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Stored Grain Pests and Current Advances for Their Management

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Abstract

During the off-season, 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
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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.

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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 (Olivier, 1789) Lepidoptera: Gelechiidae), maize weevil (Motschulsky, 1855 Coleoptera: Curculionidae), the Indian meal moth (*Plodia interpunctella* (Hubner, 1813) Lepidoptera: Pyralidae), the almond moths, (Walker) (Pyralidae: Lepidoptera), flour beetles (spp.), the flat bark beetles spp. (Coleoptera: Laemophloeidae) and the sap beetles 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 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 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 (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 [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.

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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.

1. : 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.
2. 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

. 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.

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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 ((Linnaeus, 1758) Coleoptera: Curculionidae)

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

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

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.

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 ((Linnaeus, 1763) Coleoptera: Curculionidae)

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.

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.

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 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.

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 ((Gyllenhal, 1838) Coleoptera: Curculionidae)

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

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

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.

It damages soft or damaged seeds and not the dry, hard, and uninjured seeds.

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

The coffee-bean weevil (Coleoptera: Brentidae) is cosmopolitan in nature.

Its main hosts are dried fruits, coffee, corn, cornstalks, seeds, and seed pods.

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.

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

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 ((Fabricius, 1792) Coleoptera: Bostrichidae)

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.

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.

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.

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 ((Horn, 1878) Coleoptera: Bostrichidae)

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

The main host is corn, wheat, rice, and millet.

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.

These are notorious for the emission of sweet, musty odor during an infestation.

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 (Olivier, 1789 Lepidoptera: Gelechiidae)

The name Angoumois is given to this pest because it was first noticed as a pest in the Angoumois province of France in 1773.

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.

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.

: 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 (Fabricius, 1775) Lepidoptera: Spingidae)

The wolf moth is cosmopolitan in distribution.

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.

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

: 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 (Boddie, 1850) Lepidoptera: Noctuidae)

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

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

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.

: 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 (Stainton, 1866) Lepidoptera: Pyralidae)

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.

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.

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.

: 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 (Walker, 1863) Lepidoptera: Pyralidae)

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

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

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.

: 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.

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 (Hübner, 1813) Lepidoptera: Pyralidae)

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

They are mainly damaging dried fruits, nuts, cashew nuts, almonds, etc.

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.

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 (Zeller, 1879) Lepidoptera: Pyralidae)

Being cosmopolitan in nature, the Mediterranean flour moth (Lepidoptera: Pyralidae) is found all around the world especially in countries that have temperate climates. It mainly prefers warm temperatures for rapid

development.

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.

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.

: 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 ((Linnaeus, 1758) Lepidoptera: Pyralidae)

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

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

: 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.

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

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 (Linnaeus, 1758 Coleoptera: Tenebrionidae)

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

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.

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.

: 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 (Fabricius, 1792 Coleoptera: Tenebrionidae)

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

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

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.

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

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 ((Linnaeus, 1758) Coleoptera: Tenebrionidae)

Cadelle is present in almost all parts of the world.

its main host is grain and grain products.

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.

: 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 ((Linnaeus, 1758) Coleoptera: Silvanidae)

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

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

: 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, flatfoot, 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.

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

4.6.3 Square-necked grain beetle ((Guérin-Ménéville, 1844) Coleoptera: Silvanidae)

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

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

: 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.

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

4.6.4 Foreign grain beetle ((Waltl, 1834) Coleoptera: Silvanidae)

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.

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

: 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.

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

4.6.5 Mexican bean beetle (Mulsant, 1850 (Coleoptera: Coccinellidae)

: 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.

: 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.

: 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.

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

4.6.6 Siamese grain beetle ((Klug, 1832) Coleoptera: Trogositidae)

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

: The main host is rice and cereals.

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.

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

4.6.7 Flat grain beetle ((Schoenherr, 1817) Coleoptera: Silvanidae)

Flat grain beetle is commonly found all over the world.

: Its main hosts are corn and wheat grains.

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.

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

4.6.8 Confused flour beetle (Jaacquelin du Val, 1868 Coleoptera: Tenebrionidae)

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

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

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.

: Being secondary pests they do not directly attack the grain but 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 ((Herbst, 1797) Coleoptera: Tenebrionidae)

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

: 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.

: 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.

: 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 (Waterhouse, 1880 Coleoptera: Tenebrionidae)

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

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

: 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 , 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.

: 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 ((Fabricius, 1801) Coleoptera: Tenebrionidae)

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

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

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

: Being secondary pests they do not directly attack the grain but 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 ((Fabricius, 1798) Coleoptera: Tenebrionidae)

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

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

: 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.

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

4.6.13 Small-eyed flour beetle ((Wissmann, 1848) Coleoptera: Tenebrionidae)

: Small-eyed flour beetle is cosmopolitan in nature.

: 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.

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.

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

4.6.14 Tobacco beetle or Cigarette beetle ((Fabricius, 1792) Coleoptera: Anobiidae)

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

: 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.

: 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 galleries. 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.

: 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 ((Linnaeus, 1758) Coleoptera: Anobiidae)

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

: 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.

: 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 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 ((Brahm, 1791) Coleoptera: Dermestidae)

: The Black carpet beetle is cosmopolitan in distribution.

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

: 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.

: 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 (Everts, 1898 Coleoptera: Dermestidae)

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

: 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.

: 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.

: 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 (sp. Coleoptera: Dermestidae)

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

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

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.

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

4.6.19 Museum beetle ((Linnaeus, 1761) Coleoptera: Dermestidae)

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

: This pest mainly prefers flour, cheese, or cocoa.

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.

: 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

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

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

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.

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

4.6.21 Black fungus beetle ((Fabricius, 1781) Coleoptera: Tenebrionidae)

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

: 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.

: 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.

: 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 ((Fabricius, 1792) Coleoptera: Nitidulidae)

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

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

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

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

4.6.23 Pulse beetle ((Linnaeus, 1758) Coleoptera: Chrysomelidae)

Pulse beetle is distributed throughout the temperate regions of the world.

is a frequent pest of all pulses, beans and grams.

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.

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.

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)

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.

: 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.

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.

: 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.

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 (Linnaeus, 1758 Sarcoptiformes: Acaridae)

Mites are microscopic and are cosmopolitan in distribution.

: 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.

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.

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

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 threshold 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

1. : In this method number of insects per kilogram of grain or the number of moths per square meter are estimated.
2. : 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.
3. : 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 , , spp., , , and 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:

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

Botanicals based on pyrethrin obtained from the flowers of 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].

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.

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.

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.

These are promising treatments for the control of stored grain pests such as , , (Coleoptera: Curculionidae), (Coleoptera: Bostrychidae), (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 , , and 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:

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

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.

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. and are highly susceptible to cold, whereas spp., , and 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.

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.

Air flow 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.

Insects perform aerobic respiration for their survival. Maintenance of low O₂ atmosphere is blown at the base of the containers, bins, and other stored chambers, forcing out the existing O₂ rich atmosphere is a convenient method for infestation control.

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:

1. Gravity screens, with which grains are passed over a screen during handling.
2. Rotary screens, are very effective cleaners that tumble and separate fines from grains.
3. Perforated auger, is used to separate fines when the grain is conveyed over the auger.
4. 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].

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 m² 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 (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 () 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 , 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, spp. has been used against moths in groundnut, wheat, bakeries as well as in warehouses and retail shops [36]. spp. is a larval and pupal parasitoid of spp., spp., , and 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, ecdisis, 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].

Plant species	Family	Active ingredient	Target pest
	Acoraceae	β-Asarone	
	Verbenaceae	Citronellal and sabinene	
	Verbenaceae	Carvone and limonene	
	Asteraceae	1, 8-cineole	
	Asteraceae	3-Carene	
	Asteraceae	β-Pinene	
	Solanaceae	β-Pinene	
	Apiaceae	Carvone, Limonene, (E)-Anethole	, ,
	Cupressaceae	Bornyl acetate	,
	Amaranthaceae	Hexadecane	,
	Lauraceae	Cinnamaldehyde	,
	Rutaceae	Limonene Eugenol	,
	Araceae	2, 3-Dimethylmaleic anhydride	, ,
	Convolvulaceae	Hexadecanoic acid	
	Asteraceae	Dicotylhexanedioate	
	Apiaceae	Linalool	
	Cupressaceae	Umbellulone and α-pinene	
	Annonaceae	2,4,5-trimethoxystyrene	
spp.	Myrtaceae	α-Terpinene; 1, 8-Cineole; α-pinene	
	Myrtaceae	p-Cymene	
	Rutaceae	Triterpenes	
	Apiaceae	Phenylpropenes (E)-anethole Estragole (p)-Fenchone	
	Cupressaceae	Citronellol	
	Verbanaceae	Coumaran	
	Myrtaceae	Terpine-4-ol Terpinolene γ-Terpinene	
	Lamiaceae	Carvone, menthol, linalool, linalyl acetate	
	Caprifoliaceae	Aristolone	
	Lamiaceae	Linalool	
	Lamiaceae	Camphor	
	Myrtaceae	Linalool	
	Lamiaceae	Camphor	
	Lamiaceae	Xanthohumol	

Plant species	Family	Active ingredient	Target pest
	Asteraceae	(E)-anethole and estragole	
	Malvaceae	Phenol	
	Zingiberaceae	1, 8-cineole	
	Zingiberaceae	β -Zingiberene	

Table 1.

Plant volatile organic compounds used against stored grain pests.

Source: 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:

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 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 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].

Plant volatiles have 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]. could inhibit molting and induce several morphogenic abnormalities in the larvae of at the concentration of 1 $\mu\text{g}/\mu\text{l}$.

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 , , [52], , , , are the oviposition deterrents, thereby reducing the viability of eggs and emergence of , , and . Finely powdered and dried leaves of can completely suppress the oviposition of at 2%W/W, with an EC50, of 0.45% W/W [53]. The powdered form of , , , and , applied at the rate of 1.5 kg/100 kg of , was found to be the most effective in the mortality of *Z. subfascial* and *A. objects* [54]. Some phytochemicals obtained from and are causing egg mortality [55].

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 and ar-turmerone isolated from are potent repellents against and [56, 57]. Infestation by can be effectively controlled by different solvent extracts, acting as repellents, obtained from , , , and . Ethanolic extract of *Acorus calamus* is an active constituent *Z*-asarone, which acts as a strong repellent against [58]. Repellent used against is an essential oil obtained from [59].

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 , in antifeedant against various pests, is highly appreciable. Some essential oils acting as antifeedants are obtained from , against and [60]. Some flavonoid compounds acting as antifeedants are Isoglabratephrin, -glabratephrin, tephroapollin-F, and lanceolatin-A, isolated from , against , , and .

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

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Control of Insects in Post-Harvest: Inert Dusts and Mechanical Means

References

- Bahr I., (1990). Reduction of stored product insects during pneumatic unloading of ship cargoes. pp. 1135–1144, in F. Fleurat-Lessard and P. Ducom (eds.) Proceedings 5th Int. Working Conf. Stored Product Protection. INRA/SPV Bordeaux, 2066 p.
Google Scholar
- Bailey S.W., (1962). The effects of percussion on insect pests in grain. J. Econ. Entomol. 55: 301–304.
Google Scholar
- Banks H.J., (1986). Impact, physical removal and exclusion for insect control in stored products. pp. 165–184, in E.J. Donahaye and S. Navarro. Proceedings 4th Int. Working Conf. Stored Products Protection, Tel Aviv, 668 p.
Google Scholar
- Banks H.J., Fields P.G., (1995). Physical methods for insect control in stored grain ecosystems. pp 353–409 in D.S. Jayas, N.D.G. White, and W.E. Muir (eds) Stored-grain ecosystems. Marcel Dekker, Inc., New York, 757 p.
Google Scholar
- Bridgeman, B., (1998). Application Technology and Usage Patterns of Diatomaceous Earth In Stored Product Protection. in Z. Jin, Q. Liang, Y. Liang, X. Tan and D. Guan (eds), Proceedings 7th Int. Working Conf. Stored Products Protection, Beijing, Sichuan Publishing House of Science and Technology, Chengdu, China, pp. 785–789.
Google Scholar
- Bryan J.M., Elvidge J., (1977). Mortality of adult grain beetles in sample delivery systems used in terminal grain elevators. Can. Entomol. 109: 209–213.
CrossRefGoogle Scholar
- Carlson S.D., Ball H.J., (1962). Mode of action and insecticidal value of a diatomaceous earth as a grain protectant. J. Econ. Entomol. 55: 964–969.
Google Scholar
- Desmarchelier J.M., Dines J.C., (1987). Dryacide treatment of stored wheat: its efficacy against insects, and after processing. Aus. J. Exper. Agr. 27: 309–312.
CrossRefCAS Google Scholar
- Dowdy A., Fields P.G. Heat combined with diatomaceous earth to control the confused flour beetle (Coleoptera: Tenebrionidae) in a flour mill. J. Stored. Prod. Res., in press.
Google Scholar
- Ebeling W., (1971). Sorptive dusts for pest control. Ann. Rev. Entomol. 16: 123–158.
CrossRefCAS Google Scholar
- Fields P.G., (1998). Diatomaceous earth: Advantages and limitations. in Z. Jin, Q. Liang, Y. Liang, X. Tan and D. Guan (eds), Proceedings 7th Int. Working Conf. Stored Products Protection, Beijing, Sichuan Publishing House of Science and Technology, Chengdu, China, pp. 781–784.
Google Scholar
- Fields P.G., Korunic Z., (2000). The effect of grain moisture content and temperature on the efficacy of diatomaceous earths from different geographical locations against stored-product beetles. J. Stored. Prod. Res., 36:1–13.
CrossRefGoogle Scholar

- Fields P.G., Muir W.E., (1995). Physical Control pp. 195–222, in B. Subramanyam and D.W. Hagstrum (eds.) Integrated Pest Management of Insects in Stored Products, Marcel-Dekker Inc., New York, 426 p.
Google Scholar
- Fleurat-Lessard F., (1985). Les traitements thermiques de désinfestation des céréales et des produits céréaliers : possibilité d'utilisation pratique et domaine d'application. Bull. Org. Eur. Prot. Plantes 15: 109–118.
Google Scholar
- Fleurat-Lessard F., (1989). La désinsectisation des stocks de farine. Ind. Céréales 60: 17–22.
Google Scholar
- Fusillier A., (1986). Forte diminution de la teneur en "filth" par une nouvelle conception du diagramme de nettoyage. Ind. Céréales 39: 21–25.
Google Scholar
- Glover T.J., (1997). Pocket Ref. Sequoia Publishing, Inc. Littleton, CO, USA, 554 p.
Google Scholar
- Golob P., (1997). Current status and future perspectives for inert dusts for control of stored product insects. J. Stored Prod. Res. 33: 69–79.
CrossRefGoogle Scholar
- International Agency for Research on Cancer (IARC), (1997). Silica, some silicates, coal dust and paraaramid fibrils. Volume 68, IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, Lyon, 506 p.
Google Scholar
- Joffe A., (1963). The effect of physical disturbance or "turning" of stored maize on the development of insect infestations I. Grain elevator studies. S. Afr. J. Agric. Sci. 6: 55–68.
Google Scholar
- Korunic Z., (1997). Rapid assessment of the insecticidal value of diatomaceous earths without conducting bioassays. J. Stored Prod. Research, 33: 219–229
CrossRefGoogle Scholar
- Korunic Z., (1998). Diatomaceous earths, a group of natural insecticides. J. Stored Prod. Res. 34:87–97.
CrossRefGoogle Scholar
- Korunic Z., Fields P.G., (1995). Diatomaceous earth insecticidal composition. US patent 5,773,017.
Google Scholar
- Korunic Z., Fields P.G., Kovacs M.I.P., Noll J.S., Lukow O., Demianyk C.J., Shibley K. J., (1996). The effect of diatomaceous earth on grain quality. Postharvest Biol. Technol. 9: 373–387.
CrossRefCAS Google Scholar
- Korunic Z., Ormesher P., (1998). Evaluation and standardised testing of diatomaceous earth. In Z. Jin, Q. Liang, Y. Liang, X. Tan and D. Guan (eds), Proceedings 7th Int. Working Conf. Stored Products Protection, Beijing, Sichuan Publishing House of Science and Technology, Chengdu, China, pp. 738–744.
Google Scholar
- Lagarde A., (1986). Limitation de l'infestation dans les moulins. Incidence sur la conception des machines et de l'installation. Ind. Céréales 39: 13–18.
Google Scholar
- Le Patourel G.N.J., Shawir M., Moustafa F.I., (1989). Accumulation of mineral dusts from wheat by *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). J. Stored Prod. Res. 25: 65–72.
CrossRefGoogle Scholar
- Macejski, M., Korunic Z., (1971). Trials of inert dusts in water suspension for controlling stored-product pests. Zastita Bilja (Plant Protection), Belgrade, 22:119–128.
Google Scholar
- Paliwal J., Jayas D.S., Muir W.E., White N.D.G., (1999). Effect of pneumatic conveying of wheat on mortality of insects. App. Eng. Agr. in press.
Google Scholar
- Quarles W., (1992). Silica gel for pest control. IPM Practioner, 14:1–11.
Google Scholar
- Quentin N.E., Spencer J.L., Milles J.R., (1991). Bean tumbling as a control measure for the common bean weevil *Acanthoscelides obtectus*. Entomol. Exp. Appl. 60: 105–109.
CrossRefGoogle Scholar
- Rees D., van Gerwen T., Hillier T., (1994). The effect of grain movement on *Liposcelis decolor* (Pearman), *Liposcelis bostrychophila* Badonnel (Psocoptera: Liposcelidae) and *Cryptolestes ferrugineus* (Stephens) (Coleopter: Cucujidae) infesting bulk-stored barely. pp. 1214–1219, in E. Highley, E.J. Wright, H.J. Banks and B.R. Champ (eds.) Proceedings 6th Int. Working Conf. Stored Product Protection. CABI International, Wallingford, U.K., 1274 p
Google Scholar
- Sigaut F., (1978). Les réserves de grain à long terme. Techniques de conservation et fonctions sociales dans l'histoire. Maison des Sciences de l'Homme, Paris et Université de Lille III, 202 p.
Google Scholar
- Stratil H., Wohlgenuth R., Bolling H., Zwingelberg H., (1987). Optimization of the impact machine method of killing and removing insect pests from foods, with particular reference to quality of flour products. Getreide, Mehl Und Brot 1987; 41:294–302.
Google Scholar
- Vallery, (1839). Description de l'appareil à conserver les grains, dit grenier mobile. Bull. Soc. Enrouagement Indust. Natle. 38: 123–131.
Google Scholar
- White N.D.G., Leesch J.G., (1995). Chemical Control pp. 287–330 in Subramanyam, B, and Hagstrum, D, Editors, Integrated management of insects in stored products: Marcel Dekker Inc., New York, 425 p.
Google Scholar

- White N.D.G., Jayas D.S., Demianyk C.J., (1997). Movement of grain to control stored-product insects and mites. *Phytoprotection* 78: 75–84.

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More Stored-Product Entomology Books

The following list adds 67 stored-product entomology books, many not in English, to those listed in *Stored-Product Insect Resource*, *Atlas of Stored-Product Insects and Mites*, and *Chapter 1 of Stored Product Protection S156* (<http://www.ksre.ksu.edu/bookstore/Category.aspx?id=521&catId=522&Page=2>).

Al-Iraqi, R.A. 2010. *Grains and Stored Product Pests and Methods of Their Control*. Mosul Univ. Press, pp. 616. (In Arabic)

Athanassiou, C. G. and F. Arthur (eds.) 2018. *Recent Advances in Stored Product Protection*. Springer, Berlin, Heidelberg

Bagheri-Zenouz, E. 1984. *Methods of Control of the Pests of Stored Products and Quarantine*. Adib Publishing Co., Tehran. 252 p. (Persian)

Bagheri-Zenouz, E. 1996. *Les Animaux Nuisibles aux Produits Entrepôts. Volume 1: Les Coleopteres Depredaterures des Produits Alimentaires et Industriels*. (Pests of Stored Products. Volume 1: Injurious Coleoptera of Food and Industrial Products) Sepehr Publishing Center, Tehran. 309 p.

Berger, H. K., and P. P. Kohlhaas. 1988. *Vorrats- und Materialschädlinge* (Storage and material pests). Bundesministerium für Land- und Forstwirtschaft, Wien.

Bhargava, M. C., & Kumawat, K. C. 2010. *Pests of Stored Grains and Their Management*. New India Publishing, New Delhi.

Brandt, H., and M. Laubmann. 1955. *Vorrats- und Materialschädlinge* (Storage and material pests). Obst- u. Gartenbauverlag, München.

Butler, Edward Albert 1893. *Our Household Insects: An Account of the Insect-pests Found in Dwelling-houses*. Longmans, Green, and Company.
<https://books.google.com/books?hl=en&lr=&id=jjIIAQAAIAAJ&oi=fnd&pg=PA1&dq=%22Ptilinus%20pectinicornis%22+&ots=lqQcu3T242&sig=PLq5Hd37AvMvp4JtmwwbOeaY8dg#v=onepage&q=%22Ptilinus%20pectinicornis%22&f=false>

Calderon, Moshe and Rivka Barkai-Golan. 1990. *Food Preservation by Modified Atmospheres*. CRC Press, Boca Raton, Florida

Champ, B. R. and E. Highley. 1986. Pesticides and humid tropical grain storage systems: proceedings of an international seminar, Manila, Philippines, 27-30 May 1985. *ACIAR Proceedings* No. 14, 364 p.

Chao, Y., L. Hung-Shing, and K. Ging-Ya. 1980. *Surveys of Chinese Stored Products Insect Pest Fauna*. Agriculture Press, Beijing, China.

Chen, Q. Z., and J. G. Huang. 1985. *Album of Warehouse Insects*. Chinese Scientific Press, Beijing, China.

Chen, Yung-Chang, Lee Hung-Shung and Kao Ging-Ya 1980. *Survey of Chinese Stored Product Insect Pest Fauna*. Agricultural Press, Beijing, China

Chen, Y. X. 1985. *Warehouse Pests* (Supplement Edition). Chinese Agricultural Press, Beijing, China.

Delobel, A. and M. Tran. 1993. Les Coleopteres des denrees alimentaires entreposes dans les regions chaudes. *Faune Trop.* 32: 1-425. Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), Paris. (The Coleoptera of food stuffs originating in hot areas) (in French)

Dick, K. M. 1987. *Pest Management in Stored Groundnuts*. Patancheru, India : ICRISAT 28 p.

Domenichini, G. 1996. *Protezione degli alimenti. Contaminazione biologica e sanità ambientale nelle industrie alimentari*. (Food protection. Biological contamination and environmental health in the food industry) EtasLibri, Milano, 235 p.

Fujii, K., A. M. R. Gatehouse, C. D. Johnson, R. Mitchell and T. Yoshida. 1990. *Bruchids and Legumes: Economics, Ecology and Coevolution*. Proceedings of 2nd International Symposium on Bruchids and Legumes, September 6-9, 1989, Okayama, Japan.

Gelosi, Attilio and Stüss, Luciano 1991. *Insetti e acari dei cereali in magazzino*. (Insects and mites of cereals in storehouses) Edagricole, Edizioni Agricole, Bologna, Italy 120 pp.

