highly resistant to starvation. Larva have ability to survive without food for few years, under abnormal condition (Setyaningrum 2015). This beetle damaged almost all parts of the grains, but prefer mostly germ position and also the viability of seed is lost long before any quantity damages occurs. Larva is a destructive stage because adult doesn't feed and its life is very short.

Almond Moth *Cadraicautella* (Lepidoptera: Phycitidae)

It is also known as fig moth, widely spread in the tropics and subtropics. It mainly attacks the figs, rough rice, dry fruits, wheat, barley, sorghum, soybean, and oilseeds etc.

Life Cycle

Adult almond moth has a dark band on their forewings and its length is three fourth of the size of rice moth (*C. cephalonia*) and has greyish body. Adult females lay about 200–250 eggs per individual, randomly scattered in stores, in cracks, on grains or another surfaces. Eggs are less than 1 mm, and hatch within 3–4 days (Jacob 2012). The young larvae spin silk profusely and at maturity these form small silken tubes among in the grain in which they remain lodged and grow. Larval stage known is the damaging stage. Fully developed larvae are white with pinkish shade. Its colour and habit of spinning tubes in food material are most prominent diagnostic characters. About 7–10 days is pupal period. Generally, moths are more abundant during rainy and humid seasons.

Miscellaneous Invertebrates

Rodents are important pests of storage found all over the world, there are 1700 species of rodents, although 5–10% of species are major pest that infest the stored grain. These consume substantial amounts of stored grains. In developing countries farmers consider rodents as the main impediment to higher yields (Makundi and Massawe 2011). Every year in Asia, rats consume about 200 million people's feed consumed for an entire year (Singleton et al. 2005). In South America, native rodents damage the crops varying between 5 and 90% of total production. During storage it is necessary to control the insect pest infestation in grains, pest included birds and rodents that contaminate the stored grains. Rodents damage both stored grains and storage structure, their droppings, hairs and urines are main factor for contamination of the grains. The main species of rodents which causing damage are the house mouse, (*Mus musculus*) (Meehan 1984), the brown rat (*Rattus norvegicus*) (Niethammer 1981) and the Pacific rat (*Rattus exulans*) (Poché 1980) and the brown rat (*Rattus norvegicus*) (Niethammer 1981). Weight loss was observed 10.3% in the dry season and 7.4% in the wet season (Brown et al. 2013).

Storage Types

Chomchalow (2003) identified the storage of products on three levels which are as follows:

Farmer Storage

On this level large proportion of harvested food grains are retained by traditional storage methods and use botanicals with other inert materials for prevention of pest and insect infestation. Farmers generally store the food stuff at the site of harvest. This includes underground cellars, straw bins, cement bins, wooden bins, mud bins, bamboo bins, etc.

Community Storage

In Thailand many Rice Banks and Seed Banks are established for storage of food stuff at community level. These are owned by farmer groups or farmer cooperatives. Storage is done in bulk or in bags with certain fumigation facilities.

Commercial Storage

Commercial storage covers millers, exporters, middlemen and industrial manufacturers. Carbon dioxide fumigation is used in large warehouses which is effective for prevention of insect and pest control as compared to conventional methods.

Management

Preventive Methods

Measures are adopted before the infestation to prevent the produce from storage pests; rodents, insects and microbes. Among these methods; cleaning and sanitation, selection of storage structure, rodent proofing includes doors, filling of holes and openings, and foundations and floors, vents and windows are important (Brown et al. 2006)

