Chapter

# Stored Grain Pests and Current Advances for Their Management

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## Abstract

During the offseason, when fresh food is not available, humans have to consume stored grain food. Unfortunately, these stored grains are later infested with many pests. Foods stored in bags and bins are very much susceptible to infestation with several pests which can cause extensive post-harvest losses, spoilage, and less demand in markets, causing a huge economic crisis. Hence, successful management of stored grain pests becomes necessary to prevent these from insect pests. Current approaches for their management are one of the promising goals, as it includes preventive practices, monitoring, sanitation, and identification of main pathogens. Different management strategies of all the common stored grain pests viz. grain weevils, grain borers, grain moths, flour moths, mealworms, grain and flour beetles, booklice, mites, and parasites are enlisted here.

**Keywords:** stored grain insect pests, grain loss management, integrated pest management, economic loss management, pest classification

## 1. Introduction

Stored grains are heavily damaged by insect pests. These pests cause damage to stored grains resulting in both qualitative and quantitative losses. The main reason behind the occurrence of stored grain pests is the presence of favorable climates for their growth and survival. At various processing stages of grains, i.e., during the process of development and maturation of seeds, processing in threshing yards, during transmission of seeds, or storage large number of insect pests gain access to stored grains. Some pests start damaging the seeds at the ripening stage and continue during storage. Old bags, storage structures, old containers are the major source of infestation [1]. The dispersal and distribution of stored grain pests are caused by the movement of grains from one area to another area either by a passive or active flight of pests as some adult insects possess strong flight. Almost one thousand species are stored grain pests of different stored products all around the world. Undesirable smells and flavor. The majority of stored grain pests belong to two orders, i.e., Coleoptera and Lepidoptera [2].

Stored grain pests possess a serious threat to dried, stored, durable and, perishable agricultural products and non-food derivatives of agricultural products worldwide. Stored grain pests cause serious post-harvest losses, almost 9% in developed countries to almost 20% or more in developing countries [3], besides they also cause contamination of food products by the presence of various live insects, insect products like chemical excretions or silk, dead insects or some other storage structures. Almost 8–10%, i.e., 13 million tons of grains lost due to insects and 100 million tons due to failure to store properly is estimated in stored food products all around the world. Pests such as various insects, pathogens, mites possess serious threats and cause severe damage to grains by producing certain enterotoxins and mycotoxins [4]. Approximately one-third of the world's production, which values almost $100 billion has been destroyed by almost 20,000 species of field and stored grain pests [5]. The majority of stored grain pests belong to the order of Coleoptera and Lepidoptera that accounting for almost 60 and 10% respectively. Of all the stored grain pests [6]. Stored grain pests generally feed on grain, bore into the kernel and then destroy the germ portion, cause heat and then cause deterioration in-stored grain products thus resulting in huge losses mainly due to nutritional depletion and reduction in market value besides cause contamination by their excretory products, that can be extremely hazardous to human health who process and infest the grains so the loss caused by insect pests is not in terms of quantity but mostly in terms of quality. Qualitative loss in stored grain is caused by chemical changes in proteins, carbohydrates, amino acids which negatively affect the nutritional value of grains.

## 2. Pre- and post-harvest losses by stored grain pests

Grains are generally attacked by several insect pests during all the stages of growth from seedlings to storage [7]. Insect pests possess a major threat to grain production and are also responsible for both direct and indirect losses of grain both in the field as well as in the storage [8]. Mihale et al. estimated that almost 15–100% pre-harvest losses and almost 10–60% post-harvest losses of stored grains are caused by stored grain pests in developing countries [9]. Two major insect groups, i.e., Coleoptera and Lepidoptera are economically important on stored grains. In the case of Lepidoptera, its larva causes the damage while in the case of Coleoptera both larva and adult causes damage.

Weevils and moths are the major stored grain pests that cause huge damage to maize and sorghum [10]. Most important stored grain pests include Angoumois grain moth (*Sitotroga cerealella* (Olivier, 1789) Lepidoptera: Gelechiidae), maize weevil (*Sitophilus zeamais* Motschulsky, 1855 Coleoptera: Curculionidae), the Indian meal moth (Plodia interpunctella (Hubner, 1813) Lepidoptera: Pyralidae), the almond moths, *Ephestia cautella* (Walker) (Pyralidae: Lepidoptera), flour beetles (*Tribolium* spp.), the flat bark beetles *Cryptolestes* spp. (Coleoptera: Laemophloeidae) and the sap beetles *Carpophilus* spp. Stephens, 1830 (Coleoptera: Nitidulidae) [11]. The maize weevil is a major pest mainly found in warm humid areas all around the world. It mainly damages a wide range of cereals and is well established in tropical countries.

Grains such as sorghum and maize are mainly attacked by pests in the field before their harvest. After one week of storage adults of *S. zeamais* were found on all maize portions of the cobs that indicating that cobs are already infested before their harvest. The level of damage to the grains in storage gives an idea about the extent of damage [12]. Maize weevil although commonly found on maize can also attack many cereal grains such as wheat, barley, sorghum, and rice. Although, maize weevil prefers whole grains it has been reported to feed on many processed grain products including pasta and pet food [13].

Almost 10–20% losses have been reported in maize by *S. zeamais* after three months of storage [14]. Thus, millions of tons of maize are lost by stored grain pests due to inefficient storage technologies. More serious damage to maize grains is due to a larger number of adult weevils [15]. It is estimated that almost 63.85% of grain weight losses occurred due to three to six months of storage by stored grain pests.

Pulses are heavily damaged by weevils and beetles in the field and also during storage time [16]. In the case of pulses, the adzuki bean weevil *Callosobruchus chinensis* (Linnaeus, 1758) (Coleoptera: Chrysomelidae) is found to be highly damaging as a stored grain pest. It is estimated that almost 50% of losses are found in important legumes such as chickpea field pea, faba bean by stored grain pests like *C. chinensis* [17]. Bruchids are found to be serious threats to faba bean and chickpea with an extent of damage sometimes reaching 90% after three months of storage.

## 3. Classification of pests

Stored insect pests are grouped into two types. This grouping is made according to the basis of the feeding ability of the insects in whole or previously damaged grain. They are classified as primary and secondary pests.

### 3.1 Primary insect pests

Primary insect pests cause damage to the previously undamaged kernel or new grain. Stored grain pests are classified as major and minor pests based on the damage they cause. These insects can be classified as external feeders and internal feeders based on their feeding behavior.

(i) *External feeder*: As the name indicates these pests feed on external or surface parts of the grains such as the outside part of germ and endosperm. These pests either feed on whole seeds or damage the germinal portion of seeds and also feed on those seeds which are already damaged or attacked by other pests or are mechanically broken. These pests are generally visible among the seeds such as rice weevil, pulse beetle, granary weevil, Angoumois moth, etc.

(ii) *Internal feeders*: As the name indicates these pests are usually found inside the seeds. These pests mostly lay eggs inside or on the surface of grains, then spend a part or entire larval and pupal life within the grains and emerge as an adult. These pests cause significant loss of germination that is not detected externally, e.g., rice weevil, pulse beetle, granary weevil, Angoumois moth, etc.

### 3.2 Secondary insect pests

**Secondary feeders**. As the name indicates these pests are secondary because these pests attack on already infested crops these generally feed on cut and broken seeds, molds, dead insects, animal wastes, e.g., common mites, cheese mites, etc. Damage caused by these pests results in loss of germination, contamination like ball formation, and webbing besides deterioration of grains. Damage caused by these pests results in fungal activity, moisture migration across the stored grains.

## 4. Stored grain pests

Some common stored grain pests found all over the world as described below:

### 4.1 Grain weevils

Weevils or snout beetles (Coleoptera: Curculionidae) have long, elbowed antennae with a special groove on the snout.

#### *4.1.1 Granary weevil (*Sitophilus granarius *(Linnaeus, 1758) Coleoptera: Curculionidae)*

*Distribution:* Being cosmopolitan in nature and it is found all around the world.

*Host range*: This pest mainly feeds voraciously on a large great variety of grains such as oats, wheat, rice, barley, or corn pest.

*Bionomics:* The granary weevil is the oldest, cosmopolitan, small, brownish or blackish beetle, moderately polished having a long slender snout with a pair of stout mandibles or jaws, and having chewing-type mouthparts [18]. Thorax is well marked with longitudinal punctures and has no wings under its wing covers (**Figure 1**). Larvae or grubs are legless and whitish in color. Adults, as well as larvae, are feeding voraciously on a large great variety of grains. Gravid females lay 200–300 eggs in a small hole in the grain berry with her snout. After oviposition, the hole is covered with a protective gelatinous fluid. Eggs hatched inside holes and white fleshy, legless grubs are formed, which are later transformed into pupae and adults. A short life cycle is seen in summer seasons than in cold seasons.

*Damage symptoms:* It is one of the most serious pests of grains causing huge damage to the grain. It drastically reduces the crop yields by causing huge damage to harvested stored grains holes are created to the grains that are fed by the pest (**Figure 2**).

#### *4.1.2 Rice weevil (*Sitophilus oryzae *(Linnaeus, 1763) Coleoptera: Curculionidae)*

*Distribution:* The rice weevil is highly favored by the hot and humid climate. Being cosmopolitan in nature causes huge economic losses, both larva and adult cause severe damage.

*Host range:* Crops like paddy, wheat, millet, barley, maize, sorghum dried beans, cotton, nuts, cereals, wheat, corn, flour, pasta, dried flowers, decorative ornaments, stored clothes, dried plants, bread, and other cereals are highly infested by this pest. This pest results in both qualitative and quantitative loss of these crops during their storage.

*Bionomics:* Rice weevil or Black weevils are small snout beetles, dark brown having 4 distinct patches on the elytra, and prominent spots on the thorax and abdomen. Adults are similar to granary weevils but differ in color, markings, presence of wings beneath wing covers, and thorax with densely pitted with round


**Figure 1.**
*Dorsal view of adult of* Sitophilus granarius.

**Figure 2.**
*Damage status of* Sitophilus granarius *on wheat.*

punctures (**Figure 3**). Adults are tiny about 2.5 mm long and dark brown in color. Mostly both sexes are alike but in male's rostrum is short and broader. Females lay about 300–400 eggs. Adults are strong fliers and fly from granaries to granaries and to the grain fields for direct infestation. During summer life cycle is very short as compared to winter. Under hot and humid weather eggs take 4–5 days to hatch but under cold conditions eggs take 6–9 days to hatch. The newly hatched larvae bore into the kernel of the grain. Grubs are white in color, curved with a yellow or brown head's and hitting jaws. As grubs emerge from eggs they start feeding on the starchy material of the seeds, till it becomes fully grown and leaves behind only intact pericarp shell which is filled with grass. The grub stage mainly lasts for 19–34 days and then pupates to a non-feeding pupal stage after passing away prepupa for 2–3 days. The pupal stage mainly lasts for almost 1 week and after that adult emerges out of it and starts breeding. This pest completes its life cycle within a month. Most of the severely damaged crops resemble moldy grains.