- Gelosi, Attilio and Luciano Suss. 1995. Un pastificio sano per un prodotto di qualità : manuale dei rischi, controllo e sanificazione per l'industria della pasta. (A pasta healthy for a quality product: Manual of risks, control and sanitation for the pasta industry) Bologna : Avenue Media ; Roma ; Istituto Italiano Paste Alimentari, 181 p.
- Ghosh, S. K. and S. L. Durbey 2003. Integrated management of stored grain pest. Lucknow : International Book Distributing Co.
- Heinze K. 1974. Leitfaden der Schädlingsbekämpfung. Band.IV. Vorrats- und Materialschädlinge (Vorratsschutz). Guide for pest control. Band.IV. Storage and material pests (storage protection). Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart., 348 pp
- Herf, Adolf and Hermann Stötter. 1951. Wollschädlinge und ihre moderne Bekämpfung (Wool pests and their modern fight against). Farbenfabrik Bayer Aktiengesellschaft, Leverkusen, Germany.
- Jansson, R. K. and K. V. Raman 1991. Sweet Potato Pest Management: a global perspective. Westview Press, Boulder.
- Kemper H. 1939. Die Nahrungs- und Genussmittelschädlinge und ihre Bekämpfung. The food and beverage pests and their control. Dr. Paul Schöps, Leipzig, 266 pp.
- Khare, B.P. 1994. Stored grain pests and their management, 1st ed. Kalyani Publishers, New Delhi.
- Khare, B. P. 2004, 2011. Stored grain pests and their management. Ludhiana, India: Kalyani Publishers. 314 p.
- Kong, Y. 1986. Pests in Storage. Chinese Finance and Economics Publisher, Beijing, China
- Kono, Tunemori. 1951. Theory and Practice of Storing Grain. Kawaide Syobo, Tokyo. (Cited in Kiritani, K. 1965. Biological Studies on the Sitophilus Complex (Coleoptera: Curculionidae) in Japan. J. Stored Prod. Res. 1: 169-176.)
- Labeyrie, V. (ed.) 1981. The ecology of Bruchids Attacking Legumes (Pulses). Proceedings of the International Symposium held at Tours (France), April 16-19, 1980. Series Entomologica 19, Junk, Hague.
- Lale, N.E.S. 2002. Stored Product Entomology and Acraology in Tropical Africa. Mole Publications, Maiduguri, Nigeria 204pp.
- Lepesme, P. 1944. Les Coléoptères des denrées alimentaires et des produits industriels entreposés. Paul Lechevalier, Paris.
- Li, F. 2002. Zhongguo chi mu zhi (Psocoptera of China). Ke xue chu ban she/Science Press, Beijing
- Li, L. and W. Zhu. 2009. Stored Product Entomology. Chongqing Publishing House, Chongqing
- Li, Long-shu, and Yun-rui Li. 1988. Acarology. Chongqing Publishing House, Chongqing, China. 520 pp.
- Liu, Yongping and Zhang, Shengfang 1986. Chinese dermestid beetles associated with stored products (in Chinese, Zhongguo cang chu pin pi du hai chong). Agriculture Publishing House/ Nong Ye Chu Ban She, Beijing, China.
- Lorini, Irineu, Francisco Carlos Krzyzanowski, José de Barros França-Neto, Ademir Assis Henning and Fernando Augusto Henning 2015. Manejo Integrado de Pragas de Grãos e Sementes Armazenadas. (Integrated Management of Grain Pests and Stored Seeds) Embrapa, Brasília, DF, Brazil 81 p.
- Lorini, Irineu; Lincoln Hiroshi Milke and Vildes M. Scussel. 2002. Armazenagem de grãos. (Grain storage) Instituto de Bio Geneziz (IBG), Campinas, SP (Brazil), 983 p.
- Maier, Dirk E. 2020. Advances in postharvest management of cereals and grains. Burleigh Dodds series in Agricultural Science Number 88, Burleigh Dodds Science Publishing, Cambridge, UK
- Narayanasamy, P., S. Mohan and J.S. Awaknabar. 2009. Pest Management in Store Grains. Proceedings National Symposium entitled Towards pest free grains and seeds in storage, 26-27 March, 2007, Department of Entomology, Annamalai University, Tamil Nadu, India. Satish Serial Publishing House, Delhi, India. 272 p.
- Odeyemi O. O. and A. M. Daramola. 2000. Storage practices in the tropics. Vol. 1: Food Storage and Pest Problems. First Edition, Dave Collins Publication, Nigeria 235 p.
- Otiya, T.I. and Lale, N.E.S. 2001. Pests of Stored Cereals and Pulses in Nigeria-biology, ecology and control. Nigeria: Dave Collins Publications. 174 pp.
- Osugi, Fabian. 1985. Outlines of stored products entomology for the tropics. Enugu, Nigeria : Fourth Dimension Publishers.
- Pachecco, I. A. and D. C. de Paula. 1995. Insetos de graos armazenados – identificacao e biologia. Campinas, Brazil, Fundacao, Cargill, 228 p. (Cited in Cristina, M., Z. DePaula, F. A. Lazzari and S. M. Lazzari. 1999. Insect monitoring outside paddy rice grain storage facilities in southern Brazil. p.532-1533. In 7th IWCSP).
- Perez-Mendoza, Joel. 1993. Insectos de Granos Almacenados: Biología, Danos, Deteccion y Combate. (Stored Grain Insects: Biology, Damage, Detection and Combating) Centro de Investigacion Regional del Centro Campo Experimental Bajío, Celaya, Gto., Mexico.
- Popov, V. I. 1939. Warehouse insect pests in Bulgaria and their control. Sofia. 195 p.
- Portchinsky, I. A. 1913. Insects injurious to grain in stores and warehouses. Memoirs of the Bureau of Entomology of the Scientific Committee of the Central Board of Land Administration and Agriculture, St. Petersburg. Review of Applied Entomology A 2: 39-41 (1913)
- Prakash, A., J. Rao, I. C. Pasalu and K. C. Mathur. 1987. Rice storage and insect pest management. Delhi : B.R. Pub. Corp., 1987. 337 pages
- Prakash, A., J. Rao, D. S. Jayas and J. Allotey. 2003. Insect pests of stored products: a global scenario. Applied Zoologists Research Association (AZRA), Central Rice Research Institute, Cuttack, India.
- Pruthi, H. S.: Singh, M. 1950. Pests of stored grain and their control. Indian J. Agric. Sci. 18: 1-88 (3rd Ed.)
- Reichmuth, C., M. Scholler, and C. Ulrichs. 2007. Stored product pests in grain: morphology, biology, damage, control. AgroConcept, Bonn, Germany.
- Rosentrater, Kurt A. 2022. Storage of Cereal Grains and Their Products. 5th edition, Woodhead Publishing, Elsevier, UK and AACC International Press
- Stejskal, Vaclav 1998. Ochrana pred potravinovými a hygienickými škodci (Protection against food and hygiene pests) Vysehrad, Prague
- Stejskal, Vaclav and Cornel Adler 1997. Fumigace A Rizene Atmosféry (Fumigation and controlled atmosphere). Association of disinfection, disinsection, deratization workers in the Czech Republic, Prague
- Süss, Luciano. 1988. Gli infestanti delle derrate conservate e delle industrie alimentari. (The storage pests infestation and food industries) MoEdCo Edizioni, Milano, 304 pp.
- Süss, Luciano 1990. Gli intrusi. Manuale di entomologia urbana. (The intruders. Handbook of Urban Entomology) Edagricole, Bologna, Italy. 226 pp.
- Süss, Luciano and D.P. Locatelli. 2001. I parassiti delle derrate. Riconoscimento e Gestione delle Infestazioni nelle Industrie Alimentari. (The pests of food. Recognition and Management infestations for the Food Industry.) Calderini Edagricole, Bologna, Italy 363 pp.
- Süss, Luciano. 2004. Gli intrusi. Manuale di entomologia urbana. (The intruders. Handbook of Urban Entomology) L'Informatore Agrario 179 pp.
- Trematerra, Pasquale and Luciano Suss. 2007. Prontuario di entomologia merceologica e urbana : con note morfologiche, biologiche e di gestione delle infestazioni. (Handbook of commodity and urban entomology: with notes morphological, biological and management of infestations) Aracne Editrice, Roma, 154 p.
- Vukasovic P., Stojanovic., Šenborn A. (Redakcija) 1972. Štetoèine u skladištima. Biología i suzbijanje. (Pests in warehouses. Biology and control). Novi Sad. 540 pp.
- Wang, Dianxuan; Xuguang, Bai; Zhou,Yuxiang and Zhao, Yingile. 2008. Illustrated book of stored grain insects in China. China National Publications Import & Export (Group) Corp. (CNPI)
- Yanucci, D. 1989. Control de plagas: post cosecha de granos y semillas. Artes Graficas Mantova, Buenos Aires, Argentina. (Pest management: post harvest grain and seed)
- Yanucci, D. A., Lazzari, F., and Cotto, H. 2002. Control Integrado. Insectos, ácaros, hongos y roedores en postcosecha de granos y semillas. (Integrated Control. Insects, mites, fungi and rodents postharvest grain and seed) Granos, Buenos Aires, Argentina
- Zacher F. 1927. Die Vorrats-, Speicher- und Materialschädlinge und ihre Bekämpfung. (The supply, storage and material pests and their control. Paul Parey Berlin, 366 pp.

Zakladnoi, Gennadii Alekseevich and V. F. Ratanova. 1973. Vrediteli Khlebnykh Zapasov i Mery Borby s Nimi. Kolos Publishers, Moscow (Translated 1986 Stored-grain pests and their control. New Delhi : Published for the United States Dept. of Agriculture and the National Science Foundation, Washington, D.C., by Amerind Publishing Co. Pvt. Ltd., 268 pages)

Zakladnoi, G.A. and V.F. Ratanova. 1987. Vrediteli Khlebnykh Zapasov i Mery Borby s Nimi. (Stored-grain pests and their control) translator, Indira Nair ; general editor, V.S. Kothekar. Rotterdam : A.A. Balkema.

Zhang, S., and Y. Liu. 1998. Zhongguo chu cang wu jia chong (Beetles associated with stored products in China). Zhongguo nong ye ke ji chu ban she/ Z Hongguo Agricultural Science and Technology Press, Beijing Shi.

Zhang, S. 2004. Chu cang wu jia chong jian ding (Identification of beetles associated with stored products). Zhongguo nong ye ke ji chu ban she/Beijing shi: Z Hongguo Agricultural Science and Technology Press, Beijing Shi.

Zhang, S., H. Chen, and G. Xue. 2008. Atlas of beetles associated with stored products (in Chinese). Chinese Agricultural Science and Technology Press/ Zhong guo nong ye ke xue ji shu chu ban she, Beijing

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Stored-Product Entomology Courses

Hagstrum and Subramayam (2009) reported that stored-product entomology courses have been or are currently offered at land grant universities in four states in the United States and in at least nine other countries. See Additional Literature for overview of recent literature on stored product insects.

Hagstrum, D. W., and Bh. Subramanyam. 2009. A review of stored-product entomology information sources. Amer. Entomol. 55: 174-183.

Nicoli Aldini Rinaldo is now teaching the Insect of Stored Products course at School of Agriculture and Veterinary Medicine, Universita di Bologna, Italy.

<http://www.agricultureveterinarymedicine.unibo.it/en/programmes/course-unit-catalogue/course-unit/2008/158274> . For more information on the course “Protecting foods from pests” by Marco Pagani at Universita Parma, Italy see webpage <http://en.unipr.it/ugov/degrecourse/25218>.

In addition to these courses, a course entitled “Pests of Stored Products” was offered by Panagiotis A. Eliopoulos to undergraduate students between 2000 and 2011 at Technological Educational Institute of Larissa School of Agriculture in Greece. Approximately, 1000 students (70-100 every semester) took the course. Pests of stored products are now covered in their Applied Entomology course. Post-harvest safety of stored agricultural products and food at University of Thessaly, a post-graduate course, is taught by Christos G. Athanassiou with 70 students per year.

The following undergraduate courses covering stored-product pests are also offered in Greece:

Pests of Annual Crops and Stored Products at Technological Educational Institute of Thessaloniki taught by Smaragdi Ch. Papadopoulou with 150 students per year.

Post-Harvest Pests and Diseases at Technological Educational Institute of Ionian Islands taught by Andreas Vitoratos and Charilaos Giotis.

Agricultural Entomology & Zoology at Agricultural University of Athens taught by Constantine Th. Buchelos prior to 2008 and then Nickolas G. Kavallieratos with 150 students per year.

Pests of Stored Products and Sanitation Insects at Democritus University of Thrace taught by Georgios Broufas and Maria Pappa.

Protection of Stored Products at University of Thessaly taught by Christos G. Athanassiou.

Pests of Stored Products at Aristotle University of Thessaloniki taught by Demetrius Koveos and Nikos Koulousis.

A Course entitled “Biology of Pests of Stored Products and Their Control” is taught by Mrs A.C Adeyemo in the Deptment of Biology, Federal University of Technology, Akure, Nigeria. See <http://www.futa.edu.ng/futacms/admin/attachments/BIO%20411.pdf>

Florence M'mogi Olubayo has taught the course “Post harvest Pests and Diseases” from 2007 to the Present in the Department of Plant Science and Crop Protection, University of Nairobi, Nairobi, Kenya. See https://profiles.uonbi.ac.ke/olubayo/files/curriculum_vitae_prof._f.m.olubayo_april_2013.pdf

Girish, G. K. 1987. Training programmes on scientific storage of foodgrains offered by Department of Food, Government of India. Bulletin of Grain Technology 25(1): 70-84 describes several courses offered in India.

We more recently discovered that Don C. Peters taught a stored-product entomology course at Oklahoma State University in 1978 and 1980, and Gerrit Cuperus taught it in 1996. More recently, George Opit and Brad Kard have taught in odd years Postharvest, Structural and Urban Arthropod Pests (ENTO 3021) at Oklahoma State University, Stillwater, OK.

Also, we more recently learned that George Dean began teaching a course in stored-product entomology (called Milling Entomology) at Kansas State University in 1914, primarily for undergraduate milling and baking students. Donald A. Wilbur began teaching the course in 1949. In 1971 the College of Agriculture made major revisions in the curricula and the course was no longer required for milling students. Wilbur began teaching the current Insects of Stored Products course in 1956.

Every other year, between 2002 and 2010, David Hagstrum taught Insects of Stored Products (ENTOM 805) at Kansas State University, Manhattan, KS. Every other year, between 2012 and 2020, David Hagstrum and Tom Phillips co-taught the course. A textbook and three other books were published to keep the course up to date (Hagstrum and Subramayam 2006, 2009; and Hagstrum et al. 2012, 2013).

The following describes the Insects of Stored Products course offered at Kansas State University.

Schedule:

Week 1 Introduction (Ch1 textbook and Ch2, Techniques p. 23-25)

Week 2 Mobility (Ch3 textbook and Ch2 Techniques p. 30-37)

Week 3 Sources of Infestation (Ch4 textbook)

Week 4 Sampling (Ch5 textbook and Ch2, Techniques p. 26-30)

Week 5 Life History (Ch6 textbook)

Week 6 Population Growth (Ch7 textbook)

Week 7 Decision Aids (Ch8 textbook and Ch9 Economics)

Week 8 Biological Control (Ch11 textbook)

Week 9 Aeration (Ch12 textbook)

Week 10 Sanitation and Exclusion (Ch13 textbook)

Week 11 Extreme Temperatures (Ch14 textbook)

Week 12 Impact and Removal (Ch15 textbook and Ch16, Ionizing Radiation)

Week 13 Residual Insecticides (Ch17 textbook and Ch10, Resistance)

Week 14 Fumigants and Modified Atmospheres (Ch18 textbook)

Week 8 Regulatory Control (Quarantine Ch 26 in KSU S156)

Student Learning Outcomes (SLOs) for ENTOM 805 include:

- 1) Become familiar with the biology, ecology and behavioral diversity of stored product insects and mites
- 2) Understand monitoring-based IPM in relation to variables in the broad environment, variation in population dynamics, use of predictive models at all levels, and management options ranging from prevention to population suppression methods.
- 3) Appreciate the need for understanding foundational and current scientific literature, as well as regulatory and economic issues, in the design and implementation of IPM programs in the US and elsewhere in the world.

Course Design:

Stored product insects and mites can damage stored grains and other commodities with serious economic losses and food security and safety issues. ENTOM 805 is targeted to graduate students in Entomology, related agricultural sciences and the life sciences who desire knowledge of this economically important group of arthropod pests that also serve as excellent examples for biological study. The class will meet twice a week to discuss a series of topics. Discussion of topics will be lead by a different student each class meeting. Local field trips and laboratory meetings will familiarize students with insect identification, grain storage and processing facilities, sampling and fumigation. Grading is based on class participation, discussions and quizzes taken at the beginning, and revised at the end, of each class.

Textbook:

Hagstrum, D. W. and Bh. Subramanyam. 2006. Fundamentals of Stored Product Entomology, AACC International, St. Paul, MN

Supplemental Chapters:

Hagstrum, D. W., T. W. Phillips and G. Cuperus (eds.). 2012. Stored Product Protection. Kansas State University S156 at <http://entomology.k-state.edu/departments-info/publications/stored-product-protection.html>

A comprehensive website for additional readings and information is: <https://storedproductinsects.com/biology/additional-literature/>

A section of that website for Molecular Identification of storage insects is here:
Molecular species identification

Websites:

<http://www.refworks.com/refshare2?site=015251129867200000/159211343138040369/SP%20Pest%20Mtg>

<https://www.storedproductinsects.com>

http://www.ksre.ksu.edu/grsc_subi/speir/

<http://bru.gmpcr.ksu.edu/proj/iwscpp/>

On Reserve at Library:

Hagstrum, D. W., and Bh. Subramanyam. 2009. Stored-Product Insect Resource. AACC International, St. Paul, Minnesota.

Hagstrum, D. W., T. Z. Klejdysz, Bh. Subramanyam and J. Nawrot. 2013. Atlas of Stored-Product Insects and Mites. AACC International, St. Paul, Minnesota.

Grading:

1. Participation in discussion 40%
2. Preparedness as discussion leader 20%
3. Weekly quizzes 20%
4. Revision of chapter 20% (due May 15)

Recommended Readings:

Ch. 1 Introduction

American Institute of Baking. 1979. How to handle regulatory inspections. p. 19-21. In Basic Food Plant Sanitation Manual. American Institute of Baking, Manhattan, Kansas.

Arbogast, R. T., S. R. Chini and P. E. Kendra. 2005. Infestation of stored saw palmetto berries by *Cadra cautella* (Lepidoptera: Pyralidae) and the host paradox in stored-product insects. Florida Entomol. 88: 314-320.

Arthur, F. H. and T. Rogers. 2003. Legislative and regulatory actions affecting insect pest management for postharvest systems in the United States. p. 435-438. In Credland, P. F., D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley [eds.]. Advances in Stored Product Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, York, United Kingdom. CAB International, Wallingford, United Kingdom.

Bailey, J. E. 1992. Terminal elevator storage. p. 157-182. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Buckland, P. C. 1981. The early dispersal of insect pests of stored products as indicated by archaeological records. J. Stored Prod. Res. 17: 1-12.

Cowley, R. J., D. C. Howard and R. H. Smith. 1980. The effect of grain stability on damage caused by *Prostephanus truncatus* (Horn) and three other beetle pests of stored maize. J. Stored Prod. Res. 16: 75-78.

Freeman, J. A. 1974. A review of changes in the pattern of infestation in international trade. EPPO Bull. 4: 251-273.

Gecan, J. S. 2002. Food defect action levels, pp. 77-86. In Y. H. Hui, B. L. Bruinsma, J. R. Gorham, W. K. Nip, P. S. Tong and P. Ventresca (eds.), Food Plant Sanitation. Marcel Dekker, Inc., New York, N. Y.

Hagstrum, D. W., T. Z. Klejdysz, Bh. Subramanyam and J. Nawrot. 2013. Atlas of Stored-Product Insects and Mites. AACC International, St. Paul, Minnesota. (book)

Hagstrum, D. W. and T. W. Phillips. 2017. Evolution of Stored-Product Entomology: Protecting the World Food Supply. Annu. Rev. Entomol. 62: 379-397.

Hagstrum, D. W., C. Reed and P. Kenkel. 1999. Management of stored wheat insect pests in the USA. Integrated Pest Management Review 4: 127-142.

Hagstrum, D. W. and Bh. Subramanyam. 2009. Stored-Product Insect Resource. AACC International, St. Paul, Minnesota. (book)

Hill, D. S. 2002. Types of Damage. p. 71-78. In Pests of Stored Foodstuffs and Their Control. Kluwer Academic Publishers, Boston.

Howe, R. W. 1991. Origins of insects as storage pests. p. 13-16. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.

Olsen, A. R., T. H. Sidebottom and S. A. Knight. 1996. Fundamentals of Microanalytical Entomology, a practical guide to detecting and identifying filth in foods. CRC Press, Boca Raton, Florida (book)

Reed, C. 1992. Development of storage techniques: a historical perspective. p. 143-156. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Ch. 2 Techniques

- Borgemeister, C., A. Tchabi and D. Scholz. 1998. Trees or stores? The origin of migrating *Prostephanus truncatus* collected in different ecological habitats in southern Benin. *Entomol. Exp. Appl.* 87: 285-294.
- Camara, M., C. Borgemeister, R. H. Markham and H. M. Poehling. 2003. Electrophoretic analysis of the prey spectrum of *Teretrius nigrescens* (Lewis) (Col., Histeridae), a predator of *Prostephanus truncatus* (Horn) (Col., Bostrichidae), in Mexico, Honduras and Benin. *J. Appl. Entomol.* 127: 360-368.
- Ching'oma, G. P. 2006. Spatial distribution of movement of the lesser grain borer, *Rhyzopertha dominica* (F.). PhD Thesis, Kansas State University, Manhattan, KS
- Halstead, D. G. H. 1963. External sex differences in stored-products Coleoptera. *Bull. Entomol. Res.* 54: 119-134.
- Howe, R. W. 1991. Principles of rearing stored-product insects and of insectary management. p. 535-544. In J. R. Gorham (ed.) *Ecology and Management of Food-Industry Pests*, Assoc. Official Analytical Chem., Arlington, Virginia.
- Perez-Mendoza, J., J. E. Throne and J. E. Baker. 2004. Ovarian physiology and age-grading in the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). *J. Stored Prod. Res.* 40: 179-196.
- Pfaffenberger, G. S. 1985. Description, differentiation, and biology of the four larval instars of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). *Coleopterist's Bull.* 39: 239-256.
- Rajendran, S. 1999. Detection of insect infestation in stored food commodities. *J. Food Sci. Technol.* 36: 283-300.
- Scholz, D., C. Borgemeister, R. H. Markham and H. M. Poehling. 1998. Physiological age-grading and ovarian physiology of *Prostephanus truncatus*. *Physiol. Entomol.* 23: 81-90.
- Vowotor, K. A., N. A. Bosque-Perez and J. N. Ayerley. 1995. Effect of maize variety and storage form on the development of the maize weevil, *Sitophilus zeamais* Motschulsky. *J. Stored Prod. Res.* 31: 29-36.

Ch. 3 Mobility

- Barney, R. J. and P. A. Weston. 1996. Movement of Angoumois grain moth (Lepidoptera: Gelechiidae) in a small-farm ecosystem. *Environ. Entomol.* 25: 261-267.
- Campbell, J. F. and D. W. Hagstrum. 2002. Patch exploitation by *Tribolium castaneum*: movement patterns, distribution and oviposition. *J. Stored Prod. Res.* 38: 55-68.
- Campbell, J. F. and C. Rummion. 2003. Patch exploitation by female red flour beetles, *Tribolium castaneum*. *J. Insect Sci.* <http://www.insectscience.org/3.20>
- Campos, M. and T. W. Phillips. 2014. Attract-and-Kill and Other Pheromone-Based Methods to Suppress Populations of the Indianmeal Moth (Lepidoptera: Pyralidae). *J. Econ. Entomol.* 107: 473-480.
- Ching'oma, G. P. 2006. Spatial distribution of movement of the lesser grain borer, *Rhyzopertha dominica* (F.). PhD Thesis, Kansas State University, Manhattan, KS
- Cox, P. D., M. E. Wakefield and T. A. Jacob. 2007. The effects of temperature on flight initiation in a range of moths, beetles and parasitoids associated with stored products. *J. Stored Prod. Res.* 43: 111-117.
- Desouhant, E., G. Driessen, L. Lapchin, S. Wieland and C. Bernstein. 2003. Dispersal between host populations in field conditions: navigation rules in the parasitoid *Venturia canescens*. *Ecol. Entomol.* 28: 257-267
- Hagstrum, D. W. 1984. Growth of *Ephestia cautella* (Walker) population under conditions found in an empty peanut warehouse and response to variations in the distribution of larval food. *Environ. Entomol.* 13: 171-174.
- Hagstrum, D. W. 1989. Infestation by *Cryptolestes ferrugineus* of newly-harvested wheat stored on three Kansas farms. *J. Econ. Entomol.* 82: 655-659.
- Hagstrum, D. W. 2000. Using five sampling methods to measure insect distribution and abundance in bins storing wheat. *J. Stored Prod. Res.* 36: 253-262.
- Hagstrum, D. W. 2001. Immigration of insects into bins storing newly harvested wheat on 12 Kansas farms. *J. Stored Prod. Res.* 37: 221-229.
- Hagstrum, D. W. and L. R. Davis Jr. 1980. Mate-seeking behavior of *Ephestia cautella*. *Environ. Entomol.* 9: 589-592.
- Hagstrum, D. W. and E. E. Gilbert. 1976. Emigration rate and age structure dynamics of *Tribolium castaneum* populations during growth phase of a colonizing episode. *Environ. Entomol.* 5: 445-448.
- Hagstrum, D. W. and B. J. Snittle. 1980. Age- and sex-specific tunneling rates of adult *Tribolium castaneum*. *Ann. Entomol. Soc. Amer.* 73: 11-13.
- Hagstrum, D. W.; Subramanyam, Bhadriraju. 2010. Immature insects: Ecological roles of mobility. *American Entomologist* 56(4): 230-241.
- Hawkin, Karen J., Dean M. Stanbridge and Paul G. Fields 2013. Sampling *Tribolium castaneum* and *Tribolium confusum* in flour mill rollstands. *Journal of Stored Products Research* 52: 7-11
- Hawkin, K. J., D. M. Stanbridge and P. G. Fields. 2011. Sampling *Tribolium confusum* and *Tribolium castaneum* in mill and laboratory settings: differences between strains and species. *Canadian Entomologist* 5: 504-517.
- Jian, F. and D. S. Jayas. 2009. Detecting and responding to resources and stimulus during the movement of *Cryptolestes ferrugineus* adults. *Food Bioprocess Technol.* 2: 45-56.
- Jian, F., D. S. Jayas and N. D. G. White. 2009. Optimal environmental search and scattered orientations during movement of adult rusty grain beetles, *Cryptolestes ferrugineus* (Stephens), in grain bulks – suggested movement and distribution patterns. *J. Stored Prod. Res.* 45: 177-183.
- Kuenen, L. P. S. and H. C. Rowe. 2006. Cowpea weevil flights to a point source of female sex pheromone: analysis of flight tracks at three wind speeds. *Physiol. Entomol.* 31: 103-109.
- Mankin, R. W. and D. W. Hagstrum. 1995. Three-dimensional orientation of male *Cadra cautella* (Lepidoptera: Pyralidae) flying to calling females in a windless environment. *Environ. Entomol.* 24: 1616-1626.
- Mankin, Richard W., David W. Hagstrum, Christian Nansen and William G. Meikle. 2014. Almond moth oviposition patterns in continuous layers of peanuts. *Journal of Stored Products Research* 59: 48-54.
- McFarlane, J. A., I. Gudrups and H. Fletcher. 1993. Biotype differences affecting the pest status of stored-grain insects. *Intern. J. Pest Management* 39: 35-43.
- Romero, S. 2007. Influence of landscape structure on movement behavior and habitat use by red flour beetle (*Tribolium castaneum*). PhD Thesis, Kansas State University, Manhattan, KS
- Romero, S., J. F. Campbell, J. R. Nechols and K. A. With. 2009. Movement behavior in response to landscape structure: the role of functional grain. *Landscape Ecol.* 24: 39-51.
- Romero, S., J. F. Campbell, J. R. Nechols and K. A. With. 2010. Movement behavior of red flour beetle: response to habitat cues and patch boundaries. *Environ. Entomol.* 39: 919-929.
- Savoldelli, S. and P. Trematerra. 2011. Mass-trapping, mating-disruption and attracticide methods for managing stored-product insects: success stories and research needs. *Stewart Postharvest Review* 3: 7.
- Semeao, A. A., J. F. Campbell, R. J. Whitworth, and P. E. Sloderbeck. 2013. Movement of *Tribolium castaneum* within a flour mill. *J. Stored Prod. Res.* 54: 17-22.
- Steel, R., D. Elmouttie, and G. Hamilton. 2012. Geostatistical analysis of adult *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) in wheat stored at constant temperatures. *J. Stored Prod. Res.* 50: 8-14.
- Toews, M. D., J. F. Campbell, F. H. Arthur and M. West. 2005a. Monitoring *Tribolium castaneum* (Coleoptera: Tenebrionidae) in pilot-scale warehouses treated with residual applications of (S)-hydroprene and cyfluthrin. *J. Econ. Entomol.* 98: 1391-1398.
- Ukeh, D. A., I. A. Udo and E. I. Ogban. 2008. Trapping of stored-product insects using flight traps outside traditional African storage granaries. *J. Food Agric. Environ.* 6: 399-401.
- Utida, S. 1972. Density dependent polymorphism in the adult of *Callosobruchus maculatus* (Coleoptera: Bruchidae). *J. Stored Prod. Res.* 8: 111-126.