Cleanliness

- Keep the farms and storage area clean as possible
- Do not pile food or trash inside and outside of the storage building.
- Destroy safely all garbage and old food, at a distance from the storage area.
- Store the all food grains in covered containers
- Sweep out all dust, dirt, spilled food, straw, old cloth that rodents nest and hide in and destroy it immediately.
- If possible, to cover mud floors in storage area with a thin layer of mortar. This keeps rats from digging up through the floors.
- All around the storage area keep the grass cut in shorts due to rodent hide in tall grasses.
- Make sure the storage building have rodent proof. This means that the farmer has to construct the store in such a way where rodent cannot enter in the store.
- Drying platforms—The products should dry before storage should be placed at least 80 cm above the ground from the protection of rat jumps. And also use of barrier around the poles that's the rodent does not climb the poles. These types of barrier called rat baffles or rat guards that made of metal sheet or empty tins.
- Greater than ¼-in. in diameter of holes are allowed for rodent entry into the structures. To seal such types of opening with use of cement and metal collars. Greater than ¼-in. holes in diameter that's set aside entry of mouse into structures.
- At storage area make sure doors and grain outlets close tightly. A wooden door has a thick metal sheet at the bottom that's to stop rodents from eating through.
- Using heavy wire netting with an 8 mm mesh is a good size for cover of all windows and large openings.

Traps Setting

For catching of rodents' regular traps are very effective method and safer than poison. Generally, poisons are toxic for human beings and domestic animals; it could be transferred by the rodents to the stored products. So, traps are very effective if correctly used and placed (Brown et al. 2006).

Rodenticides

Rodenticides are poisons that kill rodents and rodents are mammals so it is also very poisonous to others mammals such as human beings, domestic animals and to wild animals. It is categorised into anticoagulants and non-anticoagulants (Tobin and Fall 2004) (Table 2).

- **Anticoagulant Poisons**—These rodenticides have properties to destroy the blood clotting of poisoned animals and after the use of this animals die from internal bleeding. The anticoagulant is relatively slow-acting, lethal dosing of its animal death after 3–5 days.
- **Non-anticoagulant Poisons**—It's also called single dose poisons. They act quickly and decrease rodent populations and also control anticoagulant-resistant populations.

Another disadvantage of rodenticides is that they are costly and not always in stock.

Prevention

1. **Sanitation**
   Infestation of grain mostly begins from the field. Mostly harmful pests are present in farm storage bin. For reducing the infestation of these insects, an effective sanitation is necessary.

Table 2 Some examples of oils used for storage protection (Campolo et al. 2018)

Storage product	Type of oil	Amount of oil	Effect
Cowpea	Peanut oil	5 ml/kg	Peanut oil protects the cowpeas against the Cowpea weevil infestation for about 6 months
Mung beans	Cotton seed oil	6 ml/kg	After 6 months only 3.5% of the seeds were damaged.
Mung beans	Rice husk oil	5 ml/kg	Prevents against damage for about 4 months
Cowpea	Maize Denettia oil	1 ml/kg	Denettia oil protects cowpea against Cowpea weevil for more than 3 months. Maize is also protected for a period of 3 months, even when only 2/3 of the given amount of oil is added
Beans	Neem oil	2–3 ml/kg	If well mixed this amount of neem oil protects the beans for about 6 months. Neem oil has an insecticidal effect as well

Equipment—It includes trucks, augers and grain driers. These should be cleaned from all old grains.

(a) **Empty bins**

The best strategy to protect stored grains from insect damage is to properly sanitize the bin before introduction of new grains to minimize the need of pesticides. Primary sanitization of bin involves the removal of old grains and dust from the corner, floor and walls. When infested grains present in the bin contaminate new grains so it is important to sanitize. After cleaning, attention should be given to repair all cracks, areas around doorways and other places where insect can hide and enter (Boxall et al. 1997). It is important that screening is done to eliminate broken kernels. After transferring the grains in clean bins, it should be checked regularly at 2-week interval during warm months and at 1-month interval in cold months for the presence of hotspots, mouldy areas, and live insects. If these conditions exist, the grain should be aerated to lower temperature and moisture levels. For grains that are stored for a long period of time it is important to use an approved insecticide. If infestation occurs, fumigation is necessary. Fumigation is toxic, so qualified pesticide personnel is necessary to perform it.

(b) **Near the bin**

It is important to remember that the surrounding of the bins always be clean. And always remember to take out and demolish all spill grains Control the weeds and grasses, since they harbour insects, rodents and pests. Carefully check the outside walls, the base and roof for damage that allow the pests and moisture to enter. Keep away stock feeders as far as possible from the bins.