*Damage symptoms:* Both larva and adult of this pest are extremely damaging larva enters inside the grain and then starts living and feeding inside the grain due to which irregular holes of about 1.5 mm diameter are produced on the grain. These pests cause extreme damage to stored grains.

#### *4.1.3 Broad-nosed grain weevil (*Caulophilus oryzae *(Gyllenhal, 1838) Coleoptera: Curculionidae)*

*Distribution:* Being cosmopolitan in nature, it is found all around the world.


**Figure 3.**
*Dorsal view of adult of* Sitophilus oryzae.

*Host range:* Corn is the main host of this pest. Both fields as well as stored ones are very much susceptible to infestation.

*Bionomics:* Broad-nosed grain weevil is a small, dark brown with short and broad snout, and similar with granary beetle. It damages soft or damaged seeds and not the dry, hard, and uninjured seeds. These are also strong fliers and can damage the crop fields especially cornfields before the harvesting season. Gravid females lay around 200–300 small whitish eggs inside broken and soft grains. These eggs are hatched in a few days into small, white footless grubs and later into whitish pupae. During summer seasons when environmental conditions are favorable, a very small life cycle can be seen than during harsh cold winter seasons.

*Damage symptoms:* It damages soft or damaged seeds and not the dry, hard, and uninjured seeds.

#### *4.1.4 Coffee-bean weevil/nutmeg weevil (*Araecerus fasciculatus *(De Geer, 1775) Coleoptera: Curculionidae)*

*Distribution:* The coffee-bean weevil (Coleoptera: Brenthidae) is cosmopolitan in nature.

*Host range:* Its main hosts are dried fruits, coffee, corn, cornstalks, seeds, and seed pods.

*Bionomics:* The coffee-bean weevil is very active, dark brown in color, with mottled light and dark-brown pubescence, robust beetle. It can be seen in cornfields where they fly here and there. They are usually seen inside soft seeds than hard seeds so they can damage a little to the stored grains gravid females lays eggs inside soft kernels of corn holes.

*Damage symptoms:* Coffee-Bean weevil can be seen flying in cornfields as well as both larvae and adults inside containers or bins containing grains.

**Management of grain weevils:**

Freezing is one traditional method in which stored grains are stored in freezing conditions to increase their shelf life free from infestation. Vacuum cleaning is another traditional method in which any stage of any pest can be pulled from any surface with the vacuum cleaners by sucking all of them. Sun drying of grains is also beneficial. Cleaning, damp-proofing, and heating arrangements should be made possible before storing grains in storehouses or godowns. Corn and other husk-bearing crops should be stored in the shuck if the husk is tight, and covers the whole tip, but if all ears with loose, short, broken, damaged, or perforated husks should be shucked and stored separately in clean bins. Placing neem leaves inside grain containers is also recommended. Chemical control can be performed by applying 5% BHC at the rate of 0.15% by weight. Before storage of grains, godowns, containers, and bins should be sprayed with 0.02% Malathion or 0.4% BHC or DDT. Fumigants such as methyl bromide, ethylene dibromide, phostoxin tablets, and HCN are also used for fumigation for 18 h in the closed godowns.

### 4.2 Grain borers

Grain borers can bore into almost anything such as fabrics, furniture, paper, seed kernels, and seeds.

#### *4.2.1 Lesser grain borer (*Rhyzopertha dominica *(Fabricius, 1792) Coleoptera: Bostrichidae)*

*Distribution:* This pest is originated in India but now this pest has spread all around the world. After rice weevil lesser grain borer is considered as second in importance as a destroyer of stored grains.


**Figure 4.**
*Dorsal view of adult of* Rhyzopertha dominica.

*Host range:* Initially, it was mainly found to invest wheat packings but now it's found to be a pest of all cereals. It's mainly found in warmer areas of the world and damages mainly wheat, barley maize, paddy, sorghum, and other crops. It causes its damage by mainly boring into the wood in both larval and adult stages.

*Bionomics:* Lesser grain borer or Australian wheat weevil are cosmopolitan, small, cylindrical-shaped, dark brown or black in color, roughened surface bodied entities. The head of lesser grain borers are turned down under the thorax and are armed with powerful jaws for cutting and piercing the wood (**Figure 4**). Adults and larvae, both are causing serious damage in warm climates than in cold climatic conditions. Gravid females lay 300–500 eggs loosely or in clusters in the grains. After hatching small, whitish grubs are emerged and voraciously feed on the seeds. Inside grains, these larvae are transformed into pupae and later into adult beetles that came out of the grain through holes.

*Damage symptoms:* Both larvae and adults of this pest cause serious damage. Highly infested grains become completely hollow inside and only the outer thin shell remains intact. Almost four beetles can be present in bigger grains such as maize. Adults are mostly good fliers so they can easily migrate from one godown to other. Adults produce a considerable amount of frass, spoiling more than what they eat.

#### *4.2.2 Larger grain borer (*Prostephanus truncatus *(Horn, 1878) Coleoptera: Bostrichidae)*

*Distribution:* The larger grain borer is originated from India but now this pest is cosmopolitan in nature.

*Host range:* The main host is corn, wheat, rice, and millet.

*Bionomics:* A larger grain borer is a small, dark brown, cylindrical, with a smooth polished surface. Both larvae and adults feed on grain kernels and leave dust and thin brown shells. Females lay 2–30 eggs in clusters on kernels which are later transformed into creamy colored C-shaped grubs with a small dark head that is partly retracted into the thorax, having three pairs of small legs. Adults are brown to black cylindrical bodied pests with numerous small pits on wing covers.

*Damage symptoms:* These are notorious for the emission of sweet, musty odor during an infestation.

**Management of grain borers:**

The most economical and efficient method of controlling this pest is the prevention of crops. One such preventive method is fumigation. Corn and other husk-bearing crops should be stored in the shuck if the husk is tight, and covers the whole tip, but if all ears with loose, short, broken, damaged, or perforated husks should be shucked and stored separately in clean bins. The application of insecticides is the rapidly controlling method for immediate results.

### 4.3 Grain moths

Grain moths are found to damage solid, sound, and unbroken stored grains. They reduce kernels as well as grains to powder and shells. Following pests are included in the moth category:

#### *4.3.1 Angoumois grain moth (*Sitotroga cerealella *Olivier, 1789 Lepidoptera: Gelechiidae)*

*Distribution:* The name Angoumois is given to this pest because it was first noticed as a pest in the Angoumois province of France in 1973.

*Host range:* It is mainly found in a warm temperate climate and attacks both stored as well as field grains. It causes huge damage to the grains of paddy, sorghum, bajra, wheat, etc.

*Bionomics:* The Angoumois grain moth is considered one of the most serious pests or internal feeders in stored grains. It is a small, yellow-brown moth that attacks all cereal grains directly in fields as well as stored ones in all parts of the world. Females lay on or inside grains, around 150–350 eggs, which are initially white and later turned into a reddish color. Eggs are hatched into white caterpillars that are voracious feeders and eat out a channel to the outside of the grain. Larva enters into the grains and starts eating and then turns about and spins a silken web over the opening from which it enters therefore it's difficult to locate the pest. Only larvae are voracious feeders and they feed on kernels. Infestation cannot be assessed in the early stages. Germination is seriously affected after infestation. It is the most devastating pest out of all Lepidopteran storage pests. White larvae are transformed into reddish-brown pupae and later emerge as moths. Adults are usually good fliers. Infestation starts in maturing cereal crops right in the field.

*Damage symptoms*: The first infestation starts when the grain is in or passing through the milk stage in the field and when only a small percent of grains is infested. By the time grains are threshed or stored infestation increases quickly. When storing the grains infestation of these pests is restricted only to the upper surface. Early infestation is difficult to detect because a hole made by young is so small that it cannot be seen. The first indication of infestation of pests is given by the appearance of moths in the stores and round holes on the grains or sometimes grains get heated up in the bin. Infested grains are hollow insides and filled with excreta or webs of larva leaving a circular opening for moths' emergence. If the pest is breeding in farm godowns, the moth is attracted by instinct to the nearby field in search of maturing grains to lay eggs.

#### *4.3.2 Wolf moth (*Manduca rustica *(Fabricius, 1775) Lepidoptera: Sphingidae)*

*Distribution:* The wolf moth is cosmopolitan in distribution.

*Host range:* It is mainly found in a warm temperate climate and attacks both stored as well as field grains. It causes huge damage to the grains of paddy, sorghum, bajra, wheat, etc.

*Bionomics:* Wolf moth is a small, creamy white and has a thickly mottled appearance with brown color that distinguished it from the Angoumois grain moth.

*Damage symptoms*: Infestation can be assessed during early stages with the presence of creamy-colored grubs as well as brown-colored adults.

#### *4.3.3 Pink cornworm (*Helicoverpa zea *(Boddie, 1850) Lepidoptera: Noctuidea)*

*Distribution:* The pink cornworm is found all over the world especially in warmer regions.

*Host range:* They mainly feed on corn seeds, husk, and cob in both fields and storage ones.

*Bionomics:* Pink corn worm is a small moth having banded fore wings with black, yellow, and brown bands. Hind wings are gray in color, cylindrical, and are edged with long fringes. Females are laying single or occasionally two or three eggs which are white in color. The larvae or caterpillars are pink with pale brown thorax and head.

*Damage symptoms*: The main indication of its presence in the formation of a large amount of frass that is loosely webbed together and fills the gaps between the kernels.

#### *4.3.4 Rice moth (*Corcyra cephalonica *(Stainton, 1866) Lepidoptera: Pyralidae)*

*Distribution:* The rice moth is mainly distributed in Africa, Asia, and Europe. It is one of the most important pests in both India and Pakistan in its larval stage.

*Host range:* Rice moth is a very serious pest of stored paddy, rice, and other cereals. It is widely distributed in all rice-growing areas. It grows well in humid and warm climates and also infests wheat, sorghum, maize, barley, oilseeds, and sweet products.