Ch. 4 Sources of insect infestation

- Arbogast, R. T., S. R. Chini and J. E. McGovern. 2005. *Plodia interpunctella* (Lepidoptera: Pyralidae): Spatial relationship between trap catch and distance from a source of emerging adults. *J. Econ. Entomol.* 98: 326-333.
- Arbogast, R. T., S. R. Chini and J. E. McGovern. 2006. Use of contour analysis in monitoring stored-product insects. *J. Econ. Entomol.* 99: 601-603.
- Arthur, F. H., D. W. Hagstrum, P. W. Flinn, C. R. Reed and T. W. Phillips. 2006. Insect populations in grain residues associated with commercial Kansas grain elevators. *J. Stored Prod. Res.* 42: 226-239.

- Boon, K. S. and S. H. Ho. 1988. Factors influencing the post-fumigation reinfestation of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in a rice warehouse. J. Stored Prod. Res. 24: 87-90.
- Borgemeister, C., A. Tchabi and D. Scholz. 1998. Trees or stores? The origin of migrating *Prostephanus truncatus* collected in different ecological habitats in southern Benin. Entomol. Exp. Appl. 87: 285-294.
- Bowditch, T. G. and J. L. Madden. 1996. Spatial and temporal distribution of *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) in a confectionary factory: causal factors and management implications. J. Stored Prod. Res. 32: 123-130.
- Curtis, C. E., R. K. Curtis and K. L. Andrews. 1984. Progression of navel orangeworm (Lepidoptera: Pyralidae) infestation and damage of almonds on the ground and on the tree during harvest. Environ. Entomol. 13: 146-149.
- Hagstrum, D. W. 1985. Preharvest infestation of cowpeas by the cowpea weevil, *Callosobruchus maculatus* (Coleoptera: Bruchidae) and population trends during storage in Florida. J. Econ. Entomol. 78: 358-361.
- Hagstrum, D. W., P. W. Flinn and R. W. Howard. 1996. Ecology, p. 92-104. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.
- Hamlin, J. C. and C. Benton. 1925. Control of the saw-toothed grain beetle in raisins: a preliminary report. J. Econ. Entomol. 18: 790-795.
- Jia, F., M. D. Toews, J. F. Campbell and S. B. Ramaswamy. 2008. Survival and reproduction of lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on flora associated with native habitats in Kansas. J. Stored Prod. Res. 44: 366-372.
- Nansen, C., A. Liebhold and P. Tobin. 2006. Contour mapping and number of point observations. J. Econ. Entomol. 99: 599-600.
- Sagnia, S. B. 1994. Mortality factors affecting *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) under field conditions in Niger. J. Stored Prod. Res. 30: 71-74.
- Soderstrom, E. L., R. T. Hinsch, A. J. Bongers, D. G. Brandl and H. Hoogendorn. 1987. Detecting adult Phycitinae (Lepidoptera: Pyralidae) infestations in a raisin-marketing channel. J. Econ. Entomol. 80: 1229-1232.
- Tilley, D. R. 2013. Incidence and spread of insects from bucket elevator leg boots. PhD Dissertation, Kansas State University Department of Grain Science and Industry.
- Williams, G. C. 1961. Infestation of a disused flour mill. Milling 86: 92.
- Ch. 5 Sampling
- Adam, B. D., M. Siaplay, P. W. Flinn, B. W. Brorsen, and T. W. Phillips. 2010. Factors influencing economic profitability of sampling-based integrated pest management of wheat in country elevators. J. Stored Prod. Res. 46:186-196.
- Belda, C., M. Ribes-Dasi, and J. Riudavets. 2011. Improving pest management in pet food mills using accurate monitoring and spatial analysis. J. Stored Prod. Res. 47:385-392.
- Buckman, K.A. and J.F. Campbell. 2013. How varying pest and trap densities affect *Tribolium castaneum* capture in pheromone traps. Entomol. Exp. Appl. 146: 404-412.
- Campbell, J. F. 2012. Attraction of walking *Tribolium castaneum* adults to traps. Journal of Stored Products Research 51: 11-22.
- Campbell, J.F. 2013. Influence of landscape pattern in flour residue amount and distribution on *Tribolium castaneum* (Herbst) response to traps baited with pheromone and kairomone. J. Stored Prod. Res. 52: 112-117.
- Fedina, T. Y. and S. M. Lewis. 2007. Effect of *Tribolium castaneum* (Coleoptera: Tenebrionidae) nutritional environment, sex, and mating status on response to commercial pheromone traps. J. Econ. Entomol. 100: 1924-1927.
- Hagstrum, D. W., P. W. Flinn and D. Shuman. 1996. Automated monitoring using acoustical sensors for insects in farm-stored wheat. J. Econ. Entomol. 89: 211-217.
- Hagstrum, D. W., P. W. Flinn and Bh. Subramanyam. 1998. Predicting insect density from probe trap catch in farm-stored wheat. J. Stored Prod. Res. 34: 251-262.
- Hagstrum, D. W., Milliken, G. A., and Wadell, M. S. 1985. Insect distribution in bulk stored wheat in relation to detection or estimation of abundance. Environ. Entomol. 14:655-661.
- Hagstrum, D. W., Bh. Subramanyam, and P. W. Flinn. 1997. Nonlinearity of a generic variance-mean equation for stored grain insect sampling data. Environ. Entomol. 26: 1213-1223.
- Haines, C., D. Rees, K. Ryder, S. Sistyanto and Y. Cahyana. 1991. Brown-rice bait-bags for monitoring insect pest populations in bag stacks of milled rice as an aid to pest control decision-making. p. 1351-1358. In Fluérat-Lessard, F. and P. Ducom [eds.]. Proceedings of the 5th International Working Conference on Stored-Prod. Entomol., Bordeaux, France, Imprimerie Médocaine, Blanquefort Cedex, France.
- Hodges, R. J. 2002. Detection and monitoring of larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Integrated Pest Management Reviews 7: 223-243.
- Kuzmanov, D. K., N. D. Dimitrov, N. P. Ginov and I. G. Yanchev. 2008. A heated trap for detecting insect infestation in stored grain at low temperatures. Bulgarian J. Agric. Sci. 14: 528-534.
- Mabbett, T. 1995. Pheromone traps reduce insurance fumigation for cocoa bean pests. International Pest Control. 37: 73-74.
- Manis, J. M. 1992. Sampling, inspection and grading. pp. 563-588. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.
- Mankin, R. W., K. W. Vick, J. A. Coffelt and B. A. Weaver. 1983. Pheromone-mediated flight by male *Plodia interpunctella* (Hubner) (Lepidoptera: Pyralidae). Environ. Entomol. 12: 1218-1222.
- Mankin, R. W., R. T. Arbogast, P. E. Kendra and D. K. Weaver. 1999. Active spaces of pheromone traps for *Plodia interpunctella* (Lepidoptera: Pyralidae) in enclosed environments. Environ. Entomol. 28: 557-565.
- Mankin, R. W., D. W. Hagstrum, M. T. Smith, A. L. Roda, and M. T. K. Kairo. 2011. Perspective and promise: a century of insect acoustic detection and monitoring. Amer. Entomol. 57: 30-44.
- Mohan, S., S. S. Sivakumar, S. R. Venkatesh, and G. S. V. Raghavan. 2006. Simple technique to increase the sensitivity of probe traps in detecting *Cryptolestes ferrugineus* (Coleoptera : Laemphloeidae) in stored wheat. Can. Entomol. 138:733-735. (increase trap catch by increasing insect activity)
- Nansen, C., W.G. Meikle, J. Campbell, T.W. Phillips, B.Subramanyam. 2008. A binomial and species-independent approach to trap capture analysis of flying insects. Journal of Economic Entomology 101: 1719-1728.
- Nansen C., T. W Phillips, P. K. Morton and E. L. Bonjour. 2006. Spatial analysis of pheromone-baited trap captures from controlled releases of male Indianmeal moths. Environmental Entomology 35: 516-523.
- Perez-Mendoza, J., P. W. Flinn, J. F. Campbell, D. W. Hagstrum and J. E. Throne. 2004. Detection of stored-grain insect infestation in wheat transported in railroad hopper-cars. J. Econ. Entomol. 97: 1474-1483.
- Subramanyam, Bh. and D. W. Hagstrum. 1996. Sampling, pp. 135-193. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.
- Subramanyam, Bh., D. W. Hagstrum, R. L. Meagher, E. C. Burkness, W. D. Hutchinson and S. E. Naranjo. 1997. Development and evaluation of sequential sampling plans for *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) infesting farm-stored wheat. J. Stored Prod. Res. 33: 321-329.
- Toews, M. D., F. H. Arthur and J. F. Campbell. 2005b. Role of food and structural complexity on capture of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in simulated warehouses. Environ. Entomol. 34: 164-169.
- Toews, M. D., F. H. Arthur and J. F. Campbell. 2009. Monitoring *Tribolium castaneum* (Herbst) in pilot-scale warehouses treated with β -cyfluthrin: are residual insecticides and trapping compatible? Bull. Entomol. Res. 99: 121-129.
- Ch. 6 Life history
- Arbogast, R. T. 1991. Beetles: Coleoptera. p. 131-176. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.
- Barrer, P. M. 1976. The influence of delayed mating on the reproduction of *Ephestia cautella* (Walker) (Lepidoptera: Phycitidae). J. Stored Prod. Res. 12: 165-169.

Bell, C. H. 1994. A review of diapause in stored-product insects. J. Stored Prod. Res. 30: 99-122.

Boczek, J. 1991. Mite pests in stored food. p. 57-79. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia. (Life histories of stored-product mites)

Chapman, R. N. 1923. The possibility of transmitting a *Calendra* infestation from wheat to macaroni thru the processes of milling and manufacturing. J. Econ. Entomol. 16: 341-348.

Cox, P. D. and C. H. Bell. 1991. Biology and ecology of moth pests of stored foods. p. 181-193. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.

Esperk, T., T. Tammaru and S. Nylin. 2007. Intraspecific variability in number of larval instars in insects. J. Econ. Entomol. 100: 627-645.

Hagstrum, D. W. and G. A. Milliken. 1988. Quantitative analysis of temperature, moisture and diet as factors affecting insect development. Ann. Entomol. Soc. Amer. 81: 539-546.

Hagstrum, D. W. and Bh. Subramanyam. 2009. A review of stored-product entomology sources. Amer. Entomol. 55 (3): 174-183.

Hagstrum, D. W., P. W. Flinn and R. W. Howard. 1996. Ecology, p. 71-91. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Huang, F. and Bh. Subramanyam. 2003. Effects of delayed mating on reproduction performance of *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). J. Stored Prod. Res. 39: 53-63.

Sedlacek, J. D., P. A. Weston and R. J. Barney. 1996. Lepidoptera and Psocoptera. p. 41-70. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Subramanyam, Bh. and D. W. Hagstrum. 1993. Predicting development times of six stored-product moth species (Lepidoptera: Pyralidae) in relation to temperature, relative humidity, and diet. Eur. J. Entomol. 90: 51-64.

Ch. 7 Population growth

Ahmad, T. R. and M. A. Ali. 1995. Forecasting emergence and flight of some *Ephestia* spp. (Lep., Pyralidae) based on pheromone trapping and degree-day accumulations. J. Appl. Entomol. 119: 611-614.

Flinn, P. W. and D. W. Hagstrum. 1995. Simulation model of *Cephalonomia waterstoni* (Hymenoptera: Bethyidae) parasitizing the rusty grain beetle (Coleoptera: Cucujidae). Environ. Entomol. 24: 1608-1615.

Flinn, P. W., T. W. Phillips, D. Hagstrum, F. Arthur and J. Throne. 2001. Modeling the effects of insect stage and grain temperature on phosphine-induced mortality for *Rhyzopertha dominica*. p. 531-539. In Donahaye, E. J., S. Navarro, and J. Leesch [eds.], Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Stored Products, Executive Printing Services, Clovis, California.

Hagstrum, D. W. and P. W. Flinn. 1990. Simulations comparing insect species differences in response to wheat storage conditions and management practices. J. Econ. Entomol. 83: 2469-2475.

Howe, R. W. 1965. A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. J. Stored Prod. Res. 1: 177-184.

Jian, F., D. S. Jayas, N. D. G. White and P. G. Fields. 2007. A distributed-delay model to predict ageing and survival rates of adults of *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemphloeidae) in granaries filled with wheat. Ecol. Model. 200: 412-420.

Jian, F., D. S. Jayas, N. D. G. White and E. A. Smith. 2008. Numerical analysis and parameter estimation technique for insect population redistribution models. Ecol. Model. 211: 47-56.

Kaliyan, N., M. A. Carrillo, R. V. Morey, W. F. Wilcke and S. A. Kellis. 2007. Mortality of Indianmeal moth (Lepidoptera: Pyralidae) populations under fluctuating low temperatures: model development and validation. Environ. Entomol. 36: 1318-1327.

Stolk, C., W. van der Werf and A. van Huis. 1999. Models of stored-product pests: their relevance to biological control in traditional storage in developing countries. p. 72-87. In Zuzan, J., L. Quan, L. Yongsheng, T. Xiachang, and G. Liaghua [eds.] Proceedings of the 7th International Working Conference on Stored Product Protection, Sichuan Publishing House, Chengdu, Peoples Republic of China.

Throne, J. 1995. Computer modeling of the population dynamics of stored product pests. p. 169-195. In Jayas, D. S., N. D. G. White and W. E. Muir. [eds.], Stored-Grain Ecosystem Marcel Dekker, Inc., New York.

Woods, S. M., N. D. G. White and R. N. Sinha. 1997. Simulation of generation times of the rusty grain beetle, *Cryptolestes ferrugineus*, in farm-stored grain in the Canadian prairies, 1952-1990. Res. Popul. Ecol. 39: 47-56.

Ch. 8 Decision aids

Bridgeman, B. W. and P. J. Collins. 1994. Integrated pest management in the GRAINCO, Queensland Australia, storage system. p. 910-914. In Highley, E., E. J. Wright, H. J. Banks and B. R. Champ [eds.] Proceedings of the 6th International Working Conference on Stored-Product Protection, Canberra, Australia, CAB International, Wallingford, United Kingdom.

Compton, J. A. F., S. Floyd, P. A. Magrath, S. Addo, S. R. Gbedevi, B. Agbo, G. Bokor, S. Amekupe, Z. Motey, H. Penni and S. Kumi. 1998. Involving grain traders in determining the effect of postharvest insect damage on the price of maize in African markets. Crop Prot. 17: 483-489.

Flinn, P. W., D. W. Hagstrum, C. R. Reed and T. W. Phillips. 2007a. Stored Grain Advisor Pro: decision support system for insect management in commercial grain elevators. J. Stored Prod. Res. 43: 375-383.

Gerberg, E. J. 1991. Professional and consultant services. p. 549-550. In Gorham, J. R. [ed.] Ecology and Management of Food-Industry Pests. Food and Drug Administration Technical Bulletin 4. Association of Official Analytical Chemists, Arlington, Virginia.

Hagstrum, D. W., P. W. Flinn, C. R. Reed and T. W. Phillips. 2010. Ecology and IPM of insects at grain elevators and flat storages. Biopestic. Intern. 6: 1-20.

Hagstrum, D. W. and Bh. Subramanyam 2000a. Monitoring and decision tool. p. 1-28. In Bh. Subramanyam and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Hagstrum, D. W. and Bh. Subramanyam 2000b. Integration. p. 419-428. In Bh. Subramanyam and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Hagstrum, D. W. and Bh. Subramanyam. 2012. Role of extension educators and consultants. p. 289-296. In D. W. Hagstrum, T. W. Phillips and G. Cuperus (eds) Stored Product Protection S156. Kansas State University, Manhattan, KS.

Hodges, R. J., M. Smith, A. Madden, D. Russell, I. Gudrups and H. Halid. 1997. Development of a decision support system for the fumigation of milled-rice bag-stacks in the tropics. p. 425-434. In Donahaye, E. J., S. Navarro, and A. Vamava [eds.]. Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Stored Products, Printco Ltd., Nicosia, Cyprus.

Holcomb, M. 1995. IPM in food processing – stop the insanity. Pest Control 63: 66.

Kuzmanov, D. and N. Dimitrov. 2009. Forecasting the necessity of grain fumigation during storage. Czech J. Food Sci. 3: 210-215.

Raney, H. 1984. Kentucky's stored grain inspection program, pp. 722. In R. B. Mills, V. F. Wright, J. R. Pedersen, W. H. McGaughey, R. W. Beeman, K. J. Kramer, R. D. Speirs and C. L. Storey (eds.), Proceedings of the 3rd International Working Conference on Stored-Product Entomology, 23-28 October, 1983, Manhattan, Kansas

Reed, C., V. F. Wright, J. R. Pedersen and K. Anderson. 1989. Effects of insect infestation of farm-stored wheat on its sale price at country and terminal elevators. J. Econ. Entomol. 82: 1254-1261.

Siddiqi, Z. 2006. IPM: The gold standard for grain processing. World Grain 24:40-41.

Skinner, M. 1982. Farmers scout stored grain investment. Extension Rev. Spring: 4-6.

Slade, P. J. 2002. Verification of effective sanitation control strategies. Food Safety Mag. Feb-Mar: 24-29, 42-43.

Smallman, B.N. 1944. Solving the infestation hazard of Canada's war-grain storage. Amer. Miller and Processor 72: 37-39, 50-51.

Ch. 9 Economics

Alexander, C., Y. A. Yigezu, D. E. Maier, L. J. Mason, and C. P. Woloshuk. 2008. Cost of Good Sanitation Practices for On-Farm Grain Storage. Purdue Extension GQ-50-W.

Arthur, F.H., J.F. Campbell, and M.D. Toews. 2013. Distribution, abundance, and seasonal patterns of *Plodia interpunctella* (Hübner) in a commercial food storage facility. J. Stored Prod. Res. 53: 7-14.

Beckett, S. J. and R. Morton. 2003. Mortality of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) at grain temperatures ranging from 50°C to 60°C obtained at different rates of heating in a spouted bed. J. Stored Prod. Res. 39: 313-332.

Chowanec, T. 1986. Sanitation cost – the bottom line. Bull. Assoc. Operative Millers December 4867-4871.

Curtis, C. E. 1976. Economics of NOW control and implementing orchard clean up. Almond Facts 41:5-8.

Kenkel, P., J. T. Criswell, G. Cuperus, R. T. Noyes, K. Anderson, W. S. Fargo, K. Shelton, W. P. Morrison and B. Adams. 1993. Current management practices and impact of pesticide loss in the hard red wheat post-harvest system. Oklahoma Cooperative Extension Service Circular E-930.

Rulon, R. A., D. E. Maier and M. D. Boehlje. 1999. A post-harvest economic model to evaluate grain chilling as an IPM technology. J. Stored Prod. Res. 35: 369-383.

Soderstrom, E. L., P. D. Gardner, J. L. Baritelle, K. N. De Lozano and D. G. Brandl. 1984. Economic cost evaluation of a generated low-oxygen atmosphere as a alternative fumigant in the bulk storage of raisins. J. Econ. Entomol. 77: 457-461.

Subramanyam, Bh. 2003. Heat Treatment Calculator, software program helps determine how much energy is needed to heat a building. Milling Journal, Third Quarter 46-48.

Tilley, D. R., M. R. Langemeier, M. E. Casada and F. H. Arthur. 2007a. Cost and risk analysis of heat and chemical treatments. J. Econ. Entomol. 100: 604-612.

Ch. 10 Resistance

Andreev, D., T. Rocheleau, T. W. Phillips, R. W. Beeman and R. H. French-Constant. 1994. A PCR diagnostic for cyclodiene insecticide resistance in the red flour beetle *Tribolium castaneum*. Pestic. Sci. 41: 345-349.

Emery, Robert N., Manoj K Nayak and Joanne C Holloway. 2011. Lessons learned from phosphine resistance monitoring in Australia. Stewart Postharvest Review doi: 10.2212/spr.2011.3.6

Haynes, K. F., T. A. Miller, R. T. Staten, W. G. Li and T. C. Baker. 1986. Monitoring insecticide resistance with insect pheromones. Experientia 42: 1293-1295.

Herron, G. A., A. D. Clift, G. G. White and H. G. Greening. 1996. Relationships between insecticide use, grain hygiene and insecticide resistance in *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) on grain-producing farms. J. Stored Prod. Res. 32: 131-136.

Opit, G. P., T. W. Phillips, M. J. Aikins, and M. M. Hasan. 2012. Phosphine resistance in *Tribolium castaneum* and *Rhyzopertha dominica* from stored wheat in Oklahoma. J. Econ. Entomol. 105(4): 1107-1114.

Schlipalius, D. I., N. Valmas, A. G. Tuck, R. Jagadeesan, L. Ma, R. Kaur, A. Goldinger, C. Anderson, J. Kuang, S. Zuryn, Y. S. Mau, Q. Cheng, P. J. Collins, M. K. Nayak, H. J. Schirra, M. A. Hilliard, and P. R. Ebert. 2012. A Core Metabolic Enzyme mediates resistance to phosphine gas. Science 338:807-810.

Sinclair, E. R. and J. Adler. 1985. Development of a computer simulation model of stored product insect populations on grain farms. Agricultural Systems 18: 95-113.

Subramanyam, Bh. and D. W. Hagstrum. 1996. Resistance measurement and management. p. 331-397. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Tabashnik, B. E. 1990. Modeling and evaluation of resistance management tactics. p. 153-182. In Roush, R. T. and B. E. Tabashnik [eds.], Pesticide Resistance in Arthropods. Chapman and Hall, New York.

Ch. 11 Biological control

Borgemeister, C., F. Djossou, C. Adda, H. Schneider, B. Djomamou, K. Azoma and R. H. Markham. 1997. Establishment, spread and impact of *Tetrtiosoma nigrescens* Lewis (Coleoptera: Histeridae), an exotic predator of the larger grain borer *Prostephanus truncatus* (Hom) (Coleoptera: Bostrichidae), in southwestern Benin. Environ. Entomol. 26: 1405-1415.