(c) **The grain**

Store only clean and dry grain in the bins. The optimum moisture content of stored grain should be 12 and 13%. Inappropriate moisture levels pose a problem for insect infestation damage. Most grain inhibiting insects require 13–15% moisture for optimum metabolic activities and reproduction (Rajendran 2005). Optimum level of the grain should be filled in the bin that allows good air flow and maintain moisture and temperature. It also allows for proper inspection and treatment.

(d) **Temperature**

There are number of factors that affect the quality and quantity of stored grains such as temperature, time, and type of dryer. Ranging from 20 °C to 40 °C temperatures, the growth of insects is accelerated and above 42 °C and temperatures below 14 °C diminishes the reproduction and growth, although use of prolonged high temperature above 45 °C and temperatures below 10 °C could kill the insects. Heating the grains at 50 °C will be lethal but is not allowed, since the grains are affected and also lose their viability.

For example, grains kept at −5 °C for 12 weeks will control insect & pests at all life stages.

The temperature of the stored grains can be lowered by:

Mixing and transferring the infested grain from one bin or pile to other.

Transferring part of the crop to a truck and exposing a small pile of the grains to low temperature air and leaving it to cool before returning it to the bin.

Aerating the bin

Aeration systems are effective for reducing grain temperatures, as well as to reduce moisture migration.

2. **Pneumatic conveyer**

   Cyclone-based grain pneumatic conveyers are also called pneumatic grain auger or grain vacs) which can be used for controlling insect infestations. Insects are killed by abrasive contact and impact as the grain and insects are moved through the discharge tube. Better control is achieved when there is a 90° bend in the tube which leads to greater abrasion of insects with the sidewalls of the tube (Gouda 2016).

Protection (Chemical)

Contact insecticides and fumigation are included in the chemical compounds that are used for protection from insect infestation in food grains approved by FAD/WHO (Bond 2007).The insecticides are used for the purposes which require prescribed dilution rates due to its low mammalian toxicity, and also using it at a non-hazardous level. Applying of this is comparatively safer than handling other pesticides that are approved and commonly applied for pre-harvest pest control.

Several factors important in assuring successful fumigation are

- For evenly fumigation, grains must be levelled in the bin
- Caking and crusting surfaces should be broken up and removed
- For proper vaporization, should maintain grain temperature 60 °F or higher (Tables 3, 4, and 5)

1. Insecticide Treatments

   Commercial facilities should be observed with the Occupational Safety and Health Administration (OSHA) bin entry permits. For treating of empty bins following pesticides are available (Table 6)

   Various insecticides are available for treating of cracks and crevice in empty bins or buildings and also uses other storage containers:

   (a) Malathion

      It is known as organophosphates is a pesticide used for control of insects on agricultural crops, and stored products. Since 1950, Malathion has been manufactured in the United States and used to kill many insects on many types of crops. The Food and Drug Administration (FDA) and the EPA permit a maximum amount of 8 parts per million (ppm) of Malathion residue to be present on specific crops used as foods (Matsumura 2012). Malathion has two forms: a pure form which is a colourless liquid and a technical-grade solution which is a brownish-yellow liquid, that contains Malathion (greater

Table 3 Recommended insecticide application rates (Tang et al. 2005)

Insecticide	Dust admixture with cereals (ppm)	Surface treatments (g/m^2)	
		Walls	Bags
Malathion	8–12	1–2	1–2
Perimorfs methyl	4–10	0.5	0.5
Fenitrothion	4–12	0.5	0.5–1
Chlorpyrifos methyl	4–10	0.5–1	0.5–1
Dichlorvos	2–20	0.5	
Methacrifos	5–15	0.2	0.4
Lindane	0.5		
Pyrethrin/piperonylbutoxide (1:5)	3	0.1	
Bioresmethrin (resmethrin)	2		
Phenothrin	5		
Permethrin	0.05–0.1	0.05–0.1	
Carbaryl	5–10	1–2	
Bendiocarb	0.1–0.2	–	
Dioxacarb	0.4–0.8	–	
Propoxur	–	0.5	–