*Bionomics:* Rice moth is pale, grayish-brown in color, and is generally 11–12 mm long. Females are larger than males. Adult life is usually for a week. The Head is provided with tufts of hairs. Almost 200 eggs are laid by females which are small, oval, and are mostly laid on bags, walls. Larvae differ from the larvae of Indian meal moths in having variable color forms such as white, green, and slightly bluish-gray. Larvae feed on rice, biscuits, candies, cocoa, and other kitchen foods. Pupae are pink, elongated, cylindrical with dark spots on the apical side.

*Damage symptoms*: While feeding, larvae produce dense silken web structures that show their infestation. Besides these pests also pollute the environment with large quantities of frass and silken cocoons, webbing together the grains into large lumps occur.

#### *4.3.5 Fig-almond moth (*Cadra cautella *(Walker, 1863) Lepidoptera: Pyralidae)*

*Distribution:* The almond month is also known as fig moth. It is widely spread in the tropics and subtropical areas.

*Host range:* It causes severe damage to figs, rough rice, dry fruits, wheat, barley, sorghum, oilseeds, etc.

*Bionomics:* The fig-almond moth (Lepidoptera: Phycitidae) is small, grayish, with transverse spines on the outer wing margin. Nearly 200–250 eggs which are small, oval, whitish in color are deposited by gravid females inside cracks and crevices. Eggs are usually less than 1 mm and hatched around 4 days. Larvae are pinkish-white, living inside the spinning tubes, and later construct silken cocoons for pupation. The pupal period is 7–10 days, which are later emerging into the adult stage, commonly referred to as moths. Moths are generally more abundant during rainy and humid seasons. In certain cases, they only use stored grain pests as their breeding sites and not for feeding purposes.

*Damage symptoms*: The presence of larvae is a sign of infestation. The larvae make tunnels inside the food grains. They can also block the machinery or mills with clot formation.

**Management of grain moths:**

Corn and other husk-bearing crops should be stored in the shuck if the husk is tight, and covers the whole tip, but if all ears with loose, short, broken, damaged, or perforated husks should be shucked and stored separately in clean bins.

### 4.4 Flour moths

The most common and most serious pests of stored grains are flour beetles and flour moths. They eat injured, broken grains, meals, and flour most commonly. Some common flour beetles are:

#### *4.4.1 Indian meal moth (*Plodia interpunctella *(Hübner, 1813) Lepidoptera: Pyralidae)*

*Distribution:* Indian meal moth is found all around the world especially in countries that have temperate climates.

*Host range:* They are mainly damaging dried fruits, nuts, cashew nuts, almonds, etc.

*Bionomics:* The Indian meal moth is a reddish-brown having peculiar markings on its forewings (**Figure 5**). Females lay 300–400 eggs on food grains either singly or in groups. Eggs, later on, hatched into whitish and sometimes into greenish or pinkish caterpillars that feed voraciously on stored grains, dried fruits, nuts, and many other foodstuffs. Larvae spin a silken cocoon and transform into a light brown pupa from which the moths emerge later on.

*Damage symptoms:* Full-grown larvae leave behind silken threads wherever they crawl, as well as the presence of greenish or pinkish caterpillars.

#### *4.4.2 Mediterranean flour moth (*Ephestia kuehniella *Zeller, 1879 Lepidoptera: Pyralidae)*

*Distribution:* Being cosmopolitan in nature, the Mediterranean flour moth (Lepidoptera: Pyralidae) is found all around the world especially in countries


**Figure 5.**
*Dorsal view of adult of* Plodia interpunctella*.*

that have temperate climates. It mainly prefers warm temperatures for rapid development.

*Host range:* The larva of the Mediterranean flour moth mainly prefers flour meal, whole grain, and grain residues. This pest shows exception in a way of feeding on cereals rather than feeding on dried fruits.

*Bionomics:* The Mediterranean flour moth is one of the most serious pests of flour mills, storehouses, granaries, and bran mills that has pale leaden gray fore wings with transverse wavy black markings. Hind wings remain inside fore wings during rest and are white in color (**Figure 6**). They produce such dense webs with flour or meals that can eventually clog mills and the machinery have to shut down thorough cleaning processes. Females lay small whitish eggs in the accumulation of flour, kernel, meal, or waste and crushed grains. Larvae that emerged from these eggs are small, white, or pink in color with a few small black spots on the body. Reddish-brown pupae are formed inside the silk cocoon formed by the full-grown larvae.

*Damage symptoms*: The infestation can be seen during the production of dense webs with flour or meals inside bins. These can eventually clog mills and the machinery have to shut down for thorough cleaning processes. This species particularly enjoys inhabiting flour mills and bakeries due to the heat, which allows it to breed year-round.

### *4.4.3 Meal snout moth (*Pyralis farinalis *(Linnaeus, 1758) Lepidoptera: Pyralidae)*

*Distribution:* Snout moths (Lepidoptera: Pyralidae), which are also called grass moths or pyralid moths are found throughout the world.

*Host range:* The meal snout moth is usually found in flour meals and cereals of all kinds.

*Bionomics*: The meal snout moth is brown, larger than the Indian meal moth with patterned fore wings. Larvae which are black and white when fully grown, usually feed on cereals of all kinds and spin their resting place of peculiar tubes made up of silk and food particles. Fully-grown larvae come out from these tubes, spin silk cocoons, and transform into pupae. During favorable conditions, pupae are transformed into adult moths to start the new generation.


**Figure 6.**
*Dorsal view of adult of* Ephestia kuehniella*.*

*Damage symptoms*: Silk cocoons inside which pupae are resting are the main indication of this pest. Brown moths are seen flying through the windows of storerooms.

**Management of flour moths:**

Pest management professionals should be informed as soon as possible to identify the pest properly and to devise the best treatment to control the infestation of food grains. Stored grain containers should be thoroughly inspected for holes, rips, and other larvae or adult presence, before purchasing and after storage. Proper ventilation to prevent moisture build-up, make sure to thoroughly wipe, down, and dust storehouses, cabinets, cupboards, and pantry areas.

### 4.5 Mealworms

Mealworms (Coleoptera: Tenebrionidae) are dark brown or black or dull pitchy black beetles frequently found in grains especially corn and their larvae are conspicuous and are about an inch in length or as around like an earthworm. Following are some stored grain pests belonging to mealworms:

#### *4.5.1 Yellow mealworm (*Tenebrio molitor *Linnaeus, 1758 Coleoptera: Tenebrionidae)*

*Distribution:* The yellow mealworm is the largest of the insect species that attack stored grain and grain products and is cosmopolitan in nature.

*Host range:* It mainly shows preference to the decaying grains, milled cereals, and usually the foodstuffs which are moist and are going out of conditions. It also feeds on the meal, grain, brand, bread, and dead insects.

*Bionomics:* Yellow mealworm or darkling beetle is a polished black or dark-brown beetle with finely punctured thorax and with longitudinally striated or grooved fore wings. Females lay about 300–500 eggs, which are bean-shaped, white, and sticky that adhere to food materials with one. Larvae are long, cylindrical, and initially white but later on changed into yellow color. Some larvae are not transformed into adults but instead that they continue their feeding and start molting and undergo hibernation during harsh conditions. Later on, some are transformed into pupae from where adults emerge in the form of beetles.

*Damage symptoms*: The presence of long, cylindrical, white larvae, usually attached to food materials is the main symptom of an infestation.

#### *4.5.2 Dark or black mealworm (*Tenebrio obscurus *Fabricius, 1792 Coleoptera: Tenebrionidae)*

*Distribution:* Being cosmopolitan in nature this pest is found all around the world, especially across Canada.

*Host range*: The presence of long, cylindrical, white larvae, usually attached to food materials is the main symptom of an infestation.

*Bionomics:* Dark mealworm resembles a yellow mealworm but differs in being dull pitchy black in contrast to the shiny or polished dark brown or black color. Larvae are long, cylindrical, and initially black but later turned into a blackish color.

*Damage symptoms*: Larvae are voracious feeders and their presence shows maximum infestation.

**Management of mealworms:**

Screening and fanning are the best methods for their removal from grain shipments. Good sanitation efforts, inspecting items, and keeping stored grain rooms fully ventilated can help to keep red flour beetles away from entering into food grains. The application of pesticides can be harmful because these pests are found in our food supply. Hence contacting experts for pest solutions at the first sign of an infestation is an effective way to protect food items from red flour beetles. Chemical control can be performed by applying 5% BHC at the rate of 0.15% by weight. Before storage of grains, godowns, containers, and bins should be sprayed with 0.02% Malathion or 0.4% BHC or DDT. Fumigants such as methyl bromide, ethylene dibromide, and HCN are also used for fumigation for 18 h in the closed godowns.

### 4.6 Grain and flour beetles

The grain and flour beetles are very common stored grain pests feeding on almost all stored grains available throughout the world.

#### *4.6.1 Cadelle (*Tenebroides mauritanicus *(Linnaeus, 1758) Coleoptera: Tenebrionidae)*

*Distribution:* Cadelle is present in almost all parts of the world.

*Host range:* its main host is grain and grain products.

*Bionomics:* Cadelle is the longest-lived pests, frequently found in granaries, mills, storehouses containing grains, flour, meal, pulses, etc. These are elongated flattened, oblong, black, or blackish beetle that resembles mealworms but, differ from them in size and body texture. These are smaller than mealworms and have loosely joined thorax and abdomen. Larvae are white, fleshy, long, with head, thoracic shield, having two black horny points on the abdomen, and are one of the largest of the stored grain pests. Both larvae and adults are very much destructive and move from grain to grain and devour the embryo.

*Damage symptoms*: It is a very serious pest of grains and bores inside wood for pupation. The presence of small holes in grains and in wood is the primary indication of its infestation.

#### *4.6.2 Saw-toothed grain beetle (*Oryzaephilus surinamensis *(Linnaeus, 1758) Coleoptera: Silvanidae)*

Distribution: The saw-toothed grain beetle is cosmopolitan in nature and is found in almost all places of the world.

*Host range*: The main host includes infesting grains, meals, flour, dried fruits, and many other seeds.

*Bionomics*: The saw-toothed grain beetle has six saw-like projections on each side of the thorax, with three-segmented antennae. It is cosmopolitan and has a long, slender, dark chocolate brown, much-flattened structure (**Figure 7**). Both larvae and adults are voracious feeders and are very active, hence do not spend their lives within a single grain but crawl as well as infest almost every grain. Larvae are white in color, with black markings, flatform, three pairs of legs, and an abdominal proleg. Larvae construct delicate cocoons by secreting silk-like secretory substances which bind food particles and grains with each other. Inside this cocoon, larvae are transformed into pupae and later into adult beetles.