Brower, J. H., L. Smith, P. V. Vail and P. W. Flinn. 1996. Biological control, p. 223-286. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Eliopoulos, P. A., C. G. Athanasiou and C. H. Buchelos. 2002. Occurrence of Hymenoptera parasitoids of stored product pests in Greece. In C. Adler, S. Navarro, M. Scholler and L. Stengard-Hansen Proceedings Integrated Protection of Stored Products IOBC Bulletin 25: 127-139.

Eliopoulos, P. A., C. G. Athanasiou, N. E. Palyvos, G. J. Stathas and C. Th. Buchelos. 2003. Dominance and frequency of predatory mites in stored products in Greece. p. 258-262. In Credland, P. F., D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley [eds.], Advances in Stored Product Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, York, United Kingdom. CAB International, Wallingford, United Kingdom

Flinn, P. W. and D. W. Hagstrum. 1995. Simulation model of *Cephalonomia waterstoni* (Hymenoptera: Bethyidae) parasitizing the rusty grain beetle (Coleoptera: Cucujidae). Environ. Entomol. 24: 1608-1615.

Flinn, P. W., D. W. Hagstrum and W. H. McCaughey. 1996. Suppression of beetles in stored wheat by augmentative releases of parasitic wasps. Environ. Entomol. 25: 505-511.

Johnson, J. A., K. A. Valero, M.M. Hannel and R. F. Gill. 2000. Seasonal occurrence of postharvest dried fruit insects and their parasitoids in a cull fig warehouse. J. Econ. Entomol. 93: 1380-1390.

Moore, D., J. C. Lord and S. M. Smith. 2000. Pathogens. p. 193-227. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Schöller, M. and P. W. Flinn. 2000. Parasites and predators. p. 229-271. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Ch. 12 Aeration

Flinn, P. W., D. W. Hagstrum and W. E. Muir. 1997. Effects of time of aeration, bin size, and latitude on insect populations in stored wheat: a simulation study. J. Econ. Entomol. 90: 646-651.

Foster, G. H. and J. Tuite. 1992. Aeration and grain management. p. 219-248. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Maier, D. E. 1994. Chilled aeration and storage of U.S. crops – a review. p. 300-311. In Highley, E., E. J. Wright, H. J. Banks and B. R. Champ [eds.] Proceedings of the 6th International Working Conference on Stored-Product Protection, Canberra, Australia, CAB International, Wallingford, United Kingdom

Navarro, S. and R. Noyes. 2002. The mechanics and physics of modern grain aeration management. CRC Press, New York. (book)

Reed, C. R. 2006. Aeration. Pages 141-180 In Managing Stored Grain to Preserve Quality and Value. AACC International, St. Paul, MN.

Reed, C. and F. H. Arthur. 2000. Aeration, p. 51-72. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Reed, C. and J. Harmer. 1998a. Cooling of stored wheat in multiple or single cycles using automatic aeration controllers. Appl. Eng. Agric. 14: 495-500.

Reed, C. and J. Harmer. 1998b. Thermostatically controlled aeration for insect control in stored hard red winter wheat. Appl. Eng. Agric. 14: 501-505.

Reed, C., T. Herman, R. Higgins and J. Harmer. 1995. Questions and answers about aeration controllers. MF-2090 Cooperative Extension Service, Kansas State University.

Ch. 13 Sanitation and pest exclusion

Adler, C. 2004. Significance of hermetic seals, controlled ventilation, and wire-mesh screens to prevent the immigration of stored product pests. IOBC/wprs Bulletin 27:13-16.

Arthur, F. H. 2000. Impact of accumulated food on survival of *Tribolium castaneum* on concrete treated with cyfluthrin wettable powder. J. Stored Prod. Res. 36: 15-23.

- Brickey, P.M., J.S. Gecan, and A. Rothschild. 1973. Method for determining direction of insect boring through food packaging materials. J. AOAC 56: 640-642.
- Brody, A. L. 1982. Packaging. p. 503-535. In Christensen, C. M. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.
- Cline, L. D. 1978. Penetration of seven flexible packaging materials by larvae and adults of eleven species of stored-product insects. J. Econ. Entomol. 71: 726-729.
- Cox, P. D., D. A. Fleming, J. E. Atkinson, K. L. Bannon and J. M. Whitefield. 1997. The effect of behavior on the survival of *Cryptolestes ferrugineus* in an insecticide-treated laboratory environment. J. Stored Prod. Res. 33: 257-269.
- Hori, M. 2004. Repellency of hinokitiol against the cigarette beetle, *Lasioderma serricorne* (Fabricius) (Coleoptera: Anobiidae). Appl. Entomol. Zool. 39: 521-526.
- Hou, X., P. Fields and W. Taylor. 2004. The effect of repellents on penetration into packaging by stored-product insects. J. Stored Prod. Res. 40: 47-54.
- Imholte, T. J. and T. K. Imholte-Tausher 1999. Engineering for Food Safety and Sanitation. Technical Institute of Food Safety, Crystal, Minnesota. (book)
- Ingemansen, J. A., Reeves, D. L., and Walstrom, R. J. 1986. Factors influencing stored-oat insect populations in South Dakota. J. Econ. Entomol. 79:518-522.
- Jacobson, R. and D. B. Pinniger. 1982. Eradication of *Oryzaephilus surinamensis* from a farm grain store. Intern. Pest Control 24: 68, 72-74.
- Karitas, J. J. 1964. Breakage and damage in grocery warehouses and retail food stores. USDA, ARS, Agricultural Market Service, Marketing Research Report No. 652.
- Mills, R. and J. Pedersen. 1990. A Flour Mill Sanitation Manual. Eagan Press, St. Paul, Minnesota. (book)
- Mowery, S. V., M. A. Mullen, J. F. Campbell and A. B. Broce. 2002. Mechanisms underlying sawtoothed grain beetle (*Oryzaephilus surinamensis* [L.]) (Coleoptera: Silvanidae) infestation of consumer food packaging materials. J. Econ. Entomol. 95: 1333-1336.
- Mullen, M. A. and J. R. Pedersen. 2000. Sanitation and exclusion. p. 29-50. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Nakamura, S., P. Visarathanonth, R. Kengkampanich, J. Uraichuen, and K. Konishi. 2008. Cleaning reduces grain losses of stored rice. Japq-Japan Agricultural Research Quarterly 42 (1):35-40.
- Reed, C. R., D. W. Hagstrum, P. W. Flinn and R. F. Allen. 2003. Wheat in bins and discharge spouts, and grain residues on floors of empty bins in concrete grain elevators as habitats for stored-grain beetles and their natural enemies. J. Econ. Entomol. 96: 996-1004.
- Rolston, L. H. and P. Rouse. 1957. Insects in stored rice can be controlled by sanitation. Arkansas Farm Res. 6 (3): 3.
- Roesli, R., Subramanyam, B., Campbell, J. F., and Kemp, K. 2003b. Impact of selected IPM practices on insect populations in retail pet stores. Pages 410-419 in: Advances in Stored Product Protection. Proc. Int. Work. Conf. on Stored Prod. Prot., 8th (York, UK.) P. F. Credland, D. M. Armitage, C. H. Bell, P. M. Cogan, and E. Highley, Eds. CAB International, Wallingford, UK.
- Riudavets, J. I. Salas and M. J. Pons. 2007. Damage characteristics produced by insect pests in packaging film. Journal of Stored Products Research 43: 564-570.
- Riudavets, J., C. Castañé, O. Alomar, M.J. Pons and R.Gabarra. 2009. Modified atmosphere packaging (MAP) as an alternative measure for controlling ten pests that attack processed food products. Journal of Stored Products Research 45: 91-96.
- ### Ch. 14 Temperature
- Beckett, S. J. and R. Qaisrani. 2003. Heat disinfestations of empty farm silos before inloading. p. 803-806. In Credland, P. F., D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley [eds.] Advances in Stored Product Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, York, United Kingdom. CAB International, Wallingford, United Kingdom.
- Burks, C. S., J. A. Johnson, D. E. Maier and J. Heaps. 2000. Temperature. p. 71-104. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Donahaye, E. J., S. Navarro and M. Rindner. 1995. Low temperature as an alternative to fumigation for disinfesting dried fruit from three insect species. J. Stored Prod. Res. 31: 63-70.
- Evans, D. E., G. R. Thorpe and T. Dermott. 1983. The disinfestations of wheat in a continuous-flow fluidized bed. J. Stored Prod. Res. 19: 125-137.
- Fields, P.G. 1992. The control of stored-product insects and mites with extreme temperatures. J. Stored Prod. Res. 28: 89-118.
- Imholte, T. J. and T. K. Imholte-Tausher 1999. Engineering for Food Safety and Sanitation. p. 303-309. Technical Institute of Food Safety, Crystal, Minnesota. (book)
- Johnson, J. A. and K. A. Valero. 2003. Use of commercial freezers to control cowpea weevil, *Callosobruchus maculatus* (Coleoptera: Bruchidae), in organic garbanzo beans. J. Econ. Entomol. 96: 1952-1957.
- Keever, D. W., B. R. Wiseman and N. W. Widstrom. 1988. Effects of threshing and drying on maize weevil populations in field-infested corn. J. Econ. Entomol. 81: 727-730.
- Mourier, H. and K. P. Poulsen. 2000. Control of insects and mites in grain using a high temperature/short time (HTST) technique. J. Stored Prod. Res. 36: 309-318.
- Nelson, S. O. 1996. Review and assessment of radio-frequency and microwave energy for stored-grain insect control. Trans. ASAE 39: 1475-1484.
- Ntoukam, G., L. W. Kitch, R. E. Shade and L. L. Murdock. 1997. A novel method for conserving cowpea germplasm and breeding stocks using solar disinfestations. J. Stored Prod. Res. 33: 175-179.
- Roesli, R. Bh. Subramanyam, F. J. Fairchild and K. C. Behnke. 2003. Trap catches of stored-product insects before and after heat treatment in a pilot feed mill. J. Stored Prod. Res. 39: 521-540.
- Shayesteh, N. and N. N. Barthakur. 1996. Mortality and behavior of two stored-product insect species during microwave irradiation. J. Stored Prod. Res. 32: 239-246.
- Tilley, D. R., M. E. Casada and F. H. Arthur. 2007b. Heat treatment for disinfestations of empty grain storage bins. J. Stored Prod. Res. 43: 221-228.
- Wang, S., J. Tang, J. A. Johnson, E. Mitcham, J. D. Hansen, R. P. Cavaliere, J. Bower and B. Biasi. 2002. Process protocols based on radio frequency energy to control field and storage pests in in-shell walnuts. Postharvest Biology and Technology 26: 265-273.
- ### Ch. 15 Impact mortality
- Banks, J. and P. Fields. 1995. Physical methods for insect control in stored-grain ecosystems. p. 384-387. In D. S. Jayas, N. D. G. White and W. E. Muir (eds.) Stored-Grain Ecosystem, Marcel Dekker Inc., New York.
- Kice, B. 1991. Multiaspirator and clean grain benefits. p. 205-210. In Proc. III Nat. Stored Grain Pest Management Training Conf., Kansas City, Missouri.
- Nahdy, M. S. 1994. Bean sieving, a possible control measure for the dried bean beetles, *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). J. Stored Prod. Res. 30: 65-69.
- Noyes, R. T., B. Kice and C. Sukup. 1991. Grain cleaning and cleaning equipment. p. 217-227. In Proc. III Nat. Stored Grain Pest Management Training Conf., Kansas City, Missouri.
- Paliwal, J., D. S. Jayas, N. D. G. White and W. E. Muir. 1999. Effects of pneumatic conveying of wheat on mortality of insects. Appl. Eng. Agric. 15: 65-68.
- Payne, J. A., L. M. Redlinger and J. I. Davidson. 1970. Shelling plant studies with insect-infested peanuts. J. Amer. Peanut Res. Educ. Assoc. 2: 103-108.
- Plarre, R. and F. Reichmuth. 2000. Impact. p. 401-417. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Quentin, M. E., J. L. Spencer and J. R. Miller. 1991. Bean tumbling as a control measure for the common bean weevil, *Acanthoscelides obtectus*. Entomol. Exp. Appl. 60: 105-109.
- Robertson, F. W. 1944. The removal of insect pests from stored products by means of behaviour stimuli. Bull. Entomol. Res. 35: 215-217.
- Toews, M. D. and Bh. Subramanyam. 2002. Sanitation in grain storage and handling. p. 481-497. In Hui, Y. H., B. L. Bruinsma, J. R. Gorham, W. Nip, P. S. Tong and P. Ventresca. (eds.) Food Plant Sanitation. Marcel Dekker, Inc., New York.

Wanzenried, H. 1986. Reducing infestation in flour. Bull. AOM. March, p. 4693-4696.

Ch. 16 Ionizing radiation

Banks, J. and P. Fields. 1995. Physical methods for insect control in stored-grain ecosystems. p. 389-391. In D. S. Jayas, N. D. G. White and W. E. Muir (eds) Stored-Grain Ecosystem, Marcel Dekker Inc., New York.

Cleghorn, D. A., S. V. Nablo, D. N. Ferro and D. W. Hagstrum. 2002. Electron beam treatment parameters for control of stored product insects. Radiation Phys. Chem. 63: 575-579.

Cogburn, R.R., E. W. Tilton and J. H. Brower. 1972. Bulk-grain gamma irradiation for control of insects infesting wheat. J. Econ. Entomol. 65: 818-821.

Fields, P. G. and W. E. Muir. 1996. Physical control. p. 206-207. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Halverson, S. L. and S. V. Nablo. 2000. Radiation. p. 381-400. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Molins, R. A. 2001. Food irradiation: principles and applications. Wiley-Interscience, New York. (book)

Tilton, E. W. and J. H. Brower. 1987. Ionizing radiation for insect control in grain and grain products. Cereal Foods World 32: 330-333.

Watters, F. L. and K. F. MacQueen. 1967. Effectiveness of gamma irradiation for control of five species of stored-product insects. J. Stored Prod. Res. 3: 223-234.

Wilkinson, V. M. and G. W. Gould. 1998. Food irradiation, a reference guide. Woodhead Publishing Limited, Cambridge, England. (book)

Ch. 17 Residual insecticides

Arthur, F. H. 1996. Grain protectants: current status and prospects for the future. J. Stored Prod. Res. 32: 293-302.

Arthur, F. H., J. E. Throne and R. A. Simonitis. 1992. Degradation and biological efficacy of chlorpyrifos-methyl on wheat stored at five temperatures and three moisture contents. J. Econ. Entomol. 85: 1994-2002.

Athanassiou, C. G., F. H. Arthur and J. E. Throne. 2009. Efficacy of spinosad in layer-treated wheat against five stored-product insect species. J. Stored Prod. Res. 45: 236-240.

Baker, J. E. and K. J. Kramer. 1996. Biotechnological approaches for stored-product insect pest management. Postharvest News and Information 7: 11-18.

Bohmont, B. L. 2007. The Standard Pesticide User's Guide. 7th Edition. Pearson Prentice Hall, Inc., Upper Saddle River, N. J. (book)

Boina, Dhana Raj and Bhadriraju Subramanyam. 2012. Insect management with aerosols in food-processing facilities. p. 195-212. In Farzana Perveen (ed.) Insecticides – Advances in Integrated Pest Management. InTech Europe, Rijeka, Croatia. <http://www.intechopen.com/books/insecticides-advances-in-integratedpest-management/insect-management-with-aerosols-in-food-processing-facilities>

Hodges, R. J., P. Carr and A. I. Hussein. 1999. Limiting the amount of pesticide applied to small bulks of maize in rural stores. p. 956-963. In Zuzan, J., L. Quan, L. Yongsheng, T. Xiachang, and G. Liaghua [eds.] Proceedings of the 7th International Working Conference on Stored Product Protection, Sichuan Publishing House, Chengdu, Peoples Republic of China.

Lale, N. E. S. 1995. An overview of the use of plant products in the management of stored product Coleoptera in the tropics. Postharvest News and Information 6: 69-75.

Minett, W. and P. Williams. 1971. Influence of malathion distribution on the protection of wheat grain against insect infestation. J. Stored Prod. Res. 7: 233-242.

Nansen, C. and T. W. Phillips. 2004. Attractancy and toxicity of an attracticide for Indianmeal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae). J. Econ. Entomol. 97: 703-710.

Nawrot, J. and J. Harmatha. 1994. Natural products as antifeedants against stored product insects. Postharvest News and Information 5: 17-21.

Obeng-Ofori, D. and S. Aniteye. 2005. Efficacy of mixing vegetable oils with piriniphos-methyl against the maize weevil, *Sitophilus zeamais* Motschulsky in stored maize. J. Stored Prod. Res. 41: 57-66.

Oberlander, H. and D. L. Silhacek. 2000. Insect growth regulators. p. 147-163. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Paragiotakopulu, E., P. C. Buckland and P. M. Day. 1995. Natural insecticides and insect repellents in antiquity: a review of the evidence. J. Archaeological Sci. 22: 705-710.

Rajapakse, R. and H. F. Van Emden. 1997. Potential of four vegetable oils and ten botanical powders for reducing infestation of cowpeas by *Callosobruchus maculatus*, *C. chinensis* and *C. rhodesianus*. J. Stored Prod. Res. 33: 59-68.

Snelson, J. T. 1987. Grain Protectants. ACIAR monograph No. 3. (book)

Subramanyam, Bh. And R. Roesli. 2000. Inert dusts. p. 321-380. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Throne, J. E., J. E. Baker, F. J. Messina, K. J. Kramer and J. A. Howard. 2000. Varietal resistance. p. 165-192. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Toews, M. D., J. F. Campbell, F. H. Arthur and M. West. 2005a. Monitoring *Tribolium castaneum* (Coleoptera: Tenebrionidae) in pilot-scale warehouses treated with residual applications of (S)-hydroprene and cyfluthrin. J. Econ. Entomol. 98: 1391-1398.

White, N. D. G. and J. G. Leesch. 1996. Chemical control. p. 287-304. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Ch. 18 Fumigation and modified atmospheres

Adler, C., H. Corinth and C. Reichmuth. 2000. Modified atmospheres. p. 105-146. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Annis, P. C. 2001. Phosphine dosage regimes required for high mortality: a data-base approach. p. 45-55. In Donahaye, E. J., S. Navarro and J. G. Leesch [eds.] Proc. Intern. Conf. Controlled Atmosphere and Fumigation in Stored Products, Executive Printing Services, Clovis, California.

Banks, J. and P. Fields. 1995. Physical methods for insect control in stored-grain ecosystems. p. 367-377. In D. S. Jayas, N. D. G. White and W. E. Muir [eds.] Stored-Grain Ecosystem, Marcel Dekker Inc., New York.

Bell, C. H. 1996. Alternatives – Physical Methods and Emission Reduction. p. 372-376. In Bell, C. H., N. Price and B. Chakrabarti [eds.] The Methyl Bromide Issue. John Wiley & Sons, New York. (book)

Bond, E. J. 1984. Manual of Fumigation for Insect Control. Food and Agriculture Organization of the United Nations Plant Production and Protection Paper 54. (book)

Buckman, K.A., J.F. Campbell, and B. Subramanyam. 2013. *Tribolium castaneum* (Coleoptera: Tenebrionidae) associated with rice mills: Fumigation efficacy and population rebound. J. Econ. Entomol. 106: 499-512.

Campbell, J. F., and R. T. Arbogast. 2004. Stored-product insects in a flour mill: population dynamics and response to fumigation treatments. Entomol. Exp. Appl. 112: 217-225.

Campbell, J. F., K. A. Buckman, P. G. Fields and B. Subramanyam. 2015. Evaluation of Structural Treatment Efficacy against *Tribolium castaneum* and *Tribolium confusum* (Coleoptera: Tenebrionidae) Using Meta-Analysis of Multiple Studies Conducted in Food Facilities. J. Econ. Entomol. 108: 2125-2140.

Campbell, J.F., M.D. Toews, F.H. Arthur, and R.T. Arbogast. 2010a. Long-term monitoring of *Tribolium castaneum* in two flour mills: seasonal patterns and impact of fumigation. J. Econ. Entomol. 103: 991-1001.

Campbell, J.F., M.D. Toews, F.H. Arthur, and R.T. Arbogast. 2010b. Long-term monitoring of *Tribolium castaneum* populations in two flour mills: rebound after fumigation. J. Econ. Entomol. 103: 1002-1011.

Davis, R. and R. H. Barrett. 1986. In-transit shipboard fumigation of grain: research to regulation. Cereal Foods World 31: 227-229.

- Flinn, P., C. Reed, D. Hagstrum and T. Phillips. 2007b. Seasonal and spatial changes in insect density in commercial elevator bins: implications for phosphine fumigation. *International Miller* 2006-2007: 36-40.
- Hamlin, J. C. and W. D. Reed. 1927. Insect revival after fumigation. *J. Econ. Entomol.* 20: 400-428.
- Hartzer, M., B. Subramanyam, W. Chayaprasert, D. E. Maier, S. Savodelli, J. F. Campbell, and P. W. Flinn. 2010. Methyl bromide and sulfuryl fluoride effectiveness against red flour beetle life stages, pp. 365-370. In M. O. Carvalho, P. G. Fields, C. S. Adler, F. H. Arthur, C. G. Athanassiou, J. F. Campbell, F. Fleurat-Lessard, P. W. Flinn, R. J. Hodges, A. A. Isikber, et al. (eds.), *Proceedings of the 10th International Working Conference on Stored Product Protection*, 27 June-2 July 2010, Estoril, Portugal. Julius Kühn-Institut, Berlin, Germany.
- Hole, B. D., C. H. Bell, K. A. Mills and G. Goodship. 1976. The toxicity of phosphine to all developmental stages of thirteen species of stored product beetles. *J. Stored Prod. Res.* 12: 235-244.
- Lindgren, D. L. and L. E. Vincent. 1962. Fumigation of food commodities for insect control. p. 85-152. In R. L. Metcalf [ed.] *Advances in Pest Control Research Volume 5*, John Wiley & Sons, New York.
- Navarro, S. 2006. Modified atmospheres for the control of stored-product insects and mites. Pages 105-145 in: *Insect Management for Food Storage and Processing*, 2nd ed. J. Heaps (ed.) AACC International, St. Paul, MN.
- Navarro, S., Jay, E. G., and Leesch, J. G. 1986. Recirculation rate for adequate distribution of carbon dioxide in grain bins. *Trans. ASAE* 29:1348-1354.
- Newman, C. J. E. 1990. Specification and design of enclosures for gas treatment. p. 108-130. In *Fumigation and controlled atmosphere storage of grain*. Australian Centre International Agricultural Research proceedings series no. 25.
- Noyes, R. T., and Kenkel, P. 1994. Closed loop fumigation systems in the south-western United States. Pages 335-341 in: *Proc. 6th International Working Conference on Stored-Product Protection*. (Canberra, Australia.) E. Highley, E. J. Wright, H. J. Banks, and B. R. Champ, Eds. CAB International, Wallingford, U.K.
- Reed, C. and H. Pan. 2000. Loss of phosphine from unsealed bins of wheat at six combinations of grain temperature and grain moisture content. *J. Stored Prod. Res.* 36: 263-279.
- Small, G. J. 2007. A comparison between the impact of sulfuryl fluoride and methyl bromide fumigations on stored product insect populations in UK flour mills. *J. Stored Prod. Res.* 43: 410-416.
- Tsai, W.-T., L. J. Mason, W. Chayaprasert, D. E. Maier, and K. E. Ileleji. 2011. Investigation of fumigant efficacy in flour mills under real-world fumigation conditions. *J. Stored Prod. Res.* 47: 179-184.
- Walter, V. E. 1991. Fumigation in the food industry. p. 441-457. In Gorham, J. R. [ed.], *Ecology and Management of Food-Industry Pests*, Assoc. Official Analytical Chem., Arlington, Virginia.
- Walter, V. 2006. Commodity and space fumigations in the food industry. Pages 183-198 in: *Insect Management for Food Storage and Processing*, 2nd ed. J. Heaps (ed.) AACC International, St. Paul, MN.
- White, N. D. G. and J. G. Leesch. 1996. Chemical control. p. 304-320. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Integrated Management of Insects in Stored Products*, Marcel Dekker, Inc., New York.
- Zettler, J. L., J. G. Leesch, H. B. Gillenwater, L. M. Redlinger, R. Davis and J. M. Zehner. 1986. Feasibility of fumigating unmodified river barges with phosphine while in transit. *J. Econ. Entomol.* 79: 1315-1318.

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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
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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.

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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 (Olivier, 1789) Lepidoptera: Gelechiidae), maize weevil (Motschulsky, 1855 Coleoptera: Curculionidae), the Indian meal moth (*Plodia interpunctella* (Hubner, 1813) Lepidoptera: Pyralidae), the almond moths, (Walker) (Pyralidae: Lepidoptera), flour beetles (spp.), the flat bark beetles spp. (Coleoptera: Laemophloeidae) and the sap beetles 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 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 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 (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 [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.

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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.

1. : 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.

2. 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

. 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.

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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 ((Linnaeus, 1758) Coleoptera: Curculionidae)

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

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

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.

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 ((Linnaeus, 1763) Coleoptera: Curculionidae)

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.

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.

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 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.

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 ((Gyllenhal, 1838) Coleoptera: Curculionidae)

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

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

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.