Table 4 Pesticides available for treating empty bins (Arthur and Subramanyam 2012)

Insecticides labelled for use as empty bin treatments		
Active ingredient	Example brands	Comments/usage
Cyfluthrin	Tempo Sc Ultra Premise Spray®	Most effective residual as compared with malathion and chloripyrifos-methyl
Diatomaceous earth (DE)	Insecto, Protect-it®	Excellent empty bin treatment. Special grade required for grain use. Must use DE labelled for grain
Malathion	Malathion	No longer recommended for empty grain bins because of high insect resistance and rapid degradation in warm, relatively moist grain
Chlorpyrifos-methyl deltamethrin	Storcide II®	Can only be applied from outside of bin and sprayed downward into bin

than 90%) and some impurities in the solvent. The technical-grade Malathion smells like garlic. It is toxic for mammals, so should be applied by trained person (Tulloch 1972). It is important for:

- Incapacitation of insect’s central nervous system (CNS).
- For best result. Used in the form of dust and liquid spray with the help of conveyer.
- Best applied as a liquid spray or dust as grain flows through an auger or conveyer.
- In oilseeds it is not recommended but formulation of malathion is registered for direct cereal grain treatment.

Table 5 Dust insecticides labelled for use as grain protectants (Nikpay 2006)

Active ingredient	Example brands	Comments/usage
Malathion	Big 6 Grain Protector®, Agri solutions 6% Malathion Grain Dust	Top-dress treatment. Insects are resistant in many areas. Millers resist purchasing grain with strong Malathion odour
Diatomaceous earth (DE)	Protect-It™, Insecto®	Can lower the test weight of grain and is expensive if it is applied to entire grain mass, so is best applied to empty bins and to the top and bottom layers of the grain mass

Table 6 Labelled insecticides for use as empty bin treatments (Matsumura 2012)

Active ingredient (A.I.)	Example brands	Comments/usage
Cyfluthrin	Tempo Sc Ultra Premise Spray®	Most effective residual as compared with malathion and chloripyrifos-methyl
Diatomaceous earth (DE)	Insecto, Protect-it®	Excellent empty bin treatment. Special grade required for grain use. Must use DE labelled for grain
Malathion	Malathion	No longer recommended for empty grain bins because of high insect resistance and rapid degradation in warm, relatively moist grain
Chlorpyrifos-methyl + deltamethrin	Storcide II®	Can only be applied from outside of bin and sprayed downward into bin.
Chloropicrin	Chlor-o-pic®	Empty bin fumigant, under false floor, aeration tubes, and tunnels
Methyl bromide	Brom-o-gas®, others	Empty bin fumigant; seldom used
Phosphine	Phostoxin®, others	Empty bin fumigant

(b) Diatomaceous earth

Diatomaceous earth has been used as a protector of grain. DE is low in mammalian toxicity and provides superior protection when food stuff is stored properly. DE is registered as a feed additive, in the USA and Canada. Amorphous silicon dioxide is considered Generally Recognized as Safe (GRAS), and registered as food additive in the USA and Canada (Korunic 1998). DE is useful to provide a preventive and structural treatment before grain storage and it is left behind as a residue on freshly harvested grain as it goes into storage. DE is ideal to use due to the long lasting protection. In addition to Australia, its registered as a protectant of grain or for structural treatment in Canada, Croatia, China, USA, Germany, and some other Asian countries.

- Mechanism of action of diatomaceous earth causing death through desiccation by absorbing wax which is coated on the skin of insect.
- During harvesting it is most effective when directly apply with dry grain into a bin.
- Treatment temperature should not be less than 20 °C for up to 6-week period
- It increases in grain friction and decreases auger flow rates by reducing test weight.