*Damage symptoms*: Larvae, as well as cocoon formation, is the primary indication of this pest infestation.

#### *4.6.3 Square-necked grain beetle (*Cathartus quadricollis *(Guérin-Méneville, 1844) Coleoptera: Silvanidae)*

*Distribution:* Square-necked grain beetle, was initially found in South America, but now its status is worldwide.


**Figure 7.**
*Dorsal view of adult of* Oryzaephilus surinamensis*.*

*Host range*: Being a stored grain pest it generally attacks the stored products such as cereals, grains, etc.

*Bionomics*: The square-necked grain beetle is a flattened, oblong, polished, reddish-brown, with thorax almost square-shaped. These are some of the most common beetles found in both cornfields as well as granaries. Usually, after three weeks eggs get converted into larva, the larva undergoes molting five times to become a pupa, pupa then again gets converted into adult [19]. Eggs are mainly oval in shape and are opaque white in color and are less than a millimeter long, 4 days eggs hatch into larva and the larva are the main predators [20]. The pupa is generally darker in color and then the pupa gradually transformed into adults.

*Damage symptoms*: Larval presence is the main symptom of infestation by this pest.

### *4.6.4 Foreign grain beetle (*Ahasverus advena *(Waltl, 1834) Coleoptera: Silvanidae)*

*Distribution:* Foreign grain beetle mainly occurs in the tropics and sub-tropics. This pest can complete the development at temperatures between 20°C and 35°C.

*Host range*: This pest mainly attacks cereals, grains, oilseeds, spices, and dried fruits.

*Bionomics*: The foreign grain beetle is a small, cosmopolitan, reddish-brown beetle. It spends its most time on damp and moldy grains and less on clean grains. This pest mainly measures about 2 mm in length. It can be easily differentiated by the slight projections on each front corner of the pronotum and the antennae are club-shaped. The larvae are mainly cream-colored, worm-like, and almost 3 mm long before they start pupation into darker adults. Males and females are alike in form both as larva as well as adults.

*Damage symptoms*: Poor storage conditions and spoiled food is mainly indicated by the presence of the beetle.

### *4.6.5 Mexican bean beetle (*Epilachna varivestis *Mulsant, 1850 (Coleoptera: Coccinellidae)*

*Distribution*: The Mexican bean beetle is mainly found in Mexico and the Eastern United States. It is largely found in wet and highly irrigated areas especially in the west of the Rocky Mountains. It cannot tolerate extremely dry conditions.

*Host range*: This pest is mainly feeding on flower, leaf, or pod tissues on beans and other legumes. The pest is generally found in different varieties of bean plants including thicket bean, cowpea, common bean, soybean. Besides it also feeds on other legumes such as alfalfa and many others.

*Bionomics*: The Mexican grain beetle is a deep brown, highly polished, long antennae, and usually breeds in grain and grain products. The adult is mainly oval shaped almost 6–7 mm in length it bears eight black spots on its elytron. The Color of the adult is highly variable ranges from bright red to rusty brown to golden yellow. Almost 1.3 mm long eggs are generally yellow and are glued in clusters on the underside of the leaves. The larvae are yellow in color. Almost 1.6 mm long when they first emerge but they grow almost a centimeter long before pupation.

*Damage symptoms*: Places wet and highly irrigated are the main infested regions by this pest.

#### *4.6.6 Siamese grain beetle (*Lophocateres pusillus *(Klug, 1832) Coleoptera: Trogositidae)*

*Distribution*: Siamese grain beetle is found in all regions where paddy and different kinds of cereals are cultivated.

*Host range*: The main host is rice and cereals.

*Bionomics:* The Siamese grain beetle is reddish-brown, flattened, elongate, long beetle with a flattened margin of the thorax and wing cover. These are making holes in the rice and hence damage its quality as well as quantity.

*Damage symptoms*: Adults are seen actively walking on and around the food grains.

#### *4.6.7 Flat grain beetle (*Cryptolestes pusillus *(Schoenherr, 1817) Coleoptera: Silvanidae)*

*Distribution:* Flat grain beetle is commonly found all over the world.

*Host range*: Its main hosts are corn and wheat grains.

*Bionomics:* The flat grain beetle is cosmopolitan, small, oblong, flat, reddish-brown beetle, with long antennae. Larvae woven cocoons by secreting sticky secretions, adhering damaged grains with each other for pupal development.

*Damage symptoms*: Flat grain beetles have the property of secreting sticky secretions.

#### *4.6.8 Confused flour beetle (*Tribolium confusum *Jaqcquelin du Val, 1868 Coleoptera: Tenebrionidae)*

*Distribution*: The confused flour beetle, is cosmopolitan, native to Africa, and commonly found in cooler places.

*Host range*: It is commonly found in flour mills, granaries, storehouses, wheat fields, dried flowers, seeds, or dried museum specimens [21].

*Bionomics:* The confused flour beetle is reddish-brown, shiny, long, oval, flattened, having four segmented antennae, with head and upper parts of thorax densely covered with small punctures and with ridges on wing covers (**Figure 8**). Eggs are small white in color, laid by gravid females inside boxes, barrels, and other food containers. These sticky secretions help them to adhere to the flour as well as with the walls of containers. Eggs are transformed into long, worm-like larvae which are cylindrical and wiry in appearance. The pupal stage is small, initially white and later yellow and brown, where adult beetles emerge shortly.

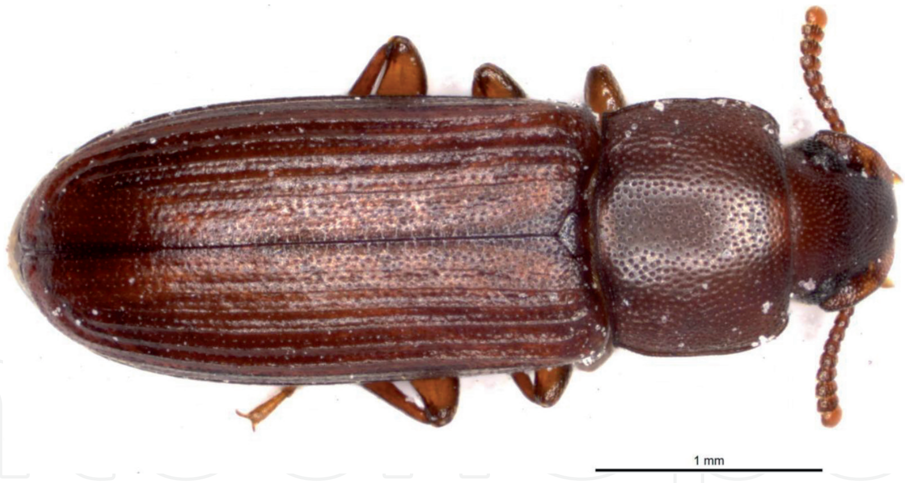


**Figure 8.**
*Dorsal view of adult of* Tribolium confusum.

*Damage symptoms*: Being secondary pests they do not directly attack the grain bur when the grain is already infested, they show their effect. These pests generally give an unpleasant odor and also due to their presence, the growth of mold is encouraged.

### *4.6.9 Rust-red flour beetle or red flour beetle (*Tribolium castaneum *(Herbst, 1797) Coleoptera: Tenebrionidae)*

*Distribution*: Being cosmopolitan in nature red flour beetle, is mainly found all around the world.

*Host range*: It is a serious pest of cereal products, including grain, flour, porridge oats, and rice bran. Other products which may be attacked are oilseed, oil cake, nuts, dried fruit, spices, chocolate, and even bones of animals.

*Bionomics*: The rust-red flour beetle is cosmopolitan, shiny, reddish-brown, has antennae enlarged at the tip with the three-segmented club, head margins are continuous and not expanded and notched at the eyes (**Figure 9**). They are notorious for causing bad smells and tastes imparted to the food materials they infest. Their main hosts are maize, wheat, and other mills and granaries.

*Damage symptoms*: When present in abundance, this beetle makes the flour prone to molding and also turns the products into a gray color.

### *4.6.10 Long-headed flour beetle (*Latheticus oryzae *Waterhouse, 1880 Coleoptera: Tenebrionidae)*

*Distribution*: This pest was first reported from India in Kolkata in 1880. Later it was reported from many other countries.

*Host range*: This mainly attacks broken grains, wheat, rice, corn, flour, barley, and many other granaries, grocery stores, and mills.

*Bionomics*: The long-headed flour beetle is cosmopolitan, pale yellow, slender, flattened beetle, with slightly bulged antennae, and the presence of canthus behind each eye. It has been reported from wheat, rice, corn, flour, barley, and many other granaries, grocery stores, and mills. It is mainly associated with *T. castaneum*, and its behavior and life cycle are very similar to flour beetle. Eggs are mostly smooth and translucent in color. Grubs are generally white in color with dark eyes. Larval body is covered by pale-colored hairs. The life cycle of the pest is completed in 25–39 days.


**Figure 9.**
*Dorsal view of adult of* Tribolium castaneum.

*Damage symptoms*: Milled products are fed by both grubs and adults as well. Occurs as secondary infestation in stored sorghum, wheat, etc.

#### *4.6.11 Slender-horned flour beetle (*Gnathocerus maxillosus *(Fabricius, 1801) Coleoptera: Tenebrionidae)*

*Distribution*: The slender-horned flour beetle is cosmopolitan in nature.

*Host range*: It is most commonly found in flour, meal, and a variety of grains.

*Bionomics:* The slender-horned flour beetle is cosmopolitan, flat, brown, with a pair of incurved horns on its mandibles of the male partner.

*Damage symptoms*: Being secondary pests they do not directly attack the grain bur when the grain is already infested, they show their effect. These pests generally give an unpleasant odor and also due to their presence mold growth is encouraged.

#### *4.6.12 Broad-horned flour beetle (*Gnatocerus cornutus *(Fabricius, 1798) Coleoptera: Tenebrionidae)*

*Distribution*: Broad-horned flour beetle is especially found in Canada and is distributed all over the world.

*Host range*: It is commonly found in granaries, mills, and many other stored grains.

*Bionomics*: The broad-horned flour beetle is slender, elongated beetle, with mandibular broad and stout horns in males. After mating female lays eggs either singly or in batches within the food source. From the eggs larva hatch and then they start feeding and gets converted into an adult again. This species primarily feeds dead insects besides feeding on protein sources. Adults show sexual dimorphism. Horns are absent in females but they are present in males.

*Damage symptoms*: The presence of dead insects inside grains is the prime indication of pest attack.