It damages soft or damaged seeds and not the dry, hard, and uninjured seeds.

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

The coffee-bean weevil (Coleoptera: Brentidae) is cosmopolitan in nature.

Its main hosts are dried fruits, coffee, corn, cornstalks, seeds, and seed pods.

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.

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

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 ((Fabricius, 1792) Coleoptera: Bostrichidae)

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.

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.

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.

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 ((Horn, 1878) Coleoptera: Bostrichidae)

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

The main host is corn, wheat, rice, and millet.

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.

These are notorious for the emission of sweet, musty odor during an infestation.

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 (Olivier, 1789 Lepidoptera: Gelechiidae)

The name Angoumois is given to this pest because it was first noticed as a pest in the Angoumois province of France in 1773.

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.

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.

: 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 ((Fabricius, 1775) Lepidoptera: Sphingidae)

The wolf moth is cosmopolitan in distribution.

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.

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

: 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 ((Boddie, 1850) Lepidoptera: Noctuidae)

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

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

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.

: 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 ((Stainton, 1866) Lepidoptera: Pyralidae)

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.

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.

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.

: 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 ((Walker, 1863) Lepidoptera: Pyralidae)

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

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

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.

: 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.

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 ((Hübner, 1813) Lepidoptera: Pyralidae)

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

They are mainly damaging dried fruits, nuts, cashew nuts, almonds, etc.

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.

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 (Zeller, 1879 Lepidoptera: Pyralidae)

Being cosmopolitan in nature, the Mediterranean flour moth (Lepidoptera: Pyralidae) is found all around the world especially in countries that have temperate climates. It mainly prefers warm temperatures for rapid development.

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.

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.

: 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 ((Linnaeus, 1758) Lepidoptera: Pyralidae)

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

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

: 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.

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

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 (Linnaeus, 1758 Coleoptera: Tenebrionidae)

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

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.

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.

: 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 (Fabricius, 1792 Coleoptera: Tenebrionidae)

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

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

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.

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

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 ((Linnaeus, 1758) Coleoptera: Tenebrionidae)

Cadelle is present in almost all parts of the world.

its main host is grain and grain products.

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.

: 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 ((Linnaeus, 1758) Coleoptera: Silvanidae)

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

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

: 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, flatfoot, 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.

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

4.6.3 Square-necked grain beetle ((Guérin-Ménéville, 1844) Coleoptera: Silvanidae)

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

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

: 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.

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

4.6.4 Foreign grain beetle ((Waltl, 1834) Coleoptera: Silvanidae)

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.

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

: 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.

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

4.6.5 Mexican bean beetle (Mulsant, 1850 (Coleoptera: Coccinellidae)

: 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.

: 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.

: 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.

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

4.6.6 Siamese grain beetle ((Klug, 1832) Coleoptera: Trogositidae)

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

: The main host is rice and cereals.

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.

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

4.6.7 Flat grain beetle ((Schoenherr, 1817) Coleoptera: Silvanidae)

Flat grain beetle is commonly found all over the world.

: Its main hosts are corn and wheat grains.

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.

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

4.6.8 Confused flour beetle (Jaquelin du Val, 1868 Coleoptera: Tenebrionidae)

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

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

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.

: Being secondary pests they do not directly attack the grain but 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 ((Herbst, 1797) Coleoptera: Tenebrionidae)

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

: 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.

: 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.

: 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 (Waterhouse, 1880 Coleoptera: Tenebrionidae)

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

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

: 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 , 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.

: 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 ((Fabricius, 1801) Coleoptera: Tenebrionidae)

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

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

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

: Being secondary pests they do not directly attack the grain but 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 ((Fabricius, 1798) Coleoptera: Tenebrionidae)

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

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

: 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.

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

4.6.13 Small-eyed flour beetle ((Wissmann, 1848) Coleoptera: Tenebrionidae)

: Small-eyed flour beetle is cosmopolitan in nature.

: 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.

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.

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

4.6.14 Tobacco beetle or Cigarette beetle ((Fabricius, 1792) Coleoptera: Anobiidae)

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

: 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.

: 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.

: 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 ((Linnaeus, 1758) Coleoptera: Anobiidae)

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

: 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.

: 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 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 ((Brahm, 1791) Coleoptera: Dermestidae)

: The Black carpet beetle is cosmopolitan in distribution.

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

: 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.

: 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 (Everts, 1898 Coleoptera: Dermestidae)

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

: 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.

: 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 Frass. The larval stage is the devastating stage. Adults are non-feeders.

: 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 (sp. *Coleoptera: Dermestidae*)

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

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

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.

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

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

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

: This pest mainly prefers flour, cheese, or cocoa.

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.

: 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

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

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

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.

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

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

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

: 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.

: 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.

: 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 ((*Fabricius, 1792*) *Coleoptera: Nitidulidae*)

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

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

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

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

4.6.23 Pulse beetle ((*Linnaeus, 1758*) *Coleoptera: Chrysomelidae*)

Pulse beetle is distributed throughout the temperate regions of the world.

is a frequent pest of all pulses, beans and grams.

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.

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.

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*)

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.

: 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.

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.

: 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.

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 (Linnaeus, 1758 Sarcoptiformes: Acaridae)

Mites are microscopic and are cosmopolitan in distribution.

: 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.

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.

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

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.

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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 threshold 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

1. : In this method number of insects per kilogram of grain or the number of moths per square meter are estimated.
2. : 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.
3. : 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 , , spp., , , and 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:

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

Botanicals based on pyrethrin obtained from the flowers of 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].

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.

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.

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.

These are promising treatments for the control of stored grain pests such as , , (Coleoptera: Curculionidae), (Coleoptera: Bostrychidae), (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 , , and 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:

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

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.

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. and are highly susceptible to cold, whereas spp., and 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.

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.

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.

Insects perform aerobic respiration for their survival. Maintenance of low O₂ atmosphere is blown at the base of the containers, bins, and other stored chambers, forcing out the existing O₂ rich atmosphere is a convenient method for infestation control.

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:

- 1. Gravity screens, with which grains are passed over a screen during handling.
- 2. Rotary screens, are very effective cleaners that tumble and separate fines from grains.
- 3. Perforated auger, is used to separate fines when the grain is conveyed over the auger.
- 4. 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].

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. Treatment of alleyways and gangways should be done with malathion 50 EC 10 mL. Spraying of malathion 50 EC 10 mL with @ 3 L of spray fluid/100 m² 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 (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 () 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 , 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, spp. has been used against moths in groundnut, wheat, bakeries as well as in warehouses and retail shops [36]. spp. is a larval and pupal parasitoid of spp., spp., and 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].

Plant species	Family	Active ingredient	Target pest
spp.	Acoraceae	β-Asarone	,,
	Verbenaceae	Citronellal and sabinene	
	Verbenaceae	Carvone and limonene	
	Asteraceae	1, 8-cineole	
	Asteraceae	3-Carene	
	Asteraceae	β-Pinene	
	Solanaceae	β-Pinene	
	Apiaceae	Carvone, Limonene, (E)-Anethole	
	Cupressaceae	Bornyl acetate	
	Amaranthaceae	Hexadecane	
	Lauraceae	Cinnamaldehyde	
	Rutaceae	Limonene Eugenol	
	Araceae	2, 3-Dimethylmaleic anhydride	
	Convolvulaceae	Hexadecanoic acid	,,
	Asteraceae	Dicolyhexanedioate	
	Apiaceae	Linalool	
	Cupressaceae	Umbellulone and α-pinene	
	Annonaceae	2,4,5-trimethoxystyrene	
	Myrtaceae	α-Terpinene; 1, 8-Cineole; α-pinene	
	Myrtaceae	p-Cymene	
	Rutaceae	Triterpenes	
	Apiaceae	Phenylpropenes (E)-anethole Estragole (p)-Fenchone	
	Cupressaceae	Citronellol	

Plant species	Family	Active ingredient	Target pest
	Verbanaceae	Coumaran	
	Myrtaceae	Terpine-4-ol Terpinolene γ -Terpinene	
	Lamiaceae	Carvone, menthol, linalool, linalyl acetate	
	Caprifoliaceae	Aristolone	
	Lamiaceae	Linalool	
	Lamiaceae	Camphor	
	Myrtaceae	Linalool	
	Lamiaceae	Camphor	
	Lamiaceae	Xanthohumol	
	Asteraceae	(E)-anethole and estragole	
	Malvaceae	Phenol	
	Zingiberaceae	1, 8-cineole	
	Zingiberaceae	β -Zingiberene	

Table 1.

Plant volatile organic compounds used against stored grain pests.

Source: 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:

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 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 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].

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]. could inhibit molting and induce several morphogenic abnormalities in the larvae of at the concentration of 1 $\mu\text{g}/\mu\text{l}$.

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 , , [52], , , , are the oviposition deterrents, thereby reducing the viability of eggs and emergence of , , and . Finely powdered and dried leaves of can completely suppress the oviposition of at 2%W/W, with an EC50, of 0.45% W/W [53]. The powdered form of , , and , applied at the rate of 1.5 kg/100 kg of , was found to be the most effective in the mortality of *Z. subflascial* and *A. objects* [54]. Some phytochemicals obtained from and are causing egg mortality [55].

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 and ar-turmerone isolated from are potent repellents against and [56, 57]. Infestation by can be effectively controlled by different solvent extracts, acting as repellents, obtained from , , , and . Ethanolic extract of *Acorus calamus* is an active constituent *Z*-asarone, which acts as a strong repellent against [58]. Repellent used against is an essential oil obtained from [59].

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 , in antifeedant against various pests, is highly appreciable. Some essential oils acting as antifeedants are obtained from , against and [60]. Some flavonoid compounds acting as antifeedants are Isoglabratephrin, -glabratephrin, tephroapollin-F, and lanceolatin-A, isolated from , against , , and .

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

Источник: <https://www.intechopen.com/chapters/79822>

More Stored-Product Entomology Books

The following list adds 67 stored-product entomology books, many not in English, to those listed in Stored-Product Insect Resource, Atlas of Stored-Product Insects and Mites, and Chapter 1 of Stored Product Protection S156 (<http://www.ksre.ksu.edu/bookstore/Category.aspx?d=521&catId=522&Page=2>).

Al-Iraqi, R.A. 2010. Grains and Stored Product Pests and Methods of Their Control. Mosul Univ. Press, pp. 616. (In Arabic)

Athanassiou, C. G. and F. Arthur (eds.) 2018. Recent Advances in Stored Product Protection. Springer, Berlin, Heidelberg

Bagheri-Zenouz, E. 1984. Methods of Control of the Pests of Stored Products and Quarantine. Adib Publishing Co., Tehran. 252 p. (Persian)

Bagheri-Zenouz, E. 1996. Les Animaux Nuisibles aux Produits Enterposes. Volume 1: Les Coleopteres Depredaterures des Produits Alimentaires et Industriels. (Pests of Stored Products. Volume 1: Injurious Coleoptera of Food and Industrial Products) Sepehr Publishing Center, Tehran. 309 p.

Berger, H. K., and P. P. Kohlhaas. 1988. Vorrats- und Materialschädlinge (Storage and material pests). Bundesministerium für Land- und Forstwirtschaft, Wien.

Bhargava, M. C., & Kumawat, K. C. 2010. Pests of Stored Grains and Their Management. New India Publishing, New Delhi.

Brandt, H., and M. Laubmann. 1955. Vorrats-und Materialschädlinge (Storage and material pests). Obst- u. Gartenbauverlag, München.

Butler, Edward Albert 1893. Our Household Insects: An Account of the Insect-pests Found in Dwelling-houses. Longmans, Green, and Company. <https://books.google.com/books?hl=en&lr=&id=jjIIAQAAIAAJ&oi=fnd&pg=PA1&dq=%22Ptilinus+pectinicornis%22+&ots=lqQcu3T242&sig=PLq5Hd37AvMvp4JtmwwbOeaY8dg#v=onepage&q=%22Ptilinus%20pectinicornis%22&f=false>

Calderon, Moshe and Rivka Barkai-Golan. 1990. Food Preservation by Modified Atmospheres. CRC Press, Boca Raton, Florida

Champ, B. R. and E. Highley. 1986. Pesticides and humid tropical grain storage systems: proceedings of an international seminar, Manila, Philippines, 27-30 May 1985. ACIAR Proceedings No. 14, 364 p.

Chao, Y., L. Hung-Shing, and K. Ging-Ya. 1980. Surveys of Chinese Stored Products Insect Pest Fauna. Agriculture Press, Beijing, China.

Chen, Q. Z., and J. G. Huang. 1985. Album of Warehouse Insects. Chinese Scientific Press, Beijing, China.

Chen, Yung-Chang, Lee Hung-Shung and Kao Ging-Ya 1980. Survey of Chinese Stored Product Insect Pest Fauna. Agricultural Press, Beijing, China

Chen, Y. X. 1985. Warehouse Pests (Supplement Edition). Chinese Agricultural Press, Beijing, China.

Delobel, A. and M. Tran. 1993. Les Coleopteres des denrees alimentaires entreposes dans les regions chaudes. Faune Trop. 32: 1-425. Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), Paris. (The Coleoptera of food stuffs originating in hot areas) (in French)

Dick, K. M. 1987. Pest Management in Stored Groundnuts. Patancheru, India : ICRISAT 28 p.

Domenichini, G. 1996. Protezione degli alimenti. Contaminazione biologica e sanità ambientale nelle industrie alimentari. (Food protection. Biological contamination and environmental health in the food industry) EtasLibri, Milano, 235 p.

- Fujii, K., A. M. R. Gatehouse, C. D. Johnson, R. Mitchell and T. Yoshida. 1990. Bruchids and Legumes: Economics, Ecology and Coevolution. Proceedings of 2nd International Symposium on Bruchids and Legumes, September 6-9, 1989, Okayama, Japan.
- Gelosi, Attilio and Stüss, Luciano 1991. Insetti e acari dei cereali in magazzino. (Insects and mites of cereals in storehouses) Edagricole, Edizioni Agricole, Bologna, Italy 120 pp.
- Gelosi, Attilio and Luciano Süss. 1995. Un pastificio sano per un prodotto di qualità : manuale dei rischi, controllo e sanificazione per l'industria della pasta. (A pasta healthy for a quality product: Manual of risks, control and sanitation for the pasta industry) Bologna : Avenue Media ; Roma ; Istituto Italiano Paste Alimentari, 181 p.
- Ghosh, S. K. and S. L. Durbey 2003. Integrated management of stored grain pest. Lucknow : International Book Distributing Co.
- Heinze K. 1974. Leitfaden der Schädlingsbekämpfung. Band.IV. Vorrats- und Materialschädlinge (Vorratsschutz). Guide for pest control. Band.IV. Storage and material pests (storage protection). Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart., 348 pp
- Herfs, Adolf and Hermann Stötter. 1951. Wollschädlinge und ihre moderne Bekämpfung (Wool pests and their modern fight against). Farbenfabrik Bayer Aktiengesellschaft, Leverkusen, Germany.
- Jansson, R. K. and K. V. Raman 1991. Sweet Potato Pest Management: a global perspective. Westview Press, Boulder.
- Kemper H. 1939. Die Nahrungs- und Genussmittelschädlinge und ihre Bekämpfung. The food and beverage pests and their control. Dr. Paul Schöps, Leipzig, 266 pp.
- Khare, B.P. 1994. Stored grain pests and their management, 1st ed. Kalyani Publishers, New Delhi.
- Khare, B. P. 2004, 2011. Stored grain pests and their management. Ludhiana, India: Kalyani Publishers. 314 p.
- Kong, Y. 1986. Pests in Storage. Chinese Finance and Economics Publisher, Beijing, China
- Kono, Tunemori. 1951. Theory and Practice of Storing Grain. Kawaide Syobo, Tokyo. (Cited in Kiritani, K. 1965. Biological Studies on the Sitophilus Complex (Coleoptera: Curculionidae) in Japan. J. Stored Prod. Res. 1: 169-176.)
- Labeyrie, V. (ed.) 1981. The ecology of Bruchids Attacking Legumes (Pulses). Proceedings of the International Symposium held at Tours (France), April 16-19, 1980. Series Entomologica 19, Junk, Hague.
- Lale, N.E.S. 2002. Stored Product Entomology and Acraology in Tropical Africa. Mole Publications, Maiduguri, Nigeria 204pp.
- Lepesme, P. 1944. Les Coléoptères des denrées alimentaires et des produits industriels entreposés. Paul Lechevalier, Paris.
- Li, F. 2002. Zhongguo chi mu zhi (Psocoptera of China). Ke xue chu ban she/Science Press, Beijing.
- Li, L. and W. Zhu. 2009. Stored Product Entomology. Chongqing Publishing House, Chongqing
- Li, Long-shu, and Yun-rui Li. 1988. Acarology. Chongqing Publishing House, Chongqing, China. 520 pp.
- Liu, Yongping and Zhang, Shengfang 1986. Chinese dermestid beetles associated with stored products (in Chinese, Zhongguo cang chu pin pi du hai chong). Agriculture Publishing House/ Nong Ye Chu Ban She, Beijing, China.
- Lorini, Irineu, Francisco Carlos Krzyzanowski, José de Barros França-Neto, Ademir Assis Henning and Fernando Augusto Henning 2015. Manejo Integrado de Pragas de Grãos e Sementes Armazenadas. (Integrated Management of Grain Pests and Stored Seeds) Embrapa, Brasília, DF, Brazil 81 p.
- Lorini, Irineu; Lincoln Hiroshi Milke and Vildes M. Scussel. 2002. Armazenagem de grãos. (Grain storage) Instituto de Bio Geneziz (IBG), Campinas, SP (Brazil), 983 p.
- Maier, Dirk E. 2020. Advances in postharvest management of cereals and grains. Burleigh Dodds series in Agricultural Science Number 88, Burleigh Dodds Science Publishing, Cambridge, UK
- Narayanasamy, P., S. Mohan and J.S. Awaknarav. 2009. Pest Management in Store Grains. Proceedings National Symposium entitled Towards pest free grains and seeds in storage, 26-27 March, 2007, Department of Entomology, Annamalai University, Tamil Nadu, India. Satish Serial Publishing House, Delhi, India. 272 p.
- Odeyemi O. O. and A. M. Daramola. 2000. Storage practices in the tropics. Vol. 1: Food Storage and Pest Problems. First Edition, Dave Collins Publication, Nigeria 235 p.
- Ofiya, T.I. and Lale, N.E.S. 2001. Pests of Stored Cereals and Pulses in Nigeria-biology, ecology and control. Nigeria: Dave Collins Publications. 174 pp.
- Osuji, Fabian. 1985. Outlines of stored products entomology for the tropics. Enugu, Nigeria : Fourth Dimension Publishers.
- Pacheco, I. A. and D. C. de Paula. 1995. Insetos de graos armazenados – identificacao e biologia. Campinas, Brazil, Fundacao, Cargill, 228 p. (Cited in Cristina, M., Z. DePaula, F. A. Lazzari and S. M. Lazzari. 1999. Insect monitoring outside paddy rice grain storage facilities in southern Brazil. p.532-1533. In 7th IWCSPP).
- Perez-Mendoza, Joel. 1993. Insectos de Granos Almacenados: Biología, Danos, Detección y Combate. (Stored Grain Insects: Biology, Damage, Detection and Combating) Centro de Investigacion Regional del Centro Campo Experimental Bajío, Celaya, Gto., Mexico.
- Popov, V. I. 1939. Warehouse insect pests in Bulgaria and their control. Sofia. 195 p.
- Portchinsky, I. A. 1913. Insects injurious to grain in stores and warehouses. Memoirs of the Bureau of Entomology of the Scientific Committee of the Central Board of Land Administration and Agriculture, St. Petersburg. Review of Applied Entomology A 2: 39-41 (1913)
- Prakash, A., J. Rao, I. C. Pasalu and K. C. Mathur. 1987. Rice storage and insect pest management. Delhi : B.R. Pub. Corp., 1987. 337 pages
- Prakash, A., J. Rao, D. S. Jayas and J. Allotey. 2003. Insect pests of stored products: a global scenario. Applied Zoologists Research Association (AZRA), Central Rice Research Institute, Cuttack, India.
- Pruthi, H. S.: Singh, M. 1950. Pests of stored grain and their control. Indian J. Agric. Sci. 18: 1-88 (3rd Ed.)
- Reichmuth, C., M. Scholler, and C. Ulrichs. 2007. Stored product pests in grain: morphology, biology, damage, control. AgroConcept, Bonn, Germany.
- Rosentrater, Kurt A. 2022. Storage of Cereal Grains and Their Products. 5th edition, Woodhead Publishing, Elsevier, UK and AACC International Press
- Stejskal, Vaclav 1998. Ochrana pred potravinovými a hygienickými škodci (Protection against food and hygiene pests) Vysehrad, Prague
- Stejskal, Vaclav and Cornel Adler 1997. Fumigace A Rizene Atmosféry (Fumigation and controlled atmosphere). Association of disinfection, disinsection, deratization workers in the Czech Republic, Prague
- Stüss, Luciano. 1988. Gli infestanti delle derrate conservate e delle industrie alimentari. (The storage pests infestation and food industries) MoEdCo Edizioni, Milano, 304 pp.
- Stüss, Luciano 1990. Gli intrusi. Manuale di entomologia urbana. (The intruders. Handbook of Urban Entomology) Edagricole, Bologna, Italy. 226 pp.
- Stüss, Luciano and D.P. Locatelli. 2001. I parassiti delle derrate. Riconoscimento e Gestione delle Infestazioni nelle Industrie Alimentari. (The pests of food. Recognition and Management infestations for the Food Industry.) Calderini Edagricole, Bologna, Italy 363 pp.
- Stüss, Luciano. 2004. Gli intrusi. Manuale di entomologia urbana. (The intruders. Handbook of Urban Entomology) L'Informatore Agrario 179 pp.
- Trematerra, Pasquale and Luciano Süss. 2007. Prontuario di entomologia merceologica e urbana : con note morfologiche, biologiche e di gestione delle infestazioni. (Handbook of commodity and urban entomology: with notes morphological, biological and management of infestations) Aracne Editrice, Roma, 154 p.
- Vukasovic P., Stojanovic., Šenborn A. (Redakcija) 1972. Štetoèine u skladištima. Biologia i suzbijanje. (Pests in warehouses. Biology and control). Novi Sad. 540 pp.
- Wang, Dianxuan; Xuguang, Bai; Zhou, Yuxiang and Zhao, Yingile. 2008. Illustrated book of stored grain insects in China. China National Publications Import & Export (Group) Corp. (CNPI)
- Yanucci, D. 1989. Control de plagas: post cosecha de granos y semillas. Artes Graficas Mantova, Buenos Aires, Argentina. (Pest management: post harvest grain and seed)

Yanucci, D. A., Lazzari, F., and Cotto, H. 2002. Control Integrado. Insectos, ácaros, hongos y roedores en postcosecha de granos y semillas. (Integrated Control. Insects, mites, fungi and rodents postharvest grain and seed) Granos, Buenos Aires, Argentina

Zacher F. 1927. Die Vorrats-, Speicher- und Materialschädlinge und ihre Bekämpfung. (The supply, storage and material pests and their control. Paul Parey Berlin, 366 pp.

Zakladnoi, Gennadii Alekseevich and V. F. Ratanova. 1973. Vrediteli Khlebykh Zapasov i Mery Borby s Nimi. Kolos Publishers, Moscow (Translated 1986 Stored-grain pests and their control. New Delhi : Published for the United States Dept. of Agriculture and the National Science Foundation, Washington, D.C., by Amerind Publishing Co. Pvt. Ltd., 268 pages)

Zakladnoi, G.A. and V.F. Ratanova. 1987. Vrediteli Khlebykh Zapasov i Mery Borby s Nimi. (Stored-grain pests and their control) translator, Indira Nair ; general editor, V.S. Kothekar. Rotterdam : A.A. Balkema.

Zhang, S., and Y. Liu. 1998. Zhongguo chu cang wu jia chong (Beetles associated with stored products in China). Zhongguo nong ye ke ji chu ban she/ Z Hongguo Agricultural Science and Technology Press, Beijing Shi.

Zhang, S. 2004. Chu cang wu jia chong jian ding (Identification of beetles associated with stored products). Zhongguo nong ye ke ji chu ban she/Beijing shi: Z Hongguo Agricultural Science and Technology Press, Beijing Shi.

Zhang, S., H. Chen, and G. Xue. 2008. Atlas of beetles associated with stored products (in Chinese). Chinese Agricultural Science and Technology Press/ Zhong guo nong ye ke xue ji shu chu ban she, Beijing

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Stored-Product Entomology Courses

Hagstrum and Subramayam (2009) reported that stored-product entomology courses have been or are currently offered at land grant universities in four states in the United States and in at least nine other countries. See Additional Literature for overview of recent literature on stored product insects.

Hagstrum, D. W., and Bh. Subramanyam. 2009. A review of stored-product entomology information sources. Amer. Entomol. 55: 174-183.