(c) Aluminium Phosphide (Phosphine) (Weaver and Petroff 2005)

- It is put in cereal grain as in the form of pellets with the help of probe.
- For the effective treatment completely sealed structures should be used.
- Aluminium phosphide reacts with water in the air to produce the gas phosphine.
- Moisture range is not more than 10 °C and temperature at which fumigation takes place for effective treatment should not be more than 50 °C.
- Doses should be 20 times higher than normal doses for controlling egg stage because it is more resistant than adult and larvae stage
- Disadvantage of phosphine—At high humidity and temperatures it causes corrosion of some metal e.g. gold, silver, brass, copper
- Prolonged and inappropriate use of phosphine in Australia and U.S.A has resulted in resistance development.

(d) Magnesium Phosphide (Phosphine) (White and Leesch 1995)

- As like aluminium phosphide, magnesium phosphide acts with water in the air to generate the gas phosphine.
- Magnesium phosphide produces phosphine that is faster than aluminium phosphide.
- Magnesium phosphide could not contact with the fumigated commodities.
- Magnesium phosphide is used as a plates, pouches or strips.
- It is mostly used for fumigation in empty structures.
- As like aluminium phosphide it's similar as humidity, temperature, and corrosion of metals.
- To make treatment effective with Magnesium phosphide, storage structure must be well sealed.

(e) Gaseous Phosphine

- Gaseous phosphine is fast in fumigation as compare to metal phosphides and is more precise dosage of phosphine
- Fumigation at minimum temperature of 0 °C, compared to metal phosphides requires a minimum temperature of 5 °C.
- Gaseous phosphine, similarly uses as aluminium phosphide

- Two formulations are used: ECO2FUME® is ready for application, VAPORPH3OS® its needs onsite dilution.

(f) Carbon Dioxide

- As a gas carbon dioxide apply to the stored products.
- Treatment will be effective when structure must be sealed.
- Doses: Maintain up to 60% for 4 days between 20 °C and 25 °C (White and Leesch 1995)

Inspection

Grain bin inspection gives important information of the general condition, moisture temperature, and pest activity of stored food stuff. It is also important for early detection of problems that's helpful for correct action before any severe damages. The commercially available "probe" traps should be safe and easy method for grab of various beetles they infest the bin (Phillips and Throne 2010).

The traps are hollow "plastic" tube along a string of downward sloping hole along the side. The top has flat cap and the bottom has pointed piece that screws in place. The insects crawl into the tube through the small holes where they are trapped. A nylon line is securely attached for easily rescue from the stored grain. Trap should be inserted in the grains via a long pole with a cup device attached at the end. This device is easily prepared with handle of paint roller extension and various "PVC" plumbing fixtures. Attached extension handle is a PVC "reducer" that one side of the screw and other side is a cup device (Levy and Carley 1989). This device will allow push the trap into the stored grain from internal ladder, an inspection hatch, or some other safe place, therefore avoid crossing the grain surface. The trap is reclaiming using a nylon line which was close to the trap before it was placed in the grain, and it is easily tied off some convenient location in the bin. It keeps the traps from being easily sucked into the stream of grain in case they are elapsed at unloading time.

Conclusion

Insect infestation of cereals, dried seeds, pulses causes quality deterioration in the stored products kept in humid and warm climates. Stored food products infestation caused by microorganisms (mainly fungi and bacteria), bruchids, weevils, mites, rodents and birds and other insects considerable causes physical and nutritional loss. It reduces the nutritional value, quality of the grain, grain weight, and germination of stored grain by Direct-feeding of the insect. It's unhealthy for consumption of animals or humans. Commercial buyers might be paying a low price because of insect contaminated grain. A good management program is required to be maintained for proper grain-handling, regular grain inspections and pest control.

Various procedures are used for the management of pests at storage facilities before and after storage, that diminishes pest attack into storage such as: Cleaning the bins, equipment used for harvest, sealing structures, remove the weeds, cleaning up grain spill on the grounds, insecticides used in empty-bin. About 5–10% is the estimated loss in stored product caused by insects worldwide.

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