#### *4.6.13 Small-eyed flour beetle (*Palorus ratzeburgi *(Wissmann, 1848) Coleoptera: Tenebrionidae)*

*Distribution*: Small-eyed flour beetle is cosmopolitan in nature.

*Host range*: This pest generally prefers milled wheat, stored grain, oat products, flour mills. It also feeds on plant and dried animal products such as grain and cereal products. It is mainly a secondary pest, also feeds on fungus, and acts as a scavenger.

*Bionomics:* The small-eyed flour beetle is one of the smallest, flat, shiny, reddish-brown, oblong flour beetles. It is cosmopolitan and is found in ground products where they feed and breed. Eggs laid by adult females are generally sticky due to which they become coated with flour or grain dust. The larva is highly active and moves freely among the foodstuffs. Adult ate usually 2–3 mm in length and are small reddish-brown in color. The larva is generally cylindrical in shape. This pest is considered as one of the smallest flour beetles and they are generally differentiated by the presence of the eye entirely and not incised by the margin of the head.

*Damage symptoms*: Although, damage cannot be assessed clearly, however, quality of stored grains is highly affected.

#### *4.6.14 Tobacco beetle or Cigarette beetle (*Lasioderma serricorne *(Fabricius, 1792) Coleoptera: Anobiidae)*

*Distribution*: Although, the Cigarette beetle is a cosmopolitan pest it generally prefers to be in warmer environmental conditions.

*Host range*: It feeds on a wide range of food materials from spices, chocolate, cocoa, and tobacco leaves. The other hosts are paprika, dry dog food, beans, dried fruits, biscuits, grains, peanuts, rice, and vegetables.

*Bionomics*: The cigarette beetles are light brown, oval-shaped beetle, having serrated antennae, strong humped appearance on the head and thorax. Egg-laying occurs either in folds or in crevices of food material. Eggs are mostly oval in shape and white in color but become opaque before hatching. Almost 100–110 eggs are laid by females that hatch in 5–6 days. The larval stage lasts for 20–25 days followed by the pupal stage. The larvae are smaller than the adults and are worm-like hence known as cigarette beetles, and tobacco beetle because of residing inside tobacco. The pest cause damage by making little gallerias. After 25–39 days of larval life, it makes smooth-lined cells under which the pest rests. The newly formed pupa is glossy white but gradually changes to reddish-brown in color after a few days. Females are mainly larger in size than males.

*Damage symptoms*: Both adults and grubs of this pest enter into the tobacco products viz., cigarettes, cheroots, and chewing tobacco. A typical symptom of attack of this pest is the presence of circular pin-sized boreholes on the processed tobacco. Besides this pest also damages cocoa, wheat, cotton seeds, etc.

#### *4.6.15 Drug-store beetle (*Stegobium paniceum *(Linnaeus, 1758) Coleoptera: Anobiidae)*

*Distribution:* Drug-store beetle is generally found in tropical, subtropical, and temperate regions.

*Host range*: It mainly infests turmeric, ginger, pepper, coriander seeds, cumin, seeds. Adults and grubs mainly attack the grains and seeds. It is frequently seen in drug stores where it can feed and breed. Stored grain foods, seeds, flours are the common hosts of this beetle.

*Bionomics*: The drug-store beetle is an elongate, cylindrical, light brown, with its body covered with fine silky hair. Females lay almost 50–80 eggs inside grains and other stored substances that are later transformed into small white grubs after 8–10 days of hatching. The larval period lasts for 4–5 weeks which is followed by a pupal period of 6–10 days. Larvae then woven cocoons resulted in pupae that gave rise to adult beetles. Adults are pale brown and short-lived.

*Damage symptoms*: Damage caused by the pest is indicated by the presence of circular pinhead-sized boreholes on turmeric, coriander, dry vegetables, and animal matter.

#### *4.6.16 Black carpet beetle (*Attagenus unicolor *(Brahm, 1791) Coleoptera: Dermestidae)*

*Distribution*: The Black carpet beetle is cosmopolitan in distribution.

*Host range*: Larva of this pest is a voracious feeder and it mainly feeds on natural fibers, or furniture or carpets, or even clothes.

*Bionomics*: The black carpet beetle is small, with its head and thorax black colored, and wings either black or reddish-brown or golden brown, clothed with short hairs. Legs and antennae are yellowish in color. Mostly egg-laying occurs on a food source or sometimes females lay eggs in dark undisturbed areas where the larva starts feeding on carpets or clothes. Almost 5–20 days are taken by the eggs to hatch depending on external conditions like humidity, temperature. The larva is mostly 1 mm long when they hatch from the eggs they will grow faster if food sources are abundant. Almost 10–15 molting a larva is usually taken by the larva to undergo molting. The larval phase is the longest phase and then the larva converts into a pupa. Initially, the pupa is creamy colors but they quickly then turn first yellow and then dark in color. Within 8–20 days the pupa transforms into adult beetles. Adult lives only to mate and then lay eggs and finally die. Since in the end, they are black colored that's why they are commonly called black carpet beetle.

*Damage symptoms*: It is one of the serious pests of grains. Its larval stage is highly damaging, as they are voracious feeders and their presence is the indication of an infestation.

#### *4.6.17 Larger cabinet beetle (*Trogoderma granarium *Everts, 1898 Coleoptera: Dermestidae)*

*Distribution*: Larger cabinet beetle is mainly found in tropics and subtropics. It prefers to live in humid and high-temperature areas.

*Host range*: Being an external feeder it is only found on the surface of the grain. It is the main pest of wheat but, can also destroy jowar, rice, maize, sorghum, oilseeds, and pulses. These are also commonly found in beans, pumpkin seeds, gourd seeds, and many other grains.

*Bionomics*: The larger cabinet beetle is small, egg-shaped, with a black body mottled with reddish-brown, presence of hairs having gray and light brown color. The adult is usually oval in shape with gray and pale brown markings. The Head is primarily hidden under the hood like pronotum. Almost 100–120 eggs are laid by females after breeding. It takes 5–6 days for females to lay eggs after breeding. The larva is mainly brown in color, the whole body is covered by bundles of long, reddish-brown movable and erectile hair present on the posterior segments which form a sort of tail in the posterior end. First instar larva mainly feeds on broken grains and debris. The larval period persists up to 20–25 days, whereas the pupal period persists for 4–8 days. This pest is highly resistant to starvation. Although, this pest damages whole grain it primarily prefers germ portion due to which viability of seeds is lost long before any quantitative damage occurred. High infestation results in a reduction of whole grains to mere Fras. The larval stage is the devastating stage. Adults are non-feeders.

*Damage symptoms*: Only larvae are voracious feeders and feed on grain kernels. Holes of almost 1 mm diameter are seen on the grains. This pest imparts an extremely unhealthy appearance and unpleasant smell. Mostly the upper layer of the heap is severely damaged.

#### *4.6.18 Small cabinet beetle (*Trogoderma *sp. Coleoptera: Dermestidae)*

*Distribution*: Small cabinet beetles are restricted to warmer regions as well as tropical regions.

*Host range*: These are usually found in flour mills, granaries, and storehouses.

*Bionomics:* The small cabinet beetle differs from the larger cabinet beetle in size and color. These are usually small and black with yellowish-white scales on the body. Eggs, as well as larvae, are found inside piercing and broken grains.

*Damage symptoms*: Grains on keen inspection can be seen soft inside and broken because of its presence.

#### *4.6.19 Museum beetle (*Anthrenus museorum *(Linnaeus, 1761) Coleoptera: Dermestidae)*

*Distribution:* Museum beetle is mainly found in Palearctic areas including Europe, the Nearctic, and the Near East.

*Host range*: This pest mainly prefers flour, cheese, or cocoa.

*Bionomics:* The museum beetle is black, having yellowish and whitish scales on its body. Almost 50 eggs are oviposited inside grains and the larvae are mainly 4.5 mm in length and bear active hairs, hence commonly referred to as a hairy grub. The dorsal surface of the prothorax is brown in color. It possesses 3 pairs of long antennae at its rear end. The adult is about 2–4 mm in length. It is round in shape. After mating females lay eggs in carpets, flooring, to hide the eggs and to provide food supply to the larva. They are found in stored grain containers but their damage-causing status is very poorly reported.

*Damage symptoms*: As far as the damage is concerned larva are highly damaging and they mainly destroy all forms of dry grains and flour.

#### *4.6.20 Two-branded fungus beetle*

*Distribution*: The two-branded fungus beetle (Coleoptera: Endomychidae) is cosmopolitan in distribution.

*Host range*: They mainly feed on fungus and molds and are also frequently found in mills, granaries, storehouses, etc.

*Bionomics:* The two-branded fungus beetle is small, cosmopolitan, reddish-brown in color with two broad black bands across the wings. Although, feeding on fungi and molds but are also frequently found in mills, granaries, storehouses, etc. Eggs are commonly laid inside infested or damaged grains and the larvae are voracious feeders and spoil grains and cereals.

*Damage symptoms*: The larvae are voracious feeders and spoil grains and cereals, reducing their quality and quantity status.

#### *4.6.21 Black fungus beetle (*Alphitobius laevigatus *(Fabricius, 1781) Coleoptera: Tenebrionidae)*

*Distribution*: Black fungus beetle is cosmopolitan in nature, found all around the world.

*Host range*: This pest feeds on a large variety of stored products and is also a fungal feeder. It is a secondary pest which means it enhances the damage caused by primary pests.

*Bionomics*: The black fungus beetle is small, with a black or reddish-brown colored body. They frequently feed and breed in damp moldy grains. Adults are almost 5–7 mm. Based on the lateral view of eyes; adults can be easily distinguished from lesser mealworms. Larval is cylinder-shaped and is yellowish-brown in color. The larva is active and moves quickly towards the food sources.

*Damage symptoms*: Being a secondary pest it does not directly attack the grains but causes damage in presence of the primary pest. Its presence indicates poor storage and poor sanitation conditions.

#### *4.6.22 Corn sap beetle (*Carpophilus dimidiatus *(Fabricius, 1792) Coleoptera: Nitidulidae)*

*Distribution*: Corn sap beetle is cosmopolitan in distribution and mainly originated in the USA.

*Host range*: It feeds on rotten and decaying fruits and vegetables, corn, and solid grains.

*Bionomics*: The corn sap beetle is small, oblong or ovoid, dark-brown beetle with short and truncate fore wings with the uncovered abdominal tip.

*Damage symptoms*: These pests are notorious for the emission of foul smells.

#### *4.6.23 Pulse beetle (*C. chinensis *(Linnaeus, 1758) Coleoptera: Chrysomelidae)*

*Distribution:* Pulse beetle is distributed throughout the temperate regions of the world.