Nicoli Aldini Rinaldo is now teaching the Insect of Stored Products course at School of Agriculture and Veterinary Medicine, Università di Bologna, Italy. <http://www.agricultureveterinarymedicine.unibo.it/en/programmes/course-unit-catalogue/course-unit/2008/158274> . For more information on the course “Protecting foods from pests” by Marco Pagani at Università Parma, Italy see webpage <http://en.unipr.it/ugov/degrecourse/25218>.

In addition to these courses, a course entitled “Pests of Stored Products” was offered by Panagiotis A. Eliopoulos to undergraduate students between 2000 and 2011 at Technological Educational Institute of Larissa School of Agriculture in Greece. Approximately, 1000 students (70-100 every semester) took the course. Pests of stored products are now covered in their Applied Entomology course. Post-harvest safety of stored agricultural products and food at University of Thessaly, a post-graduate course, is taught by Christos G. Athanassiou with 70 students per year.

The following undergraduate courses covering stored-product pests are also offered in Greece:

Pests of Annual Crops and Stored Products at Technological Educational Institute of Thessaloniki taught by Smaragdi Ch. Papadopoulou with 150 students per year.

Post-Harvest Pests and Diseases at Technological Educational Institute of Ionian Islands taught by Andreas Vitoratos and Charilaos Giotis.

Agricultural Entomology & Zoology at Agricultural University of Athens taught by Constantine Th. Buchelos prior to 2008 and then Nickolas G. Kavalieratos with 150 students per year.

Pests of Stored Products and Sanitation Insects at Democritus University of Thrace taught by Georgios Broufas and Maria Pappa.

Protection of Stored Products at University of Thessaly taught by Christos G. Athanassiou.

Pests of Stored Products at Aristotle University of Thessaloniki taught by Demetrius Koveos and Nikos Koulousis.

A Course entitled “Biology of Pests of Stored Products and Their Control” is taught by Mrs A.C Adeyemo in the Deptment of Biology, Federal University of Technology, Akure, Nigeria. See <http://www.futa.edu.ng/futaacms/admin/attachments/BIO%20411.pdf>

Florence M'mogi Olubayo has taught the course “Post harvest Pests and Diseases” from 2007 to the Present in the Department of Plant Science and Crop Protection, University of Nairobi, Nairobi, Kenya. See https://profiles.uonbi.ac.ke/olubayo/files/curriculum_vitae_prof._f.m.olubayo_april_2013.pdf

Girish, G. K. 1987. Training programmes on scientific storage of foodgrains offered by Department of Food, Government of India. Bulletin of Grain Technology 25(1): 70-84 describes several courses offered in India.

We more recently discovered that Don C. Peters taught a stored-product entomology course at Oklahoma State University in 1978 and 1980, and Gerrit Cuperus taught it in 1996. More recently, George Opiit and Brad Kard have taught in odd years Postharvest, Structural and Urban Arthropod Pests (ENTO 3021) at Oklahoma State University, Stillwater, OK.

Also, we more recently learned that George Dean began teaching a course in stored-product entomology (called Milling Entomology) at Kansas State University in 1914, primarily for undergraduate milling and baking students. Donald A. Wilbur began teaching the course in 1949. In 1971 the College of Agriculture made major revisions in the curricula and the course was no longer required for milling students. Wilbur began teaching the current Insects of Stored Products course in 1956.

Every other year, between 2002 and 2010, David Hagstrum taught Insects of Stored Products (ENTOM 805) at Kansas State University, Manhattan, KS. Every other year, between 2012 and 2020, David Hagstrum and Tom Phillips co-taught the course. A textbook and three other books were published to keep the course up to date (Hagstrum and Subramayam 2006, 2009; and Hagstrum et al. 2012, 2013).

The following describes the Insects of Stored Products course offered at Kansas State University.

Schedule:

Week 1 Introduction (Ch1 textbook and Ch2, Techniques p. 23-25)

Week 2 Mobility (Ch3 textbook and Ch2 Techniques p. 30-37)

Week 3 Sources of Infestation (Ch4 textbook)

Week 4 Sampling (Ch5 textbook and Ch2, Techniques p. 26-30)

Week 5 Life History (Ch6 textbook)

Week 6 Population Growth (Ch7 textbook)

Week 7 Decision Aids (Ch8 textbook and Ch9 Economics)

Week 8 Biological Control (Ch11 textbook)

Week 9 Aeration (Ch12 textbook)

Week 10 Sanitation and Exclusion (Ch13 textbook)

Week 11 Extreme Temperatures (Ch14 textbook)

Week 12 Impact and Removal (Ch15 textbook and Ch16, Ionizing Radiation)

Week 13 Residual Insecticides (Ch17 textbook and Ch10, Resistance)

Week 14 Fumigants and Modified Atmospheres (Ch18 textbook)

Week 8 Regulatory Control (Quarantine Ch 26 in KSU S156)

Student Learning Outcomes (SLOs) for ENTOM 805 include:

- 1) Become familiar with the biology, ecology and behavioral diversity of stored product insects and mites
- 2) Understand monitoring-based IPM in relation to variables in the broad environment, variation in population dynamics, use of predictive models at all levels, and management options ranging from prevention to population suppression methods.
- 3) Appreciate the need for understanding foundational and current scientific literature, as well as regulatory and economic issues, in the design and implementation of IPM programs in the US and elsewhere in the world.

Course Design:

Stored product insects and mites can damage stored grains and other commodities with serious economic losses and food security and safety issues. ENTOM 805 is targeted to graduate students in Entomology, related agricultural sciences and the life sciences who desire knowledge of this economically important group of arthropod pests that also serve as excellent examples for biological study. The class will meet twice a week to discuss a series of topics. Discussion of topics will be lead by a different student each class meeting. Local field trips and laboratory meetings will familiarize students with insect identification, grain storage and processing facilities, sampling and fumigation. Grading is based on class participation, discussions and quizzes taken at the beginning, and revised at the end, of each class.

Textbook:

Hagstrum, D. W. and Bh. Subramanyam. 2006. Fundamentals of Stored Product Entomology, AACC International, St. Paul, MN

Supplemental Chapters:

Hagstrum, D. W., T. W. Phillips and G. Cuperus (eds.). 2012. Stored Product Protection. Kansas State University S156 at <http://entomology.k-state.edu/department-info/publications/stored-product-protection.html>

A comprehensive website for additional readings and information is: <https://storedproductinsects.com/biology/additional-literature/>

A section of that website for Molecular Identification of storage insects is here:
Molecular species identification

Websites:

<http://www.refworks.com/refshare2?site=015251129867200000/159211343138040369/SP%20Pest%20Mtg>

<https://www.storedproductinsects.com>

http://www.ksre.ksu.edu/grsc_subi/speir/

<http://bru.gmpnc.ksu.edu/proj/iwscpp/>

On Reserve at Library:

Hagstrum, D. W., and Bh. Subramanyam. 2009. Stored-Product Insect Resource. AACC International, St. Paul, Minnesota.

Hagstrum, D. W., T. Z. Klejdysz, Bh. Subramanyam and J. Nawrot. 2013. Atlas of Stored-Product Insects and Mites. AACC International, St. Paul, Minnesota.

Grading:

1. Participation in discussion 40%
2. Preparedness as discussion leader 20%
3. Weekly quizzes 20%
4. Revision of chapter 20% (due May 15)

Recommended Readings:

Ch. 1 Introduction

American Institute of Baking. 1979. How to handle regulatory inspections. p. 19-21. In Basic Food Plant Sanitation Manual. American Institute of Baking, Manhattan, Kansas.

Arbogast, R. T., S. R. Chini and P. E. Kendra. 2005. Infestation of stored saw palmetto berries by *Cadra cautella* (Lepidoptera: Pyralidae) and the host paradox in stored-product insects. Florida Entomol. 88: 314-320.

Arthur, F. H. and T. Rogers. 2003. Legislative and regulatory actions affecting insect pest management for postharvest systems in the United States. p. 435-438. In Credland, P. F., D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley [eds.]. Advances in Stored Product Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, York, United Kingdom. CAB International, Wallingford, United Kingdom

Bailey, J. E. 1992. Terminal elevator storage. p. 157-182. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Buckland, P. C. 1981. The early dispersal of insect pests of stored products as indicated by archaeological records. J. Stored Prod. Res. 17: 1-12.

Cowley, R. J., D. C. Howard and R. H. Smith. 1980. The effect of grain stability on damage caused by *Prostephanus truncatus* (Horn) and three other beetle pests of stored maize. J. Stored Prod. Res. 16: 75-78.

Freeman, J. A. 1974. A review of changes in the pattern of infestation in international trade. EPPO Bull. 4: 251-273.

Gecan, J. S. 2002. Food defect action levels, pp. 77-86. In Y. H. Hui, B. L. Bruinsma, J. R. Gorham, W. K. Nip, P. S. Tong and P. Ventresca (eds.), Food Plant Sanitation. Marcel Dekker, Inc., New York, N. Y.

Hagstrum, D. W., T. Z. Klejdysz, Bh. Subramanyam and J. Nawrot. 2013. Atlas of Stored-Product Insects and Mites. AACC International, St. Paul, Minnesota. (book)

Hagstrum, D. W. and T. W. Phillips. 2017. Evolution of Stored-Product Entomology: Protecting the World Food Supply. Annu. Rev. Entomol. 62: 379-397.

Hagstrum, D. W., C. Reed and P. Kenkel. 1999. Management of stored wheat insect pests in the USA. Integrated Pest Management Review 4: 127-142.

Hagstrum, D. W. and Bh. Subramanyam. 2009. Stored-Product Insect Resource. AACC International, St. Paul, Minnesota. (book)

Hill, D. S. 2002. Types of Damage. p. 71-78. In Pests of Stored Foodstuffs and Their Control. Kluwer Academic Publishers, Boston.

Howe, R. W. 1991. Origins of insects as storage pests. p. 13-16. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.

Olsen, A. R., T. H. Sidebottom and S. A. Knight. 1996. Fundamentals of Microanalytical Entomology, a practical guide to detecting and identifying filth in foods. CRC Press, Boca Raton, Florida (book)

Reed, C. 1992. Development of storage techniques: a historical perspective. p. 143-156. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Ch. 2 Techniques

Borgemeister, C., A. Tchabi and D. Scholz. 1998. Trees or stores? The origin of migrating *Prostephanus truncatus* collected in different ecological habitats in southern Benin. Entomol. Exp. Appl. 87: 285-294.

Camara, M., C. Borgemeister, R. H. Markham and H. M. Poehling. 2003. Electrophoretic analysis of the prey spectrum of *Teretrius nigrescens* (Lewis) (Col., Histeridae), a predator of *Prostephanus truncatus* (Horn) (Col., Bostrichidae), in Mexico, Honduras and Benin. J. Appl. Entomol. 127: 360-368.

Ching'oma, G. P. 2006. Spatial distribution of movement of the lesser grain borer, *Rhyzopertha dominica* (F.). PhD Thesis, Kansas State University, Manhattan, KS

Halstead, D. G. H. 1963. External sex differences in stored-products Coleoptera. Bull. Entomol. Res. 54: 119-134.

Howe, R. W. 1991. Principles of rearing stored-product insects and of insectary management. p. 535-544. In J. R. Gorham (ed.) Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.

Perez-Mendoza, J., J. E. Throne and J. E. Baker. 2004. Ovarian physiology and age-grading in the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae). J. Stored Prod. Res. 40: 179-196.

Pfaffenberger, G. S. 1985. Description, differentiation, and biology of the four larval instars of *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). Coleopterist's Bull. 39: 239-256.

Rajendran, S. 1999. Detection of insect infestation in stored food commodities. J. Food Sci. Technol. 36: 283-300.

Scholz, D., C. Borgemeister, R. H. Markham and H. M. Poehling. 1998. Physiological age-grading and ovarian physiology of *Prostephanus truncatus*. Physiol. Entomol. 23: 81-90.

Vowotor, K. A., N. A. Bosque-Perez and J. N. Ayerley. 1995. Effect of maize variety and storage form on the development of the maize weevil, *Sitophilus zeamais* Motschulsky. J. Stored Prod. Res. 31: 29-36.

Ch. 3 Mobility

Bamey, R. J. and P. A. Weston. 1996. Movement of Angoumois grain moth (Lepidoptera: Gelechiidae) in a small-farm ecosystem. Environ. Entomol. 25: 261-267.

Campbell, J. F. and D. W. Hagstrum. 2002. Patch exploitation by *Tribolium castaneum*: movement patterns, distribution and oviposition. J. Stored Prod. Res. 38: 55-68.

Campbell, J. F. and C. Rummion. 2003. Patch exploitation by female red flour beetles, *Tribolium castaneum*. J. Insect Sci. <http://www.insectscience.org/3.20>

Campos, M. and T. W. Phillips. 2014. Attract-and-Kill and Other Pheromone-Based Methods to Suppress Populations of the Indianmeal Moth (Lepidoptera: Pyralidae). J. Econ. Entomol. 107: 473-480.

Ching'oma, G. P. 2006. Spatial distribution of movement of the lesser grain borer, *Rhyzopertha dominica* (F.). PhD Thesis, Kansas State University, Manhattan, KS

Cox, P. D., M. E. Wakefield and T. A. Jacob. 2007. The effects of temperature on flight initiation in a range of moths, beetles and parasitoids associated with stored products. J. Stored Prod. Res. 43: 111-117.

Desouhant, E., G. Driessen, L. Lapchin, S. Wieland and C. Bernstein. 2003. Dispersal between host populations in field conditions: navigation rules in the parasitoid *Venturia canescens*. Ecol. Entomol. 28: 257-267

Hagstrum, D. W. 1984. Growth of *Ephestia cautella* (Walker) population under conditions found in an empty peanut warehouse and response to variations in the distribution of larval food. Environ. Entomol. 13: 171-174.

Hagstrum, D. W. 1989. Infestation by *Cryptolestes ferrugineus* of newly-harvested wheat stored on three Kansas farms. J. Econ. Entomol. 82: 655-659.

Hagstrum, D. W. 2000. Using five sampling methods to measure insect distribution and abundance in bins storing wheat. J. Stored Prod. Res. 36: 253-262.

Hagstrum, D. W. 2001. Immigration of insects into bins storing newly harvested wheat on 12 Kansas farms. J. Stored Prod. Res. 37: 221-229.

Hagstrum, D. W. and L. R. Davis Jr. 1980. Mate-seeking behavior of *Ephestia cautella*. Environ. Entomol. 9: 589-592.

Hagstrum, D. W. and E. E. Gilbert. 1976. Emigration rate and age structure dynamics of *Tribolium castaneum* populations during growth phase of a colonizing episode. Environ. Entomol. 5: 445-448.

Hagstrum, D. W. and B. J. Smittle. 1980. Age- and sex-specific tunneling rates of adult *Tribolium castaneum*. Ann. Entomol. Soc. Amer. 73: 11-13.

Hagstrum, D. W.; Subramanyam, Bhadriraju. 2010. Immature insects: Ecological roles of mobility. American Entomologist 56(4): 230-241.

Hawkin, Karen J., Dean M. Stanbridge and Paul G. Fields 2013. Sampling *Tribolium castaneum* and *Tribolium confusum* in flour mill rollstands. Journal of Stored Products Research 52: 7-11

Hawkin, K. J., D. M. Stanbridge and P. G. Fields. 2011. Sampling *Tribolium confusum* and *Tribolium castaneum* in mill and laboratory settings: differences between strains and species. Canadian Entomologist 5: 504-517.

Jian, F. and D. S. Jayas. 2009. Detecting and responding to resources and stimulus during the movement of *Cryptolestes ferrugineus* adults. Food Bioprocess Technol. 2: 45-56.

Jian, F., D. S. Jayas and N. D. G. White. 2009. Optimal environmental search and scattered orientations during movement of adult rusty grain beetles, *Cryptolestes ferrugineus* (Stephens), in grain bulks – suggested movement and distribution patterns. J. Stored Prod. Res. 45: 177-183.

Kuenen, L. P. S. and H. C. Rowe. 2006. Cowpea weevil flights to a point source of female sex pheromone: analysis of flight tracks at three wind speeds. Physiol. Entomol. 31: 103-109.

Mankin, R. W. and D. W. Hagstrum. 1995. Three-dimensional orientation of male *Cadra cautella* (Lepidoptera: Pyralidae) flying to calling females in a windless environment. Environ. Entomol. 24: 1616-1626.

Mankin, Richard W., David W. Hagstrum, Christian Nansen and William G. Meikle. 2014. Almond moth oviposition patterns in continuous layers of peanuts. Journal of Stored Products Research 59: 48-54.

McFarlane, J. A., I. Gudrups and H. Fletcher. 1993. Biotype differences affecting the pest status of stored-grain insects. Intern. J. Pest Management 39: 35-43.

Romero, S. 2007. Influence of landscape structure on movement behavior and habitat use by red flour beetle (*Tribolium castaneum*). PhD Thesis, Kansas State University, Manhattan, KS

Romero, S., J. F. Campbell, J. R. Nechols and K. A. With. 2009. Movement behavior in response to landscape structure: the role of functional grain. Landscape Ecol. 24: 39-51.

Romero, S., J. F. Campbell, J. R. Nechols and K. A. With. 2010. Movement behavior of red flour beetle: response to habitat cues and patch boundaries. Environ. Entomol. 39: 919-929.

Savoldelli, S. and P. Trematerra. 2011. Mass-trapping, mating-disruption and attracticide methods for managing stored-product insects: success stories and research needs. Stewart Postharvest Review 3: 7.

Semeao, A. A., J. F. Campbell, R. J. Whitworth, and P. E. Sloderbeck. 2013. Movement of *Tribolium castaneum* within a flour mill. J. Stored Prod. Res. 54: 17-22.

Steel, R., D. Elmoutie, and G. Hamilton. 2012. Geostatistical analysis of adult *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) in wheat stored at constant temperatures. J. Stored Prod. Res. 50: 8-14.

Toews, M. D., J. F. Campbell, F. H. Arthur and M. West. 2005a. Monitoring *Tribolium castaneum* (Coleoptera: Tenebrionidae) in pilot-scale warehouses treated with residual applications of (S)-hydroxypropyl and cyfluthrin. J. Econ. Entomol. 98: 1391-1398.

Ukeh, D. A., I. A. Udo and E. I. Ogban. 2008. Trapping of stored-product insects using flight traps outside traditional African storage granaries. J. Food Agric. Environ. 6: 399-401.

Utida, S. 1972. Density dependent polymorphism in the adult of *Callosobruchus maculatus* (Coleoptera: Bruchidae). J. Stored Prod. Res. 8: 111-126.

Ch. 4 Sources of insect infestation

Arbogast, R. T., S. R. Chini and J. E. McGovern. 2005. *Plodia interpunctella* (Lepidoptera: Pyralidae): Spatial relationship between trap catch and distance from a source of emerging adults. J. Econ. Entomol.

- Arbogast, R. T., S. R. Chini and J. E. McGovern 2006. Use of contour analysis in monitoring stored-product insects. *J. Econ. Entomol.* 99: 601-603.
- Arthur, F. H., D. W. Hagstrum, P. W. Flinn, C. R. Reed and T. W. Phillips. 2006. Insect populations in grain residues associated with commercial Kansas grain elevators. *J. Stored Prod. Res.* 42: 226-239.
- Boon, K. S. and S. H. Ho. 1988. Factors influencing the post-fumigation reinfestation of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in a rice warehouse. *J. Stored Prod. Res.* 24: 87-90.
- Borgemeister, C., A. Tchabi and D. Scholz. 1998. Trees or stores? The origin of migrating *Prostephanus truncatus* collected in different ecological habitats in southern Benin. *Entomol. Exp. Appl.* 87: 285-294.
- Bowditch, T. G. and J. L. Madden. 1996. Spatial and temporal distribution of *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) in a confectionary factory: causal factors and management implications. *J. Stored Prod. Res.* 32: 123-130.
- Curtis, C. E., R. K. Curtis and K. L. Andrews. 1984. Progression of navel orangeworm (Lepidoptera: Pyralidae) infestation and damage of almonds on the ground and on the tree during harvest. *Environ. Entomol.* 13: 146-149.
- Hagstrum, D. W. 1985. Preharvest infestation of cowpeas by the cowpea weevil, *Callosobruchus maculatus* (Coleoptera: Bruchidae) and population trends during storage in Florida. *J. Econ. Entomol.* 78: 358-361.
- Hagstrum, D. W., P. W. Flinn and R. W. Howard. 1996. Ecology, p. 92-104. In Bh. Subramanyam and D. W. Hagstrum [eds.], *Integrated Management of Insects in Stored Products*, Marcel Dekker, Inc., New York.
- Hanlin, J. C. and C. Benton. 1925. Control of the saw-toothed grain beetle in raisins: a preliminary report. *J. Econ. Entomol.* 18: 790-795.
- Jia, F., M. D. Toews, J. F. Campbell and S. B. Ramaswamy. 2008. Survival and reproduction of lesser grain borer, *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) on flora associated with native habitats in Kansas. *J. Stored Prod. Res.* 44: 366-372.
- Nansen, C., A. Liebhold and P. Tobin. 2006. Contour mapping and number of point observations. *J. Econ. Entomol.* 99: 599-600.
- Sagnia, S. B. 1994. Mortality factors affecting *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) under field conditions in Niger. *J. Stored Prod. Res.* 30: 71-74.
- Soderstrom, E. L., R. T. Hinsch, A. J. Bongers, D. G. Brandl and H. Hoogendorn. 1987. Detecting adult Phycitinae (Lepidoptera: Pyralidae) infestations in a raisin-marketing channel. *J. Econ. Entomol.* 80: 1229-1232.
- Tilley, D. R. 2013. Incidence and spread of insects from bucket elevator leg boots. PhD Dissertation, Kansas State University Department of Grain Science and Industry.
- Williams, G. C. 1961. Infestation of a disused flour mill. *Milling* 86: 92.
- Ch. 5 Sampling
- Adam, B. D., M. Siaplay, P. W. Flinn, B. W. Brorsen, and T. W. Phillips. 2010. Factors influencing economic profitability of sampling-based integrated pest management of wheat in country elevators. *J. Stored Prod. Res.* 46:186-196.
- Belda, C., M. Ribes-Dasi, and J. Riudavets. 2011. Improving pest management in pet food mills using accurate monitoring and spatial analysis. *J. Stored Prod. Res.* 47:385-392.
- Buckman, K.A. and J.F. Campbell. 2013. How varying pest and trap densities affect *Tribolium castaneum* capture in pheromone traps. *Entomol. Exp. Appl.* 146: 404-412.
- Campbell, J. F. 2012. Attraction of walking *Tribolium castaneum* adults to traps. *Journal of Stored Products Research* 51: 11–22.
- Campbell, J.F. 2013. Influence of landscape pattern in flour residue amount and distribution on *Tribolium castaneum* (Herbst) response to traps baited with pheromone and kairomone. *J. Stored Prod. Res.* 52: 112-117.
- Fedina, T. Y. and S. M. Lewis. 2007. Effect of *Tribolium castaneum* (Coleoptera: Tenebrionidae) nutritional environment, sex, and mating status on response to commercial pheromone traps. *J. Econ. Entomol.* 100: 1924-1927.
- Hagstrum, D. W., P. W. Flinn and D. Shuman. 1996. Automated monitoring using acoustical sensors for insects in farm-stored wheat. *J. Econ. Entomol.* 89: 211-217.
- Hagstrum, D. W., P. W. Flinn and Bh. Subramanyam. 1998. Predicting insect density from probe trap catch in farm-stored wheat. *J. Stored Prod. Res.* 34: 251-262.
- Hagstrum, D. W., Milliken, G. A., and Wadell, M. S. 1985. Insect distribution in bulk stored wheat in relation to detection or estimation of abundance. *Environ. Entomol.* 14:655-661.
- Hagstrum, D. W., Bh. Subramanyam, and P. W. Flinn. 1997. Nonlinearity of a generic variance-mean equation for stored grain insect sampling data. *Environ. Entomol.* 26: 1213-1223.
- Haines, C., D. Rees, K. Ryder, S. Sistyanto and Y. Cahyana. 1991. Brown-rice bait-bags for monitoring insect pest populations in bag stacks of milled rice as an aid to pest control decision-making. p. 1351-1358. In Fluérat-Lessard, F. and P. Ducom [eds.], *Proceedings of the 5th International Working Conference on Stored-Prod.* Entomol., Bordeaux, France, Imprimerie Médocaine, Blanquefort Cedex, France.
- Hodges, R. J. 2002. Detection and monitoring of larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Integrated Pest Management Reviews* 7: 223-243.
- Kuzmanov, D. K., N. D. Dimitrov, N. P. Ginov and I. G. Yanchev. 2008. A heated trap for detecting insect infestation in stored grain at low temperatures. *Bulgarian J. Agric. Sci.* 14: 528-534.
- Mabbett, T. 1995. Pheromone traps reduce insurance fumigation for cocoa bean pests. *International Pest Control.* 37: 73-74.
- Manis, J. M. 1992. Sampling, inspection and grading. pp. 563-588. In Sauer, D. B. [ed.], *Storage of Cereal Grains and Their Products*. American Association of Cereal Chemists, St. Paul, Minnesota.
- Mankin, R. W., K. W. Vick, J. A. Coffelt and B. A. Weaver. 1983. Pheromone-mediated flight by male *Plodia interpunctella* (Hubner) (Lepidoptera: Pyralidae). *Environ. Entomol.* 12: 1218-1222.
- Mankin, R. W., R. T. Arbogast, P. E. Kendra and D. K. Weaver. 1999. Active spaces of pheromone traps for *Plodia interpunctella* (Lepidoptera: Pyralidae) in enclosed environments. *Environ. Entomol.* 28: 557-565.
- Mankin, R. W., D. W. Hagstrum, M. T. Smith, A. L. Roda, and M. T. K. Kairo. 2011. Perspective and promise: a century of insect acoustic detection and monitoring. *Amer. Entomol.* 57: 30-44.
- Mohan, S., S. S. Sivakumar, S. R. Venkatesh, and G. S. V. Raghavan. 2006. Simple technique to increase the sensitivity of probe traps in detecting *Cryptolestes ferrugineus* (Coleoptera : Laemphloeidae) in stored wheat. *Can. Entomol.* 138:733-735. (increase trap catch by increasing insect activity)
- Nansen, C., W.G. Meikle, J. Campbell, T.W. Phillips, B.Subramanyam. 2008. A binomial and species-independent approach to trap capture analysis of flying insects. *Journal of Economic Entomology* 101: 1719-1728.
- Nansen C., T. W Phillips, P. K. Morton and E. L. Bonjour. 2006. Spatial analysis of pheromone-baited trap captures from controlled releases of male Indianmeal moths. *Environmental Entomology* 35: 516–523.
- Perez-Mendoza, J., P. W. Flinn, J. F. Campbell, D. W. Hagstrum and J. E. Throne. 2004. Detection of stored-grain insect infestation in wheat transported in railroad hopper-cars. *J. Econ. Entomol.* 97: 1474-1483.
- Subramanyam, Bh. and D. W. Hagstrum. 1996. Sampling. pp. 135-193. In Bh. Subramanyam and D. W. Hagstrum [eds.], *Integrated Management of Insects in Stored Products*, Marcel Dekker, Inc., New York.
- Subramanyam, Bh., D. W. Hagstrum, R. L. Meagher, E. C. Burkness, W. D. Hutchinson and S. E. Naranjo. 1997. Development and evaluation of sequential sampling plans for *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) infesting farm-stored wheat. *J. Stored Prod. Res.* 33: 321-329.
- Toews, M. D., F. H. Arthur and J. F. Campbell. 2005b. Role of food and structural complexity on capture of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in simulated warehouses. *Environ. Entomol.* 34: 164-169.
- Toews, M. D., F. H. Arthur and J. F. Campbell. 2009. Monitoring *Tribolium castaneum* (Herbst) in pilot-scale warehouses treated with β -cyfluthrin: are residual insecticides and trapping compatible? *Bull. Entomol. Res.* 99: 121-129.