*Host range: C. chinensis,* is a frequent pest of all pulses, beans and grams.

*Bionomics:* Gravid females lay single eggs, glued to the surface of pods or grains. Eggs are translucent, orange, or cream colored, changing grayish to white later. Eggs hatch into fleshy, curved, creamy white larvae with black mouth parts. Pupae take place inside seed coats in pupal cells. Adults are short, active, brownish-gray, with characteristic spots near the middle of the dorsal side. Adults are not feeding on storage products and are short-lived.

*Damage symptoms:* Adult are seen emerging and wandering over the surface of the grain, and making exit holes. Grubs are responsible for the formation of cavities in seed kernels.

**Management of grain and flour beetles:**

Pest management professionals should be informed as soon as possible to identify the pest properly and to devise the best treatment to control the infestation of food grains. Stored grain containers should be thoroughly inspected for holes, rips, and other larvae or adult presence, before purchasing and after storage. Proper ventilation to prevent moisture build-up, make sure to thoroughly wipe, down, and dust storehouses, cabinets, cupboards, and pantry areas.

Infested products with cigarette beetles should be discarded as soon as possible. Stored grain products should be kept in glass sealed containers, plastic containers instead of their original packing. Cleaning and wiping down those areas commonly occupied with food debris.

Corn and other husk-bearing crops should be stored in the shuck if the husk is tight, and covers the whole tip, but if all ears with loose, short, broken, damaged, or perforated husks should be shucked and stored separately in clean bins.

Good sanitation efforts, inspecting items, and keeping stored grain rooms fully ventilated can help to keep red flour beetles away from entering into food grains. The application of pesticides can be harmful because these pests are found in our food supply. Hence contacting experts for pest solutions at the first sign of an infestation is an effective way to protect food items from red flour beetles. Chemical control can be performed by applying carbamates, malathion, organophosphates, organochlorines, etc. These pesticides are used against many stored grain pests. New practices such as ozonation and organic pesticides have ensured grain preservation without quality loss and residue accumulation. Nitric oxide (NO), a newly discovered fumigant, has shown a great potential to control stored grain pests and has been described as a substitute for Methyl bromide.

### 4.7 Booklice (Psocoptera)

*Distribution:* Booklice (Psocoptera: Liposcelididae) is cosmopolitan in nature they are found all across the world, and mainly found in old books where they feed on the paste that is used in binding. These are very frequently found in grains, granaries, cupboards, and other solid food substances.

*Host range*: This pest generally feeds upon algae, fungi, lichen, organic detritus in nature, but they are mostly considered as stored grain pests as they feed on grains, bookbinding, etc.

*Bionomics:* The booklice or psocids are small, pale, louse-like, soft-bodied insects, with long slender antennae. Eggs of the pest are mainly laid in crevices or on foliage. Nymphs undergo molt for 6 times to reach adulthood. Length of booklice ranges from 1 to 2 mm.

*Damage symptoms*: Besides damaging books, they also sometimes infest food storage areas, where they feed on dry, starchy materials. Although, some psocids feed on starchy household products, the majority of psocids are woodland insects with little to no contact with humans, therefore they are of little economic importance. Booklice are scavengers and usually do not bite humans.

**Management of booklice:**

Cleanliness is one the most successful solution against the attack of booklice. Old books should be placed in cooler conditions, free from moisture and high temperature. Naphthalene balls should be placed on shelves and cupboards. Neem leaves should be placed inside bins or containers, containing food grains and other products.

### 4.8 Cereal mites (*Acarus siro* Linnaeus, 1758 Sarcoptiformes: Acaridae)

*Distribution:* Mites are microscopic and are cosmopolitan in distribution.

*Host range*: They mainly attack stored grain pests and rapidly increase their number within a short duration. Almost all plant and animal materials are directly or indirectly affected by these mites.

*Bionomics:* Mites are soft-bodied creatures, pale-colored, microscopic entities. They mainly attack stored grain pests and rapidly increase their number within a short duration. They can infest the crops either directly or indirectly. Mites shed their skin and dead bodies accumulate in fluffy bright brown masses beneath the sacks of food grain.

*Damage symptoms*: Decolouration or fading is the prime symptom of any mite attack.

**Management of mites:**

Biological control is one of the eco-friendly controlling strategies in which some predatory mites usually attack these grain mites and kill them. Manual method: Screening and fanning of grains will reduce their population and check the infestation level.

## 5. Management of stored grain pests

Insects are notorious to cause enormous damage to grains, pulses, and many other substances either directly or indirectly by consuming the seeds or seed products or through the accretion of exuviae, cadavers, and webbing. Hence making the stored products unfit and unhygienic for human consumption due to the accumulation of insect detritus [22]. Stored grain pests can infest almost all grains stored inside bins or containers as well as outside the fields and cause extensive post-harvest damage and pose a great threat to the economy. Once an infestation happens, a suitable environment is created for the attraction of other invasive insects for further loss. The most consumed and the most common stored food products are pulses and food grains in the tropical and sub-tropical regions of the world. In villages, about 70% of grains produced are stored in traditional objects such as earthen pots, steel drums, granaries, silos, gunny bags, baskets, and wooden buckets [23], such types of storage methods may often lead to loss of food grains and pulses [24]. Controlling strategy without synthetic pesticides requires an Integrated Pest Management (IPM) approach. The IPM approach is not based on a single component instead it is based on various components for the efficient management of insect pests. These components are described here.

### 5.1 Sampling

Sampling or pest monitoring is an important component of the IPM approach with which one can know the nature of pests in full detail so that suitable management tactics should be made accordingly. With the help of sampling, one can show the status of a pest, whether the population is below or exceeds the economic thresh hold level, and accordingly, physical, biological, or chemical approaches can be recommended. Some methods used during sampling processes of stored grain pests are:

#### *5.1.1 Sequential sampling method*

Sampling should be performed frequently after fixed intervals for best observations, and to gather information about population changes from time to time. For example, those stored grain pests stored above 20°C should be visited after a gap of 25–30 days. Grains held below 20°C permits sampling intervals to be longer than 25–30 days.

#### *5.1.2 Population density estimation method*

i. *Absolute estimation*: In this method number of insects per kilogram of grain or the number of moths per square meter are estimated.

ii. *Indirect estimation*: Here pests are marked with a specific dye and then recaptured after releasing into the stored grains, hence commonly referred to as mark-release-recapture methods. It can be easily performed with the help of suitably designed traps with baits.

iii. *Relative estimation*: This method can be done by counting all the insects caught in a sticky trap, food baited trap or perforated probe trap.

#### *5.1.3 Trapping method*

Trapping is a convenient approach in small as well as in the larger volumes of grain containing granaries and fields as well. Sticky traps, food-baited traps, pheromone traps, or perforated probe traps are used for monitoring processes.

### 5.2 Preventive measures

Infestation can be entirely prevented when some precautionary measures should be taken such as when harvesting crops should be as soon as ripe, dry, and then placed in clean, and hygienic deep bins for long storage. Newly harvested small grains are very much susceptible to infestation if stored unthrashed for longer times. Fresh and clean grains should never be stored in uncleaned, old bins and granaries containing waste grains, until they have been thoroughly cleaned, freed from the accumulation of waste materials and other substances harboring grain pests. The best storage places are solid, steel, concrete bins or containers for infestation-free and for longer storage. Traveling bags, bags used for transportation of grains, and any other products should be kept far away from the places where grains are stored.

### 5.3 Traditional practices

From time-to-time man has continuously developed various conventional methods to protect stored food grains from insect damage. Use of bamboo, wooden plank, straw, mud, bricks, cow dung, leaves of many plants, etc. is used by farmers to protect the quality as well as the number of stored foods until for further consumption [25]. One of the most common methods used by farmers was the use of plant parts or plant extracts as natural insecticides and repellents. During the 1850s, plants such as *Nicotiana tabacum*, *Derris elliptica*, *Lonchocarpus* spp., *Juglans regia*, *Azadirachta indica*, and *Chrysanthemum cineraria* folium was used for the plant extracts such as nicotine, derris dust, rotenone, Juglans, Azadirachtin, and pyrethrum respectively for controlling pests naturally [26]. The discovery of DDT by Paul Muller marked the advent of a new synthetic pesticide era since 1939.

### 5.4 Organic approach

The list of all usable, as well as prohibited controlling methods, are permissible in the national organic program (NOP). All the generic materials are enlisted under the national list of allowed and prohibited substances (NLAPS). It is mentioned in this that organic control should be the top priority, although synthetic insecticides can also be used upon specific approval. Certification to every producer, controller, processor, and handler is mandatory for authorized permissible processes. To reduce the infestation of stored grain pests, we should not make ourselves victims of pesticides. For this wearing the appropriate protective clothing and equipment during pest control to avoid contact to eyes, lungs, skin, and nose. Some control materials allowed in organic stored grains are:

*Bacillus thuringiensis:* This bacterium is used to control and prevent pests especially the larvae of Indian-meal moth. *B. thuringiensis* damages the digestive tract of caterpillars and lastly kills them.

*Pyrethrum:* Botanicals based on pyrethrin obtained from the flowers of *Chrysanthemum cinerariifolium* are primarily an insecticide that penetrates rapidly inside insect coverings, especially moths and larvae [27]. Empty containers should be treated before they are filled with grains for best results. Pyrethrum is an insecticide that is now universally accepted and is used to reduce pest damage in both tropical and temperate climatic conditions [28].

*Diatomaceous earth:* Aquatic organisms commonly referred to as diatoms have their skeletal system made of silica. The fossilized forms, having sharp edges of these diatoms are commonly referred to as diatomaceous earth. The sharp edges of diatomaceous earth can cut the pest's cuticle, resulting in death by injury and dehydration.

*Grain surface protectant:* Cleanliness is an essential factor to lower the damage rate. Containers and bins are filled only to the height of sidewalls, floors, and ceilings, and then cleaned through the fan system. Topdressing or simply capping the stored grains will act as a protective barrier from migrating insects into the bin.

*Grain rescue:* Infested grains should be treated initially with some treatments such as appropriate cooling and warming before being used for food to humans or any other animal.

*Detech and methyl eugenol:* These are promising treatments for the control of stored grain pests such as *S. granarius*, *S. zeamais*, (Coleoptera: Curculionidae), *Rhyzopertha dominica* (Coleoptera: Bostrychidae), *Tribolium confusum* (Coleoptera: Tenebrionidae). ME is a benzene-derived component, potential, and effective plant-derived synthetic chemical insecticide, and has a high knockdown effect because of the presence of more methoxy groups in it [29]. A synergistic effect of the combination of Diatomaceous Earth and Methyl Eugenol on *R. dominica*, *T. confusum*, *S granaries*, and *S. zeamais* has been reported by Erturk in 2021) [30].

### 5.5 Physical methods

Once the stored grains are infested, some physical methods used for the management of the stored grain pests are:

*Physical exclusion:* Fine perforated floors are made for the collection of dusty fines at the bottom that are susceptible to insect infestation.

*Grain distribution:* Grains inside granaries as well as inside bins and containers should be properly leveled. Improper leveling can create room for insect infestation and mold development due to the accumulation of moisture into the peaked-grained mass. To prevent the stored grains, removing grains from the old bins and redistributing them to other containers are very helpful.

*Temperature:* Based on the nature of pests, the temperature can be set either at low or high degrees. As some pests like moist and cool places and some like hot and humid regions. Most pests require temperatures above 60–70°F to reach damaging populations. Hence maintaining a cool temperature can reduce the excess loss. In certain situations, maintenance of −4°C to 0°C can kill many stored grain pests. *T. castaneum* and *Oryzaephilus mercator* are highly susceptible to cold, whereas *Trgoderma* spp., *Plodia interpunctella*, and *Ephestia* spp. are cold-tolerant species. Maintenance of very high temperatures can also be recommended but it has certain drawbacks such as it can crack, harden, and make brittle grains inside bins.

*Hermetic sealing:* To maintain a very low oxygen level inside stored grain containers this method is used. Low oxygen level causes suffocation to the pests and hence has insecticidal property.

*Aeration:* Air flown at the rate of 0.1–0.5 cubic feet per minute per bushel are used to cool stored grains. This low-volume airflow is an important component of the management of the stored grain pests. Grains remain uniform and to some extent in dry conditions as some grains are susceptible to pest attack in moist climates.

*Oxygen saturation:* Insects perform aerobic respiration for their survival. Maintenance of low $O_2$ atmosphere is blown at the base of the containers, bins, and other stored chambers, forcing out the existing $O_2$ rich atmosphere is a convenient method for infestation control.

*Sanitation:* All bins, containers, granaries, and other stored places should be cleaned using shovels, brooms, vacuum cleaners to clear old grains, dust, spider web, and fines from all cracks and crevices, windows, doors, vents, fans, elevators, and floor. Even a small old grain or fines left in any place where new grains are to be stored can harbor insects that can infest the whole grain. A suitable dryer should be used to remove the moisture from bins. To improve storability, especially in the case of wet, damaged, or immature grains, grain cleaners can be used frequently. Some grain cleaners are:

i. Gravity screens, with which grains are passed over a screen during handling.

ii. Rotary screens, are very effective cleaners that tumble and separate fines from grains.

iii. Perforated auger, is used to separate fines when the grain is conveyed over the auger.

iv. Aspirator pre-cleaner, removes all those materials which are lighter than grains such as dust, husk, awn, etc. by flowing air through it.

### 5.6 Conventional methods

Since the discovery of DDT, the use of synthetic insecticides was established as one of the most reliable and successful controlling agents worldwide [31]. No, any method is so rapid in action as synthetic chemicals are, hence farmers are indiscriminately using them without keeping any precautionary measures. Indiscriminate usage of synthetic insecticides has been characterized by several negative impacts such as resistance, toxicity, ozone depletion, adulteration, erratic supplies, and unavailability at critical periods [32].

*Fumigation:* Some most common fumigants used for treating stored grains in bulk are carbon tetrachloride, carbon disulphide, methyl bromide, phosphine, and hydrocyanic acid. However, methyl bromide is listed as an ozone-depleting compound in 1993 and has been phased out as the Montreal protocol [33]. Instead of methyl bromide, phosphine is used to protect the food grains as well as other products such as spices, cocoa beans, dried fruits, nuts, and even fresh fruits [34]. Fumigation is one of the convenient methods and the fumigants are heavier than the air and when applied on the top of the gas-tight bin of stored grains will penetrate down through the grains, killing the pests of any stage and without any harm to the grains. Fumigation should be done under a precautionary setup as these gases are highly inflammable and will explode if a fire is brought near them.

The insecticides should not be sprayed directly on food grains. Instead, treat the walls, dunnage materials, and ceilings of empty godown with malathion 50 EC 10 ml/L. Treatment of alleyways and gangways should be done with malathion 50 EC 10 ml/L. Spraying of malathion 50 EC 10 ml/L with @ 3 L of spray fluid/100 $m^2$ over the bags and other containers. In the case of flying insects and insects on surfaces, cracks, and crevices, a spray of pyrethrum seems good in action. Before storage, seed protectants like pyrethrum dust, carbaryl dust to mix with grains should be used. Ampoules of EDB should be used at 3 ml/quintal for wheat and pulses and 5 ml/quintal for rice and paddy. One of the most crucial fumigants for the control of stored grain pests is Phosphine. However, it may raise human safety concerns as phosphine is a poisonous gas and is known to be adsorbed in grains during fumigation. Nanoencapsulation of 25 kDa cysteine protease obtained from *Albizia procera* (ApCp) could be a promising ecofriendly tool of insect pest control.

### 5.7 Biological control of stored grain pests

Biological control includes the use of some predatory insects or microbes to control pests. Some beneficial insects such as hymenopterous parasites are attacking and killing many stored grain pests such as weevils, rusty grain beetle, maize weevil, confused flour beetle, lesser grain borer, Angoumois grain beetle, sawtooth grain beetle, and grain moths. Parasites are killing a large number of grain pests, but are not providing complete protection as the grains themselves have become very badly damaged. Small black wasp-like insects (*Seenopinus fenestral*) are also feeding and rearing on many stored grain pests and help to decrease their infestation. Larvae of a window-pane fly are thread-like white worm that does not harm grain but acts as predacious upon many grain pest larvae. Another parasitoid wasp *Theocolax elegans*, attacks primary grain pests whose immature stages are grown inside seed kernels, including the lesser grain borer, weevils, the drug store beetle, cowpea weevils, and the Angoumois grain moth [35]. In Europe, *Trichogramma* spp. has been used against moths in groundnut, wheat, bakeries as well as in warehouses and retail shops [36]. *Dinarmus* spp. is a larval and pupal parasitoid of *Bruchus* spp., *Callosobruchus* spp., *Bruchidius atrolineatus*, and *Acanthoscelides obtectus* in legume seeds.

Although, biological control has a limited scope in stored grain management, it is becoming an important part of an IPM strategy. The main drawbacks of this method are it is very expensive and maintenance of culture is a must for insect pest control.

### 5.8 Botanicals

Keeping in view the discouraging aspects of synthetic pesticides such as toxicity, non-biodegradability, costlier, residual effects, and many other harmful effects on plants, humans, and other animals urged experts to look for an alternative powerful, economically viable, and eco-friendly approach. One such suitable method is the use of plant volatile organic compounds that possess insecticidal properties. Some plants are bestowed by nature with several bioactive organic chemicals or phytochemicals, having a defensive role against insect pests. These organic bioactive compounds provide an odor for the repellence of insects and are volatile in nature, hence commonly referred to as plant volatile organic compounds (PVOC). Plant volatiles is the most viable options for effective control measures against various pests, having no or fewer threats to the environment [37, 38]. Secondary metabolites of plants such as terpenoids, phenols, and alkaloids [39], act as attractants or repellents, influences the growth and development, ecdysis, fertility, behavior, mating, adult emergence, and plays an important role in crop protection [40]. Especially developing countries are using botanicals to reduce the infestation level [41]. Phytochemicals can be used in the form of aqueous or solvent extracts, powders, slurries, volatiles, and oils or shredded segments [38, 42]. Hence, botanicals hold promise as an alternative to synthetic insecticides to lessen the negative impact of the pesticide on the environment. Botanicals, as well as their active ingredients and the target pest upon which these are used, are listed in **Table 1** as enlisted by Singh et al. [43].

Botanicals or phytochemicals have a different mode of action on insect pests and consist of aldehydes, ketones, alcohols, alkanes, and terpenoids. Their effect on pests in several manners are described below:

*Growth and development regulators:* Phytochemicals are known to change the physiology and behavior of insects by affecting the growth, development, and metamorphosis of insects. Reduction in weight of larvae, pupa, and adult, prolonged larval and pupal periods are also some irreversible changes caused by botanical extracts [44]. Growth and development inhibition of C. maculatus is happened on applying the essential oil extracted from the *Cymbopogon schoenanthus* of the Poaceae family [45]. Botanicals have such a power of action that they can also inhibit the development of eggs and other immature stages residing inside the grain kernels. Aqueous extract of *Xanthium strumarium* leaf was reported to show toxicity, repellency, inhibition of fecundity and adult emergence of the pests, and grains as well as cereals protection against C. chinensis [46].

*Hormone regulator:* Plant volatiles has juvenile effects as well, i.e., they are playing an active role in the hormonal regulation of insect pests. Extracts of water hyacinth contain a juvenile hormone analog that changes the reproductive behavior and causes abnormal molting and metamorphosis of stored grain pests [47]. *Solasodine* could inhibit molting and induce several morphogenic abnormalities in the larvae of *T. confusum* at the concentration of 1 μg/μl.