Ch. 6 Life history

- Arbogast, R. T. 1991. Beetles: Coleoptera. p. 131-176. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.
- Barrer, P. M. 1976. The influence of delayed mating on the reproduction of *Ephestia cautella* (Walker) (Lepidoptera: Phycitidae). J. Stored Prod. Res. 12: 165-169.
- Bell, C. H. 1994. A review of diapause in stored-product insects. J. Stored Prod. Res. 30: 99-122.
- Boczek, J. 1991. Mite pests in stored food. p. 57-79. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia. (Life histories of stored-product mites)
- Chapman, R. N. 1923. The possibility of transmitting a *Calendra* infestation from wheat to macaroni thru the processes of milling and manufacturing. J. Econ. Entomol. 16: 341-348.
- Cox, P. D. and C. H. Bell. 1991. Biology and ecology of moth pests of stored foods. p. 181-193. In J. R. Gorham [ed.] Ecology and Management of Food-Industry Pests, Assoc. Official Analytical Chem., Arlington, Virginia.
- Esperk, T., T. Tammaru and S. Nylin. 2007. Intraspecific variability in number of larval instars in insects. J. Econ. Entomol. 100: 627-645.
- Hagstrum, D. W. and G. A. Milliken. 1988. Quantitative analysis of temperature, moisture and diet as factors affecting insect development. Ann. Entomol. Soc. Amer. 81: 539-546.
- Hagstrum, D. W. and Bh. Subramanyam. 2009. A review of stored-product entomology sources. Amer. Entomol. 55 (3): 174-183.
- Hagstrum, D. W., P. W. Flinn and R. W. Howard. 1996. Ecology, p. 71-91. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.
- Huang, F. and Bh. Subramanyam. 2003. Effects of delayed mating on reproduction performance of *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae). J. Stored Prod. Res. 39: 53-63.
- Sedlacek, J. D., P. A. Weston and R. J. Barney. 1996. Lepidoptera and Psocoptera. p. 41-70. In Bh. Subramanyam and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.
- Subramanyam, Bh. and D. W. Hagstrum. 1993. Predicting development times of six stored-product moth species (Lepidoptera: Pyralidae) in relation to temperature, relative humidity, and diet. Eur. J. Entomol. 90: 51-64.

Ch. 7 Population growth

- Ahmad, T. R. and M. A. Ali. 1995. Forecasting emergence and flight of some *Ephestia* spp. (Lep., Pyralidae) based on pheromone trapping and degree-day accumulations. J. Appl. Entomol. 119: 611-614.
- Flinn, P. W. and D. W. Hagstrum. 1995. Simulation model of *Cephalonomia waterstoni* (Hymenoptera: Bethyidae) parasitizing the rusty grain beetle (Coleoptera: Cucujidae). Environ. Entomol. 24: 1608-1615.
- Flinn, P. W., T. W. Phillips, D. Hagstrum, F. Arthur and J. Throne. 2001. Modeling the effects of insect stage and grain temperature on phosphine-induced mortality for *Rhyzopertha dominica*. p. 531-539. In Donahaye, E. J., S. Navarro, and J. Leesch [eds.]. Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Stored Products, Executive Printing Services, Clovis, California.
- Hagstrum, D. W. and P. W. Flinn. 1990. Simulations comparing insect species differences in response to wheat storage conditions and management practices. J. Econ. Entomol. 83: 2469-2475.
- Howe, R. W. 1965. A summary of estimates of optimal and minimal conditions for population increase of some stored products insects. J. Stored Prod. Res. 1: 177-184.
- Jian, F., D. S. Jayas, N. D. G. White and P. G. Fields. 2007. A distributed-delay model to predict ageing and survival rates of adults of *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae) in granaries filled with wheat. Ecol. Model. 200: 412-420.
- Jian, F., D. S. Jayas, N. D. G. White and E. A. Smith. 2008. Numerical analysis and parameter estimation technique for insect population redistribution models. Ecol. Model. 211: 47-56.
- Kaliyan, N., M. A. Carrillo, R. V. Morey, W. F. Wilcke and S. A. Kellis. 2007. Mortality of Indian meal moth (Lepidoptera: Pyralidae) populations under fluctuating low temperatures: model development and validation. Environ. Entomol. 36: 1318-1327.
- Stolk, C., W. van der Werf and A. van Huis. 1999. Models of stored-product pests: their relevance to biological control in traditional storage in developing countries. p. 72-87. In Zuzan, J., L. Quan, L. Yongsheng, T. Xiachang, and G. Liaghu [eds.]. Proceedings of the 7th International Working Conference on Stored Product Protection, Sichuan Publishing House, Chengdu, Peoples Republic of China.
- Throne, J. 1995. Computer modeling of the population dynamics of stored product pests. p. 169-195. In Jayas, D. S., N. D. G. White and W. E. Muir. [eds.], Stored-Grain Ecosystem. Marcel Dekker, Inc., New York.
- Woods, S. M., N. D. G. White and R. N. Sinha. 1997. Simulation of generation times of the rusty grain beetle, *Cryptolestes ferrugineus*, in farm-stored grain in the Canadian prairies, 1952-1990. Res. Popul. Ecol. 39: 47-56.

Ch. 8 Decision aids

- Bridgeman, B. W. and P. J. Collins. 1994. Integrated pest management in the GRAINCO, Queensland Australia, storage system. p. 910-914. In Highley, E., E. J. Wright, H. J. Banks and B. R. Champ [eds.]. Proceedings of the 6th International Working Conference on Stored-Product Protection, Canberra, Australia, CAB International, Wallingford, United Kingdom.
- Compton, J. A. F., S. Floyd, P. A. Magrath, S. Addo, S. R. Gbedevi, B. Agbo, G. Bokor, S. Amekupe, Z. Motey, H. Penni and S. Kumi. 1998. Involving grain traders in determining the effect of postharvest insect damage on the price of maize in African markets. Crop Prot. 17: 483-489.
- Flinn, P. W., D. W. Hagstrum, C. R. Reed and T. W. Phillips. 2007a. Stored Grain Advisor Pro: decision support system for insect management in commercial grain elevators. J. Stored Prod. Res. 43: 375-383.
- Gerberg, E. J. 1991. Professional and consultant services. p. 549-550. In Gorham, J. R. [ed.] Ecology and Management of Food-Industry Pests. Food and Drug Administration Technical Bulletin 4. Association of Official Analytical Chemists, Arlington, Virginia.
- Hagstrum, D. W., P. W. Flinn, C. R. Reed and T. W. Phillips. 2010. Ecology and IPM of insects at grain elevators and flat storages. Biopestic. Intern. 6: 1-20.
- Hagstrum, D. W. and Bh. Subramanyam. 2000a. Monitoring and decision tool. p. 1-28. In Bh. Subramanyam and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Hagstrum, D. W. and Bh. Subramanyam. 2000b. Integration. p. 419-428. In Bh. Subramanyam and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Hagstrum, D. W. and Bh. Subramanyam. 2012. Role of extension educators and consultants. p. 289-296. In D. W. Hagstrum, T. W. Phillips and G. Cuperus (eds) Stored Product Protection S156. Kansas State University, Manhattan, KS.
- Hodges, R. J., M. Smith, A. Madden, D. Russell, I. Gudrups and H. Hald. 1997. Development of a decision support system for the fumigation of milled-rice bag-stacks in the tropics. p. 425-434. In Donahaye, E. J., S. Navarro, and A. Varnava [eds.]. Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Stored Products, Printco Ltd., Nicosia, Cyprus.
- Holcomb, M. 1995. IPM in food processing – stop the insanity. Pest Control 63: 66.
- Kuzmanov, D. and N. Dimitrov. 2009. Forecasting the necessity of grain fumigation during storage. Czech J. Food Sci. 3: 210-215.
- Raney, H. 1984. Kentucky's stored grain inspection program. pp. 722. In R. B. Mills, V. F. Wright, J. R. Pedersen, W. H. McGaughey, R. W. Beeman, K. J. Kramer, R. D. Speirs and C. L. Storey (eds.), Proceedings of the 3rd International Working Conference on Stored-Product Entomology, 23-28 October, 1983, Manhattan, Kansas.
- Reed, C., V. F. Wright, J. R. Pedersen and K. Anderson. 1989. Effects of insect infestation of farm-stored wheat on its sale price at country and terminal elevators. J. Econ. Entomol. 82: 1254-1261.
- Siddiqi, Z. 2006. IPM: The gold standard for grain processing. World Grain 24:40-41.
- Skinner, M. 1982. Farmers scout stored grain investment. Extension Rev. Spring: 4-6.

Slade, P. J. 2002. Verification of effective sanitation control strategies. Food Safety Mag. Feb-Mar: 24-29, 42-43.

Smallman, B.N. 1944. Solving the infestation hazard of Canada's war-grain storage. Amer. Miller and Processor 72: 37-39, 50-51.

Ch. 9 Economics

Alexander, C., Y. A. Yigezu, D. E. Maier, L. J. Mason, and C. P. Woloshuk. 2008. Cost of Good Sanitation Practices for On-Farm Grain Storage. Purdue Extension GQ-50-W.

Arthur, F.H., J.F. Campbell, and M.D. Toews. 2013. Distribution, abundance, and seasonal patterns of *Plodia interpunctella* (Hübner) in a commercial food storage facility. J. Stored Prod. Res. 53: 7-14.

Beckett, S. J. and R. Morton. 2003. Mortality of *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) at grain temperatures ranging from 50°C to 60°C obtained at different rates of heating in a spouted bed. J. Stored Prod. Res. 39: 313-332.

Chowanec, T. 1986. Sanitation cost – the bottom line. Bull. Assoc. Operative Millers December 4867-4871.

Curtis, C. E. 1976. Economics of NOW control and implementing orchard clean up. Almond Facts 41:5-8.

Kenkel, P., J. T. Criswell, G. Cuperus, R. T. Noyes, K. Anderson, W. S. Fargo, K. Shelton, W. P. Morrison and B. Adams. 1993. Current management practices and impact of pesticide loss in the hard red wheat post-harvest system. Oklahoma Cooperative Extension Service Circular E-930.

Rulon, R. A., D. E. Maier and M. D. Boehlje. 1999. A post-harvest economic model to evaluate grain chilling as an IPM technology. J. Stored Prod. Res. 35: 369-383.

Soderstrom, E. L., P. D. Gardner, J. L. Baritelle, K. N. De Lozano and D. G. Brandl. 1984. Economic cost evaluation of a generated low-oxygen atmosphere as a alternative fumigant in the bulk storage of raisins. J. Econ. Entomol. 77: 457-461.

Subramanyam, Bh. 2003. Heat Treatment Calculator, software program helps determine how much energy is needed to heat a building. Milling Journal, Third Quarter 46-48.

Tilley, D. R., M. R. Langemeier, M. E. Casada and F. H. Arthur. 2007a. Cost and risk analysis of heat and chemical treatments. J. Econ. Entomol. 100: 604-612.

Ch. 10 Resistance

Andreev, D., T. Rocheleau, T. W. Phillips, R. W. Beeman and R. H. French-Constant. 1994. A PCR diagnostic for cyclodiene insecticide resistance in the red flour beetle *Tribolium castaneum*. Pestic. Sci. 41: 345-349.

Emery, Robert N., Manoj K Nayak and Joanne C Holloway. 2011. Lessons learned from phosphine resistance monitoring in Australia. Stewart Postharvest Review doi: 10.2212/spr.2011.3.6

Haynes, K. F., T. A. Miller, R. T. Staten, W. G. Li and T. C. Baker. 1986. Monitoring insecticide resistance with insect pheromones. Experientia 42: 1293-1295.

Herron, G. A., A. D. Clift, G. G. White and H. G. Greening. 1996. Relationships between insecticide use, grain hygiene and insecticide resistance in *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) on grain-producing farms. J. Stored Prod. Res. 32: 131-136.

Opit, G. P., T. W. Phillips, M. J. Aikins, and M. M. Hasan. 2012. Phosphine resistance in *Tribolium castaneum* and *Rhyzopertha dominica* from stored wheat in Oklahoma. J. Econ. Entomol. 105(4): 1107-1114.

Schlipalius, D. I., N. Valmas, A. G. Tuck, R. Jagadeesan, L. Ma, R. Kaur, A. Goldinger, C. Anderson, J. Kuang, S. Zury, Y. S. Mau, Q. Cheng, P. J. Collins, M. K. Nayak, H. J. Schirra, M. A. Hilliard, and P. R. Ebert. 2012. A Core Metabolic Enzyme mediates resistance to phosphine gas. Science 338:807-810.

Sinclair, E. R. and J. Adler. 1985. Development of a computer simulation model of stored product insect populations on grain farms. Agricultural Systems 18: 95-113.

Subramanyam, Bh. and D. W. Hagstrum. 1996. Resistance measurement and management. p. 331-397. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Tabashnik, B. E. 1990. Modeling and evaluation of resistance management tactics. p. 153-182. In Roush, R. T. and B. E. Tabashnik [eds.], Pesticide Resistance in Arthropods. Chapman and Hall, New York.

Ch. 11 Biological control

Borgemeister, C., F. Djossou, C. Adda, H. Schneider, B. Djomamou, K. Azoma and R. H. Markham. 1997. Establishment, spread and impact of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae), an exotic predator of the larger grain borer *Prostephanus truncatus* (Horn) (Coleoptera: Bostrychidae), in southwestern Benin. Environ. Entomol. 26: 1405-1415.

Brower, J. H., L. Smith, P. V. Vail and P. W. Flinn. 1996. Biological control, p. 223-286. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Integrated Management of Insects in Stored Products, Marcel Dekker, Inc., New York.

Eliopoulos, P. A., C. G. Athanasiou and C. H. Buchelos. 2002. Occurrence of Hymenoptera parasitoids of stored product pests in Greece. In C. Adler, S. Navarro, M. Scholler and L. Stengard-Hansen Proceedings Integrated Protection of Stored Products IOBC Bulletin 25: 127-139.

Eliopoulos, P. A., C. G. Athanassiou, N. E. Palyvos, G. J. Stathas and C. Th. Buchelos. 2003. Dominance and frequency of predatory mites in stored products in Greece. p. 258-262. In Credland, P. F., D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley [eds.], Advances in Stored Product Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, York, United Kingdom. CAB International, Wallingford, United Kingdom

Flinn, P. W. and D. W. Hagstrum. 1995. Simulation model of *Cephalonomia waterstoni* (Hymenoptera: Bethyidae) parasitizing the rusty grain beetle (Coleoptera: Cucujidae). Environ. Entomol. 24: 1608-1615.

Flinn, P. W., D. W. Hagstrum and W. H. McGaughey. 1996. Suppression of beetles in stored wheat by augmentative releases of parasitic wasps. Environ. Entomol. 25: 505-511.

Johnson, J. A., K. A. Valero, M.M. Hannel and R. F. Gill. 2000. Seasonal occurrence of postharvest dried fruit insects and their parasitoids in a cull fig warehouse. J. Econ. Entomol. 93: 1380-1390.

Moore, D., J. C. Lord and S. M. Smith. 2000. Pathogens. p. 193-227. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Schöller, M. and P. W. Flinn. 2000. Parasites and predators. p. 229-271. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Ch. 12 Aeration

Flinn, P. W., D. W. Hagstrum and W. E. Muir. 1997. Effects of time of aeration, bin size, and latitude on insect populations in stored wheat: a simulation study. J. Econ. Entomol. 90: 646-651.

Foster, G. H. and J. Tuite. 1992. Aeration and grain management. p. 219-248. In Sauer, D. B. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.

Maier, D. E. 1994. Chilled aeration and storage of U.S. crops – a review. p. 300-311. In Highley, E., E. J. Wright, H. J. Banks and B. R. Champ [eds.], Proceedings of the 6th International Working Conference on Stored-Product Protection, Canberra, Australia, CAB International, Wallingford, United Kingdom

Navarro, S. and R. Noyes. 2002. The mechanics and physics of modern grain aeration management. CRC Press, New York. (book)

Reed, C. R. 2006. Aeration. Pages 141-180 In Managing Stored Grain to Preserve Quality and Value. AACCC International, St. Paul, MN.

Reed, C. and F. H. Arthur. 2000. Aeration, p. 51-72. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.

Reed, C. and J. Harner. 1998a. Cooling of stored wheat in multiple or single cycles using automatic aeration controllers. Appl. Eng. Agric. 14: 495-500.

Reed, C. and J. Harner. 1998b. Thermostatically controlled aeration for insect control in stored hard red winter wheat. Appl. Eng. Agric. 14: 501-505.

Reed, C., T. Herman, R. Higgins and J. Harner. 1995. Questions and answers about aeration controllers. MF-2090 Cooperative Extension Service, Kansas State University.

Ch. 13 Sanitation and pest exclusion

- Adler, C. 2004. Significance of hermetic seals, controlled ventilation, and wire-mesh screens to prevent the immigration of stored product pests. IOBC/wprs Bulletin 27:13-16.
- Arthur, F. H. 2000. Impact of accumulated food on survival of *Tribolium castaneum* on concrete treated with cyfluthrin wettable powder. J. Stored Prod. Res. 36: 15-23.
- Brickey, P.M., J.S. Gecan, and A. Rothschild. 1973. Method for determining direction of insect boring through food packaging materials. J. AOAC 56: 640-642.
- Brody, A. L. 1982. Packaging. p. 503-535. In Christensen, C. M. [ed.], Storage of Cereal Grains and Their Products. American Association of Cereal Chemists, St. Paul, Minnesota.
- Cline, L. D. 1978. Penetration of seven flexible packaging materials by larvae and adults of eleven species of stored-product insects. J. Econ. Entomol. 71: 726-729.
- Cox, P. D., D. A. Fleming, J. E. Atkinson, K. L. Bannon and J. M. Whitefield. 1997. The effect of behavior on the survival of *Cryptolestes ferrugineus* in an insecticide-treated laboratory environment. J. Stored Prod. Res. 33: 257-269.
- Hori, M. 2004. Repellency of hinokitiol against the cigarette beetle, *Lasioderma serricornis* (Fabricius) (Coleoptera: Anobiidae). Appl. Entomol. Zool. 39: 521-526.
- Hou, X., P. Fields and W. Taylor. 2004. The effect of repellents on penetration into packaging by stored-product insects. J. Stored Prod. Res. 40: 47-54.
- Imholte, T. J. and T. K. Imholte-Tausher 1999. Engineering for Food Safety and Sanitation. Technical Institute of Food Safety, Crystal, Minnesota. (book)
- Ingemansen, J. A., Reeves, D. L., and Walstrom, R. J. 1986. Factors influencing stored-oat insect populations in South Dakota. J. Econ. Entomol. 79:518-522.
- Jacobson, R. and D. B. Pinniger. 1982. Eradication of *Oryzaephilus surinamensis* from a farm grain store. Intern. Pest Control 24: 68, 72-74.
- Karitas, J. J. 1964. Breakage and damage in grocery warehouses and retail food stores. USDA, ARS, Agricultural Market Service, Marketing Research Report No. 652.
- Mills, R. and J. Pedersen. 1990. A Flour Mill Sanitation Manual. Eagan Press, St. Paul, Minnesota. (book)
- Mowery, S. V., M. A. Mullen, J. F. Campbell and A. B. Broce. 2002. Mechanisms underlying sawtoothed grain beetle (*Oryzaephilus surinamensis* [L.]) (Coleoptera: Silvanidae) infestation of consumer food packaging materials. J. Econ. Entomol. 95: 1333-1336.
- Mullen, M. A. and J. R. Pedersen. 2000. Sanitation and exclusion. p. 29-50. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Nakamura, S., P. Visarathanonth, R. Kengkampanich, J. Uraichuen, and K. Konishi. 2008. Cleaning reduces grain losses of stored rice. Jarq-Japan Agricultural Research Quarterly 42 (1):35-40.
- Reed, C. R., D. W. Hagstrum, P. W. Flinn and R. F. Allen. 2003. Wheat in bins and discharge spouts, and grain residues on floors of empty bins in concrete grain elevators as habitats for stored-grain beetles and their natural enemies. J. Econ. Entomol. 96: 996-1004.
- Rolston, L. H. and P. Rouse. 1957. Insects in stored rice can be controlled by sanitation. Arkansas Farm Res. 6 (3): 3.
- Roesli, R., Subramanyam, B., Campbell, J. F., and Kemp, K. 2003b. Impact of selected IPM practices on insect populations in retail pet stores. Pages 410-419 in: Advances in Stored Product Protection. Proc. Int. Work. Conf. on Stored Prod. Prot., 8th, (York, UK.) P. F. Credland, D. M. Armitage, C. H. Bell, P. M. Cogan, and E. Highley, Eds. CAB International, Wallingford, UK.
- Riudavets J, I. Salas and M. J. Pons. 2007. Damage characteristics produced by insect pests in packaging film. Journal of Stored Products Research 43: 564-570.
- Riudavets, J., C. Castañé, O. Alomar, M.J. Pons and R.Gabarra. 2009. Modified atmosphere packaging (MAP) as an alternative measure for controlling ten pests that attack processed food products. Journal of Stored Products Research 45: 91-96.