| Plant species | Family | Active ingredient | Target pest |
|---|---|---|---|
| *Acorus calamus* | Acoraceae | β-Asarone | *Sitophilus zeamais* |
| *Aloysia citriodora* | Verbenaceae | Citronellal and sabinene | *T. castaneum, T. confusum* |
| *A. polystachya* | Verbenaceae | Carvone and limonene | *T. castaneum, T. confusum* |
| *Artemisia annua* | Asteraceae | 1, 8-cineole | *T. castaneum* |
| *Baccharis salicifolia* | Asteraceae | 3-Carene | *T. castaneum, S. zeamais* |
| *B. salicifolia* | Asteraceae | β-Pinene | *T. castaneum, S. zeamais.* |
| *Brugmansia suaveolens* | Solanaceae | β-Pinene | *Zabrotes subfasciatus* |
| *Carum carvi* | Apiaceae | Carvone, Limonene, (E)-Anethole | *Rhyzopertha dominica*, *S. oryzae*, *S. zeamais* |
| *Chamaecyparis obtusa* | Cupressaceae | Bornyl acetate | *S. oryzae*, *C. chinensis* |
| *Chenopodium ambrosioides* | Amaranthaceae | Hexadecane | *T. castaneum*, *S. granarius* |
| *Cinnamomum aromaticum* | Lauraceae | Cinnamaldehyde | *T. castaneum*, *S. zeamais* |
| *Citrus* | Rutaceae | Limonene Eugenol | *T. castaneum*, *S. oryzae* |
| *Colocasia esculenta* | Araceae | 2, 3-Dimethylmaleic anhydride | *S. oryzae*, *T. castaneum*, *C. chinensis* |
| *Convolvulus arvensis* | Convolvulaceae | Hexadecanoic acid | *R. dominica, S. oryzae* |
| *Conyza dioscordis* | Asteraceae | Dicotlyhexanedioate | *T. castaneum, S. granarius* |
| *Coriander sativum* | Apiaceae | Linalool | *S. oryzae, R. dominica and C. pusillus* |
| *Cupressus lusitanica* | Cupressaceae | Umbellulone and α-pinene | *T. castaneum, A. obtectus, S. cerealella and S. zeamais* |
| *Duguetia lanceolata* | Annonaceae | 2,4,5-trimethoxystyrene | *Z. subfasciatus* |
| *Eucalyptus* spp. | Myrtaceae | α-Terpinene; 1, 8-Cineole; α-pinene | *S. oryzae* |
| *Eucalyptus saligna* | Myrtaceae | p-Cymene | *T. castaneum, S. oryzae* |
| *Evodia ruticarpa* | Rutaceae | Triterpenes | *T. castaneum, S. zeamais* |
| *Feoniculum vulgare* | Apiaceae | Phenylpropenes (E)-anethole Estragole (þ)-Fenchone | *S. oryzae, Lasioderma serricorne* |
| *Juniperus foestidissima* | Cupressaceae | Citronellol | *Trogoderma granarium* |
| *Lantana camara* | Verbanaceae | Coumaran | *S. oryzae, T. castaneum, R. dominica* |

| Plant species | Family | Active ingredient | Target pest |
|---|---|---|---|
| *Melaleuca cajuputi* | Myrtaceae | Terpine-4-ol Terpiniolene γ-Terpinene | *T. castaneum, S. oryzae, E. kuehniella, R. dominica* |
| *Mentha citrate* | Lamiaceae | Carvone, menthol, linalool, linalyl acetate | *T. castaneum, C. maculatus* |
| *Nardostachys jatamansi* | Caprifoliaceae | Aristolone | *T. castaneum, S. oryzae* |
| *Ocimum canum* | Lamiaceae | Linalool | *T. castaneum, S. granarius* |
| *Ocimum kilimandscharium* | Lamiaceae | Camphor | *S. oryzae* |
| *Pimenta racemose* | Myrtaceae | Linalool | *S. zeamais* |
| *Rosmarinus officinalis* | Lamiaceae | Camphor | *S. oryzae* |
| *Spent hops* | Lamiaceae | Xanthohumol | *S. granarius L., T. confusum and T. granarium* |
| *Tagetes filifolia* | Asteraceae | (E)-anethole and estragole | *T. castaneum* |
| *Thespesia populnea* | Malvaceae | Phenol | *C. maculatus* |
| *Zingiber officinale* | Zingiberaceae | 1, 8-cineole | *T. castaneum, S. zeamais* |
| *Z. officinale* | Zingiberaceae | β-Zingiberene | *T. castaneum* |

*Source: Singh et al. [43].*

**Table 1.**
*Plant volatile organic compounds used against stored grain pests.*

*Oviposition deterrent:* Chemicals that prevent or simply avoid insects from the process of oviposition is referred to as oviposition deterrent. Oviposition deterrents help to reduce the infestation level and offer the first line of defense against insect pests. An illusion is created by the plant volatiles to the gravid female pests, as these are involved in partially or completely preventing oviposition as well as the emergence of larvae from the laid eggs on stored grains [48, 49]. Garlic oil [50], 1,8 Cineole from Lamiaceae family [51], essential oils of *Eucalyptus citriodora*, *E. globulus*, *E. stageriana* [52], *Trachyspermum Ammi*, *Antheum graveolens*, *Nigella sativa*, are the oviposition deterrents, thereby reducing the viability of eggs and emergence of *Zabrotes subfaciatus*, *T. castaneum*, and *C. maculatus*. Finely powdered and dried leaves of *Ocimum* can completely suppress the oviposition of *Zabrotes subfascial* at 2%W/W, with an EC50, of 0.45% W/W [53]. The powdered form of *Chenopodium ambrosioides*, *Tagetesminuta*, *A. indica*, and *C. lusitanica*, applied at the rate of 1.5 kg/100 kg of *Phaseolus vulgaris*, was found to be the most effective in the mortality of Z. subfascial and A. objects [54]. Some phytochemicals obtained from *Laurus nobilis* and *Rosmarinus officinale* are causing egg mortality [55].

*Repellent activity:* Chemicals that protect stored grains, plants, or other products from insect damage by making the grains unattractive, offensive, or unpalatable to pests are commonly referred to as repellents. Repellents are especially more functional against various types of beetles, causing them to flee from the treated stored products. Compounds such as germacrol, pulegol, and α-terpineol isolated from *Baccharis salicifolia* and ar-turmerone isolated from *Curcuma longa* are potent repellents against *T. castaneum* and *S. zeamais* [56, 57]. Infestation by *T. castaneum* can be effectively controlled by different solvent extracts, acting as repellents, obtained from *Sphaeranthus indicus*, *Tephrosia purpurea*, *Prosopis juliflora*, *Cymbopogon flexuous, Cymbopogon winterianus*, and *C. martini*. Ethanolic extract of Acorus calamus is an active constituent Z-asarone, which acts as a strong repellent against *S. zeamais* [58]. Repellent used against *C. chinensis* is an essential oil obtained from *Callistemon lanceolatus* [59].

*Antifeedant:* Chemical substance that disrupts the feeding behavior of insect pests by making the treated stored grains unpalatable are referred to as antifeedant. The presence of certain chemicals in plants acts as a defensive mechanism to them. Antifeedants are eco-friendly, without ever disturbing the ecological balance, and do not kill the target but only prevent them from infestation. The deleterious effect of azadirachtin and neem seed extracts of *A. indica*, in antifeedant against various pests, is highly appreciable. Some essential oils acting as antifeedants are obtained from *Gaultheria procumbens*, against *S. oryzae* and *R. dominica* [60]. Some flavonoid compounds acting as antifeedants are Isoglabratephrin, −glabratephrin, tephroapollin-F, and lanceolatin-A, isolated from *Tephrosia apollinea*, against *T. castaneum*, *S. oryzae*, and *R. dominica*.

*Ovicidal effects:* Substances having the potential to kill eggs are considered to have ovicidal effects. This ovicidal property is also present in certain plants and is of great importance in the management of insect pests [61]. Plant volatiles sprayed on the stored grains could tremendously reduce the number of adult emergences because of toxicity or due to change in surface tension within the eggs [62]. Flavonoids isolated from *Calotropis Procera* provide 100% progeny suppression to the eggs of *C. chinensis* at 10 mg/ml concentration. An essential oil obtained from Anethum Sowa also shows ovicidal effects on eggs of *C. maculatus* [63]. From *Mentha ravens*, *Cinnamomum zeylanicum*, *Elettaria cardamomum*, *Syzygium aromaticum*, and *A. indica*, essential oils are extracted which has also ovicidal activity on the eggs of *T. castaneum* [64].

*Chemosterilents:* Substances that deprive insects of their ability to reproduce are known as Chemosterilents. Chemosterilents produce irreversible sterility without affecting the behavior of pests. These chemicals affect almost all stages of insect pests where eggs may not be oviposited, eggs not hatching, no pupation of larvae, and no adult emergence from these pupae [59]. Compounds possessing chemosterilent properties are asarone and 1,3,7-trimethylxanthine used against *C. chinensis* [65].

*Behavioral disturbance:* Behavioral changes are also induced by the plant volatiles, which can either stimulate or reduce insect mobility, and other physiological changes [66]. Some essential oils are known to inhibit acetylcholinesterase enzymes on insects' nervous system and also GABAergic is disrupted [67]. Essential oils of clove and Cinnamomum used on *S. zeamais* effects their locomotory and respiratory processes [68].

### 5.9 Pheromonal approach

Pheromones are ectohormones released by either male or female partners to change each other's behavior. Pheromones are now commercially available for around 20 species of stored grain pests [69]. Pheromones for *P. interpunctella*, *Lasioderma serricorne*, *T. castaneum, T. confusum, Trogoderma* variabile, are used frequently. These pheromones are placed inside suitable traps for their smooth release and maximum attraction as well as trapping processes. Proper installation of pheromone baited sticky traps within a building, granaries, and other flat landing sites plays an important role in the efficacy of pheromones used [70]. Sticky traps are placed on the sides of containers or the flat surface to capture crawling insects especially beetles, that eventually become stuck to the trapping surface. A trap with horizontal layers of corrugated cardboard was developed by [71] for beetles that walked through the tunnels of corrugations to reach a cup of oil into which they fell and suffocated.

## 6. Health and environmental hazards of pest control

Chemical insecticides are still considered as entomological weapons for the foreseeable future because of their wide host range, quick knockdown effects, easily availability to consumers. Their use in stored grain insect pests is still restricted as they pose threat to the health hazards and other environmental issues. Most of the chemical insecticides are carcinogenic and other health disorders [72]. The repeated application of insecticides leads to insecticide residues, secondary pest outbreaks. Recently the application of green synthesized nanoparticles is quite good and demonstrated satisfactory control against pulse beetle [73]. To overcome the issues of health and environmental hazards posed by chemical insecticides, workers are widely used other methods for their management. The satisfactory control has been observed when the product is not bulk and is being stored by physical and other methods which have been already discussed briefly in the chapter. Though, lot of botanicals have been applied to control a vast number of stored grain pests but satisfactory results are still wanted in large godowns especially in under-developed and developing countries. The villagers in these countries are still using the conventional methods and the damage levels are alarming and threatening. They even threaten the harvest which has been already harvested from different crops grown in the field and even protected conditions.

## 7. Conclusion

About 70% of stored grains are stored in villages in traditional methods. This creates an attractive atmosphere for the invasive pests to flourish. Especially developing countries have suffered a lot due to insect infestation. Integrated pest management is the best way to minimize the infestation status. Food supply to all human population, inhabiting any region of the world, seems less possible due to the alarming infestation rate of stored grains. IPM approach has many merits as it is the only method with which the quality as well as the number of stored products like grains, cereals, etc. are maintained to increase their economic value, as well as to provide nutritious food to even starved people.

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