Ch. 14 Temperature

- Beckett, S. J. and R. Qaisrani. 2003. Heat disinfestations of empty farm silos before inloading. p. 803-806. In Credland, P. F., D. M. Armitage, C. H. Bell, P. M. Cogan and E. Highley [eds.] Advances in Stored Product Protection. Proceedings of the 8th International Working Conference on Stored Product Protection, York, United Kingdom. CAB International, Wallingford, United Kingdom.
- Burks, C. S., J. A. Johnson, D. E. Maier and J. Heaps. 2000. Temperature. p. 71-104. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Donahaye, E. J., S. Navarro and M. Rindner. 1995. Low temperature as an alternative to fumigation for disinfesting dried fruit from three insect species. J. Stored Prod. Res. 31: 63-70.
- Evans, D. E., G. R. Thorpe and T. Dermott. 1983. The disinfestations of wheat in a continuous-flow fluidized bed. J. Stored Prod. Res. 19: 125-137.
- Fields, P.G. 1992. The control of stored-product insects and mites with extreme temperatures. J. Stored Prod. Res. 28: 89-118.
- Imholte, T. J. and T. K. Imholte-Tausher 1999. Engineering for Food Safety and Sanitation. p. 303-309. Technical Institute of Food Safety, Crystal, Minnesota. (book)
- Johnson, J. A. and K. A. Valero. 2003. Use of commercial freezers to control cowpea weevil, *Callosobruchus maculatus* (Coleoptera: Bruchidae), in organic garbanzo beans. J. Econ. Entomol. 96: 1952-1957.
- Keever, D. W., B. R. Wiseman and N. W. Widstrom. 1988. Effects of threshing and drying on maize weevil populations in field-infested corn. J. Econ. Entomol. 81: 727-730.
- Mourier, H. and K. P. Poulsen. 2000. Control of insects and mites in grain using a high temperature/short time (HTST) technique. J. Stored Prod. Res. 36: 309-318.
- Nelson, S. O. 1996. Review and assessment of radio-frequency and microwave energy for stored-grain insect control. Trans. ASAE 39: 1475-1484.
- Ntoukam, G., L. W. Kitch, R. E. Shade and L. L. Murdock. 1997. A novel method for conserving cowpea germplasm and breeding stocks using solar disinfestations. J. Stored Prod. Res. 33: 175-179.
- Roesli, R. Bh. Subramanyam, F. J. Fairchild and K. C. Behnke. 2003. Trap catches of stored-product insects before and after heat treatment in a pilot feed mill. J. Stored Prod. Res. 39: 521-540.
- Shayesteh, N. and N. N. Barthakur. 1996. Mortality and behavior of two stored-product insect species during microwave irradiation. J. Stored Prod. Res. 32: 239-246.
- Tilley, D. R., M. E. Casada and F. H. Arthur. 2007b. Heat treatment for disinfestations of empty grain storage bins. J. Stored Prod. Res. 43: 221-228.
- Wang, S., J. Tang, J. A. Johnson, E. Mitcham, J. D. Hansen, R. P. Cavaliere, J. Bower and B. Biasi. 2002. Process protocols based on radio frequency energy to control field and storage pests in in-shell walnuts. Postharvest Biology and Technology 26: 265-273.

Ch. 15 Impact mortality

- Banks, J. and P. Fields. 1995. Physical methods for insect control in stored-grain ecosystems. p. 384-387. In D. S. Jayas, N. D. G. White and W. E. Muir (eds.) Stored-Grain Ecosystem, Marcel Dekker Inc., New York.
- Kice, B. 1991. Multiaspirator and clean grain benefits. p. 205-210. In Proc. III Nat. Stored Grain Pest Management Training Conf., Kansas City, Missouri.
- Nahdy, M. S. 1994. Bean sieving, a possible control measure for the dried bean beetles, *Acanthoscelides obtectus* (Say) (Coleoptera: Bruchidae). J. Stored Prod. Res. 30: 65-69.
- Noyes, R. T., B. Kice and C. Sukup. 1991. Grain cleaning and cleaning equipment. p. 217-227. In Proc. III Nat. Stored Grain Pest Management Training Conf., Kansas City, Missouri.
- Paliwal, J., D. S. Jayas, N. D. G. White and W. E. Muir. 1999. Effects of pneumatic conveying of wheat on mortality of insects. Appl. Eng. Agric. 15: 65-68.
- Payne, J. A., L. M. Redlinger and J. I. Davidson. 1970. Shelling plant studies with insect-infested peanuts. J. Amer. Peanut Res. Educ. Assoc. 2: 103-108.
- Plarre, R. and F. Reichmuth. 2000. Impact. p. 401-417. In Subramanyam, Bh. and D. W. Hagstrum [eds.], Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, New York.
- Quentin, M. E., J. L. Spencer and J. R. Miller. 1991. Bean tumbling as a control measure for the common bean weevil, *Acanthoscelides obtectus*. Entomol. Exp. Appl. 60: 105-109.

Robertson, F. W. 1944. The removal of insect pests from stored products by means of behaviour stimuli. *Bull. Entomol. Res.* 35:215-217.

Toews, M. D. and Bh. Subramanyam. 2002. Sanitation in grain storage and handling. p. 481-497. In Hui, Y. H., B. L. Bruinsma, J. R. Gorham, W. Nip, P. S. Tong and P. Ventresca. (eds.) *Food Plant Sanitation*. Marcel Dekker, Inc., New York.

Wanzenried, H. 1986. Reducing infestation in flour. *Bull. AOM*. March, p. 4693-4696.

Ch. 16 Ionizing radiation

Banks, J. and P. Fields. 1995. Physical methods for insect control in stored-grain ecosystems. p. 389-391. In D. S. Jayas, N. D. G. White and W. E. Muir (eds) *Stored-Grain Ecosystem*, Marcel Dekker Inc., New York.

Cleghorn, D. A., S. V. Nablo, D. N. Ferro and D. W. Hagstrum. 2002. Electron beam treatment parameters for control of stored product insects. *Radiation Phys. Chem.* 63:575-579.

Cogburn, R.R., E. W. Tilton and J. H. Brower. 1972. Bulk-grain gamma irradiation for control of insects infesting wheat. *J. Econ. Entomol.* 65:818-821.

Fields, P. G. and W. E. Muir. 1996. Physical control. p. 206-207. In Bh. Subramanyam and D. W. Hagstrum [eds.], *Integrated Management of Insects in Stored Products*, Marcel Dekker, Inc., New York.

Halverson, S. L. and S. V. Nablo. 2000. Radiation. p. 381-400. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, New York.

Molins, R. A. 2001. *Food irradiation: principles and applications*. Wiley-Interscience, New York. (book)

Tilton, E. W. and J. H. Brower. 1987. Ionizing radiation for insect control in grain and grain products. *Cereal Foods World* 32:330-333.

Watters, F. L. and K. F. MacQueen. 1967. Effectiveness of gamma irradiation for control of five species of stored-product insects. *J. Stored Prod. Res.* 3:223-234.

Wilkinson, V. M. and G. W. Gould. 1998. *Food irradiation, a reference guide*. Woodhead Publishing Limited, Cambridge, England. (book)

Ch. 17 Residual insecticides

Arthur, F. H. 1996. Grain protectants: current status and prospects for the future. *J. Stored Prod. Res.* 32:293-302.

Arthur, F. H., J. E. Throne and R. A. Simonitis. 1992. Degradation and biological efficacy of chlorpyrifos-methyl on wheat stored at five temperatures and three moisture contents. *J. Econ. Entomol.* 85:1994-2002.

Athanassiou, C. G., F. H. Arthur and J. E. Throne. 2009. Efficacy of spinosad in layer-treated wheat against five stored-product insect species. *J. Stored Prod. Res.* 45:236-240.

Baker, J. E. and K. J. Kramer. 1996. Biotechnological approaches for stored-product insect pest management. *Postharvest News and Information* 7:11-18.

Bohmert, B. L. 2007. *The Standard Pesticide User's Guide*. 7th Edition. Pearson Prentice Hall, Inc., Upper Saddle River, N. J. (book)

Boina, Dhana Raj and Bhadriraju Subramanyam. 2012. Insect management with aerosols in food-processing facilities. p. 195-212. In Farzana Perveen (ed.) *Insecticides – Advances in Integrated Pest Management*. IntTech Europe, Rijeka, Croatia. <http://www.intechopen.com/books/insecticides-advances-in-integrated-pest-management/insect-management-with-aerosols-in-food-processing-facilities>

Hodges, R. J., P. Carr and A. I. Hussein. 1999. Limiting the amount of pesticide applied to small bulks of maize in rural stores. p. 956-963. In Zuzan, J., L. Qian, L. Yongsheng, T. Xiachang, and G. Liaghua [eds.] *Proceedings of the 7th International Working Conference on Stored Product Protection*, Sichuan Publishing House, Chengdu, Peoples Republic of China.

Lake, N. E. S. 1995. An overview of the use of plant products in the management of stored product Coleoptera in the tropics. *Postharvest News and Information* 6:69-75.

Minett, W. and P. Williams. 1971. Influence of malathion distribution on the protection of wheat grain against insect infestation. *J. Stored Prod. Res.* 7:233-242.

Nansen, C. and T. W. Phillips. 2004. Attractancy and toxicity of an attracticide for Indianmeal moth, *Plodia interpunctella* (Lepidoptera: Pyralidae). *J. Econ. Entomol.* 97:703-710.

Nawrot, J. and J. Harmatha. 1994. Natural products as antifeedants against stored product insects. *Postharvest News and Information* 5:17-21.

Obeng-Ofori, D. and S. Ameteye. 2005. Efficacy of mixing vegetable oils with pirimiphos-methyl against the maize weevil, *Sitophilus zeamais* Motschulsky in stored maize. *J. Stored Prod. Res.* 41:57-66.

Oberlander, H. and D. L. Silhacek. 2000. Insect growth regulators. p. 147-163. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, New York.

Panagiotakopulu, E., P. C. Buckland and P. M. Day. 1995. Natural insecticides and insect repellents in antiquity: a review of the evidence. *J. Archaeological Sci.* 22:705-710.

Rajapakse, R. and H. F. Van Emden. 1997. Potential of four vegetable oils and ten botanical powders for reducing infestation of cowpeas by *Callosobruchus maculatus*, *C. chinensis* and *C. rhodesianus*. *J. Stored Prod. Res.* 33:59-68.

Snelson, J. T. 1987. *Grain Protectants*. ACIAR monograph No. 3. (book)

Subramanyam, Bh. And R. Roesli. 2000. Inert dusts. p. 321-380. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, New York.

Throne, J. E., J. E. Baker, F. J. Messina, K. J. Kramer and J. A. Howard. 2000. Varietal resistance. p. 165-192. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, New York.

Toews, M. D., J. F. Campbell, F. H. Arthur and M. West. 2005a. Monitoring *Tribolium castaneum* (Coleoptera: Tenebrionidae) in pilot-scale warehouses treated with residual applications of (S)-hydroprone and cyfluthrin. *J. Econ. Entomol.* 98:1391-1398.

White, N. D. G. and J. G. Leesch. 1996. Chemical control. p. 287-304. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Integrated Management of Insects in Stored Products*, Marcel Dekker, Inc., New York.

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Adler, C., H. Corinth and C. Reichmuth. 2000. Modified atmospheres. p. 105-146. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Alternatives to Pesticides in Stored-Product IPM*. Kluwer Academic Publishers, New York.

Annis, P. C. 2001. Phosphine dosage regimes required for high mortality: a data-base approach. p. 45-55. In Donahaye, E. J., S. Navarro and J. G. Leesch [eds.] *Proc. Intern. Conf. Controlled Atmosphere and Fumigation in Stored Products*, Executive Printing Services, Clovis, California.

Banks, J. and P. Fields. 1995. Physical methods for insect control in stored-grain ecosystems. p. 367-377. In D. S. Jayas, N. D. G. White and W. E. Muir [eds.] *Stored-Grain Ecosystem*, Marcel Dekker Inc., New York.

Bell, C. H. 1996. Alternatives – Physical Methods and Emission Reduction. p. 372-376. In Bell, C. H., N. Price and B. Chakrabarti [eds.] *The Methyl Bromide Issue*. John Wiley & Sons, New York. (book)

Bond, E. J. 1984. *Manual of Fumigation for Insect Control*. Food and Agriculture Organization of the United Nations Plant Production and Protection Paper 54. (book)

Buckman, K.A., J.F. Campbell, and B. Subramanyam. 2013. *Tribolium castaneum* (Coleoptera: Tenebrionidae) associated with rice mills: Fumigation efficacy and population rebound. *J. Econ. Entomol.* 106:499-512.

Campbell, J. F., and R. T. Arbogast. 2004. Stored-product insects in a flour mill: population dynamics and response to fumigation treatments. *Entomol. Exp. Appl.* 112:217-225.

Campbell, J. F., K. A. Buckman, P. G. Fields and B. Subramanyam. 2015. Evaluation of Structural Treatment Efficacy against *Tribolium castaneum* and *Tribolium confusum* (Coleoptera: Tenebrionidae) Using Meta-Analysis of Multiple Studies Conducted in Food Facilities. *J. Econ. Entomol.* 108:2125-2140.

Campbell, J.F., M.D. Toews, F.H. Arthur, and R.T. Arbogast. 2010a. Long-term monitoring of *Tribolium castaneum* in two flour mills: seasonal patterns and impact of fumigation. *J. Econ. Entomol.* 103:991-1001.

- Campbell, J.F., M.D. Toews, F.H. Arthur, and R.T. Arbogast. 2010b. Long-term monitoring of *Tribolium castaneum* populations in two flour mills: rebound after fumigation. *J. Econ. Entomol.* 103: 1002-1011.
- Davis, R. and R. H. Barrett. 1986. In-transit shipboard fumigation of grain: research to regulation. *Cereal Foods World* 31: 227-229.
- Flinn, P., C. Reed, D. Hagstrum and T. Phillips. 2007b. Seasonal and spatial changes in insect density in commercial elevator bins: implications for phosphine fumigation. *International Miller* 2006-2007: 36-40.
- Hamlin, J. C. and W. D. Reed. 1927. Insect revival after fumigation. *J. Econ. Entomol.* 20: 400-428.
- Hartzer, M., B. Subramanyam, W. Chayaprasert, D. E. Maier, S. Savodelli, J. F. Campbell, and P. W. Flinn. 2010. Methyl bromide and sulfuryl fluoride effectiveness against red flour beetle life stages, pp. 365-370. In M. O. Carvalho, P. G. Fields, C. S. Adler, F. H. Arthur, C. G. Athanassiou, J. F. Campbell, F. Fleurat-Lessard, P. W. Flinn, R. J. Hodges, A. A. Isikber, et al. (eds.), *Proceedings of the 10th International Working Conference on Stored Product Protection*, 27 June-2 July 2010, Estoril, Portugal. Julius Kühn-Institut, Berlin, Germany.
- Hole, B. D., C. H. Bell, K. A. Mills and G. Goodship. 1976. The toxicity of phosphine to all developmental stages of thirteen species of stored product beetles. *J. Stored Prod. Res.* 12: 235-244.
- Lindgren, D. L. and L. E. Vincent. 1962. Fumigation of food commodities for insect control. p. 85-152. In R. L. Metcalf [ed.] *Advances in Pest Control Research* Volume 5, John Wiley & Sons, New York.
- Navarro, S. 2006. Modified atmospheres for the control of stored-product insects and mites. Pages 105-145 in: *Insect Management for Food Storage and Processing*, 2nd ed. J. Heaps (ed.) AACC International, St. Paul, MN.
- Navarro, S., Jay, E. G., and Leesch, J. G. 1986. Recirculation rate for adequate distribution of carbon dioxide in grain bins. *Trans. ASAE* 29:1348-1354.
- Newman, C. J. E. 1990. Specification and design of enclosures for gas treatment. p. 108-130. In *Fumigation and controlled atmosphere storage of grain*. Australian Centre International Agricultural Research proceedings series no. 25.
- Noyes, R. T., and Kenkel, P. 1994. Closed loop fumigation systems in the south-western United States. Pages 335-341 in: *Proc. 6th International Working Conference on Stored-Product Protection*. (Canberra, Australia.) E. Highley, E. J. Wright, H. J. Banks, and B. R. Champ, Eds. CAB International, Wallingford, U.K.
- Reed, C. and H. Pan. 2000. Loss of phosphine from unsealed bins of wheat at six combinations of grain temperature and grain moisture content. *J. Stored Prod. Res.* 36: 263-279.
- Small, G. J. 2007. A comparison between the impact of sulfuryl fluoride and methyl bromide fumigations on stored product insect populations in UK flour mills. *J. Stored Prod. Res.* 43: 410-416.
- Tsai, W.-T., L. J. Mason, W. Chayaprasert, D. E. Maier, and K. E. Ileleji. 2011. Investigation of fumigant efficacy in flour mills under real-world fumigation conditions. *J. Stored Prod. Res.* 47: 179-184.
- Walter, V. E. 1991. Fumigation in the food industry. p. 441-457. In Gorham, J. R. [ed.], *Ecology and Management of Food-Industry Pests*, Assoc. Official Analytical Chem., Arlington, Virginia.
- Walter, V. 2006. Commodity and space fumigations in the food industry. Pages 183-198 in: *Insect Management for Food Storage and Processing*, 2nd ed. J. Heaps (ed.) AACC International, St. Paul, MN.
- White, N. D. G. and J. G. Leesch. 1996. Chemical control. p. 304-320. In Subramanyam, Bh. and D. W. Hagstrum [eds.], *Integrated Management of Insects in Stored Products*, Marcel Dekker, Inc., New York.
- Zettler, J. L., J. G. Leesch, H. B. Gillenwater, L. M. Redlinger, R. Davis and J. M. Zehner. 1986. Feasibility of fumigating unmodified river barges with phosphine while in transit. *J. Econ. Entomol.* 79: 1315-1318.
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References

- Bahr I., (1990). Reduction of stored product insects during pneumatic unloading of ship cargoes. pp. 1135–1144, in F. Fleurat-Lessard and P. Ducom (eds.) *Proceedings 5th Int. Working Conf. Stored Product Protection*. INRA/SPV Bordeaux, 2066 p.
[Google Scholar](#)
- Bailey S.W., (1962). The effects of percussion on insect pests in grain. *J. Econ. Entomol.* 55: 301–304.
[Google Scholar](#)
- Banks H.J., (1986). Impact, physical removal and exclusion for insect control in stored products. pp. 165–184, in E.J. Donahaye and S. Navarro. *Proceedings 4th Int. Working Conf. Stored Products Protection*, Tel Aviv, 668 p.
[Google Scholar](#)
- Banks H.J., Fields P.G., (1995). Physical methods for insect control in stored grain ecosystems. pp 353–409 in D.S. Jayas, N.D.G. White, and W.E. Muir (eds) *Stored-grain ecosystems*. Marcel Dekker, Inc., New York, 757 p.
[Google Scholar](#)
- Bridgeman, B., (1998). Application Technology and Usage Patterns of Diatomaceous Earth In Stored Product Protection. in Z. Jin, Q. Liang, Y. Liang, X. Tan and D. Guan (eds), *Proceedings 7th Int. Working Conf. Stored Products Protection*, Beijing, Sichuan Publishing House of Science and Technology, Chengdu, China, pp. 785–789.
[Google Scholar](#)
- Bryan J.M., Elvidge J., (1977). Mortality of adult grain beetles in sample delivery systems used in terminal grain elevators. *Can. Entomol.* 109: 209–213.
[CrossRef](#)[Google Scholar](#)
- Carlson S.D., Ball H.J., (1962). Mode of action and insecticidal value of a diatomaceous earth as a grain protectant. *J. Econ. Entomol.* 55: 964–969.
[Google Scholar](#)
- Desmarchelier J.M., Dines J.C., (1987). Dryacide treatment of stored wheat: its efficacy against insects, and after processing. *Aus. J. Exper. Agr.* 27: 309–312.
[CrossRef](#)[CAS](#) [Google Scholar](#)
- Dowdy A., Fields P.G. Heat combined with diatomaceous earth to control the confused flour beetle (Coleoptera: Tenebrionidae) in a flour mill. *J. Stored. Prod. Res.*, in press.
[Google Scholar](#)
- Ebeling W., (1971). Sorptive dusts for pest control. *Ann. Rev. Entomol.* 16: 123–158.
[CrossRef](#)[CAS](#) [Google Scholar](#)
- Fields P.G., (1998). Diatomaceous earth: Advantages and limitations. in Z. Jin, Q. Liang, Y. Liang, X. Tan and D. Guan (eds), *Proceedings 7th Int. Working Conf. Stored Products Protection*, Beijing, Sichuan Publishing House of Science and Technology, Chengdu, China, pp. 781–784.

Google Scholar

- Fields P.G., Korunic Z., (2000). The effect of grain moisture content and temperature on the efficacy of diatomaceous earths from different geographical locations against stored-product beetles. J. Stored. Prod. Res., 36:1–13.

CrossRefGoogle Scholar

- Fields P.G., Muir W.E., (1995). Physical Control. pp. 195–222, in B. Subramanyam and D.W. Hagstrum (eds.) Integrated Pest Management of Insects in Stored Products, Marcel-Dekker Inc., New York, 426 p.

Google Scholar

- Fleurat-Lessard F., (1985). Les traitements thermiques de désinfestation des céréales et des produits céréaliers : possibilité d'utilisation pratique et domaine d'application. Bull. Org. Eur. Prot. Plantes 15: 109–118.

Google Scholar

- Fleurat-Lessard F., (1989). La désinsectisation des stocks de farine. Ind. Céréales 60: 17–22.

Google Scholar

- Fusillier A., (1986). Forte diminution de la teneur en “filth” par une nouvelle conception du diagramme de nettoyage. Ind. Céréales 39: 21–25.

Google Scholar

- Glover T.J., (1997). Pocket Ref. Sequoia Publishing, Inc. Littleton, CO, USA, 554 p.

Google Scholar

- Golob P., (1997). Current status and future perspectives for inert dusts for control of stored product insects. J. Stored Prod. Res. 33: 69–79.

CrossRefGoogle Scholar

- International Agency for Research on Cancer (IARC), (1997). Silica, some silicates, coal dust and paraaramid fibrils. Volume 68, IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, Lyon, 506 p.

Google Scholar

- Joffe A., (1963). The effect of physical disturbance or “turning” of stored maize on the development of insect infestations I. Grain elevator studies. S. Afr. J. Agric. Sci. 6: 55–68.

Google Scholar

- Korunic Z., (1997). Rapid assessment of the insecticidal value of diatomaceous earths without conducting bioassays. J. Stored Prod. Research, 33: 219–229

CrossRefGoogle Scholar

- Korunic Z., (1998). Diatomaceous earths, a group of natural insecticides. J. Stored Prod. Res. 34:87–97.

CrossRefGoogle Scholar

- Korunic Z., Fields P.G., (1995). Diatomaceous earth insecticidal composition. US patent 5,773,017.

Google Scholar

- Korunic Z., Fields P.G., Kovacs M.I.P., Noll J.S., Lukow O., Demianyk C.J., Shibley K. J., (1996). The effect of diatomaceous earth on grain quality. Postharvest Biol. Technol. 9: 373–387.

CrossRefCAS Google Scholar

- Korunic Z., Ormesher P., (1998). Evaluation and standardised testing of diatomaceous earth. In Z. Jin, Q. Liang, Y. Liang, X. Tan and D. Guan (eds), Proceedings 7th Int. Working Conf. Stored Products Protection, Beijing, Sichuan Publishing House of Science and Technology, Chengdu, China, pp. 738–744.

Google Scholar

- Lagarde A., (1986). Limitation de l'infestation dans les moulins. Incidence sur la conception des machines et de l'installation. Ind. Céréales 39: 13–18.

Google Scholar

- Le Patourel G.N.J., Shawir M., Moustafa F.I., (1989). Accumulation of mineral dusts from wheat by *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). J. Stored Prod. Res. 25: 65–72.

CrossRefGoogle Scholar

- Macejlski, M., Korunic Z., (1971). Trials of inert dusts in water suspension for controlling stored-product pests. Zastita Bilja (Plant Protection), Belgrade, 22:119–128.

Google Scholar

- Paliwal J., Jayas D.S., Muir W.E., White N.D.G., (1999). Effect of pneumatic conveying of wheat on mortality of insects. App. Eng. Agr. in press.

Google Scholar

- Quarles W., (1992). Silica gel for pest control. IPM Practioner, 14:1–11.

Google Scholar

- Quentin N.E., Spencer J.L., Milles J.R., (1991). Bean tumbling as a control measure for the common bean weevil *Acanthoscelides obtectus*. Entomol. Exp. Appl. 60: 105–109.

CrossRefGoogle Scholar

- Rees D., van Gerwen T., Hillier T., (1994). The effect of grain movement on *Liposcelis decolor* (Pearman), *Liposcelis bostrychophila* Badonnel (Psocoptera: Liposcelidae) and *Cryptolestes ferrugineus* (Stephens) (Coleopter: Cucujidae) infesting bulk-stored barely. pp. 1214–1219, in E. Highley, E.J. Wright, H.J. Banks and B.R. Champ (eds.) Proceedings 6th Int. Working Conf. Stored Product Protection. CABI International, Wallingford, U.K., 1274 p

Google Scholar

- Sigaut F., (1978). Les réserves de grain à long terme. Techniques de conservation et fonctions sociales dans l'histoire. Maison des Sciences de l'Homme, Paris et Université de Lille III, 202 p.

Google Scholar

- Stratil H., Wohlgenuth R., Bolling H., Zwingelberg H., (1987). Optimization of the impact machine method of killing and removing insect pests from foods, with particular reference to quality of flour products. Getreide, Mehl Und Brot 1987; 41:294–302.

Google Scholar

- Vallery, (1839). Description de l'appareil à conserver les grains, dit grenier mobile. Bull. Soc. Ennouragement Indust. Natle. 38: 123–131.

Google Scholar

- White N.D.G., Leesch J.G., (1995). Chemical Control pp. 287–330 in Subramanyam, B, and Hagstrum, D, Editors, Integrated management of insects in stored products: Marcel Dekker Inc., New York, 425 p.

Google Scholar

- White N.D.G., Jayas D.S., Demianyk C.J., (1997). Movement of grain to control stored-product insects and mites. Phytoprotection 78: 75–84.

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