The Planta RBS, Vol.-6, Issue-1, April 2025: 1759 – 1775 // ISSN: 3048:8494
Pande et.al. (Series Chapter No. – 193 // ISBN: 978-81-965701-4-9)
https://www.pgrindias.in

# STORED GRAIN INSECT PEST AND THEIR MANAGEMENT IN THE KUMAUN REGION OF UTTARAKHAND: A REVIEW

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Received: 04 February, 2025 Accepted: 28 March, 2025

## Abstract

This study provides an in-depth review of the life cycle, characteristics, and impact of insect pests on stored grains. These pests, primarily from the orders Lepidoptera and Coleoptera, cause significant damage to grain quality, leading to substantial economic losses globally. Insects are categorized into various feeding groups based on their behaviour: External Feeders, which feed on the surface of grains; Internal Feeders, which infest the grains; and Primary and Secondary Feeders, depending on whether they directly damage the grain or exploit previously damaged material. The presence of these pests leads to a range of issues, including reduced nutritional value, contamination, and the promotion of mould growth, which further compromises grain safety for consumption. Given the severe consequences of pest infestations, effective pest control is critical. Management strategies to control these pests include microbial, cultural, chemical, and physical methods, each targeting specific aspects of pest behaviour and grain preservation. Microbial control utilizes natural enemies such as bacteria, fungi, and viruses; cultural methods focus on environmental modifications to discourage pest survival; chemical controls involve insecticides and fumigants; and physical methods include techniques like temperature regulation, sealing, and storage structure modifications. A comprehensive understanding of these strategies and their effective implementation is essential for minimizing the adverse impact of insect pests on stored grains, ensuring food security, and reducing economic losses in the agricultural sector.

**Keywords:** Stored grains, Insect pests, Pest Management, Food preservation, Lepidoptera, Coleoptera

**Citation:** Pande Himanshu, Divya Pangtey, Akanksha Singh and Isha Chandra (2025), Stored Grain Insect Pest and their Management in the Kumaun Region of Uttarakhand: A Review. *The PLANTA Research Book Series, 6* (1), 1759-1775. www.pgrindias.in

## Introduction

The Kumaun region of Uttarakhand, located in the northern part of India, is home to a variety of agro-climatic zones conducive to the cultivation of staple grains such as wheat, rice, and maize. Indeed, agriculture forms the backbone of livelihoods for millions globally, with India's dependence on it even more pronounced, given that over 70% of its population relies on this sector (Negi and Solanki, 2016). The issue of stored grain pests, especially prevalent in regions like India with conducive climates, highlights the critical need for implementing proper grain storage techniques. Post-harvest losses resulting from unscientific storage not only threaten food security but also present economic hurdles (Daglish et al., 2018).

These pests infest grains to satisfy their need for sustenance and shelter, leading to both quantitative and qualitative losses (Bhargava & Kumawat, 2010). Interestingly, the economic impact isn't solely attributed to the actual consumption of grain by these pests but also to the contamination they introduce, including their excretions, rendering food unsuitable for human consumption. Addressing this issue requires a multifaceted approach, including the implementation of scientifically sound storage methods, the use of pest management techniques, and perhaps even innovations in storage technology to minimize losses and ensure food security for India's large population. The worldwide annual loss of food grains, estimated to be between 10-40%, (Stejskal et al., 2014) is largely attributed to insect pests, with a significant portion belonging to the orders Lepidoptera and Coleoptera. Stored grain pests are categorized as major or minor pests based on the severity of damage they cause. Further classification is based on their feeding habits (Deshwal et al., 2020).

**Primary Pests**

These pests directly feed on undamaged grains. They include species like the larger grain borer (*Prostephanus truncatus*) and the rice weevil (*Sitophilus oryzae*) (Deshwal et al., 2020).

**a) External Feeder:** Both the larval and adult stages of external feeders consume grains from outside. These pests typically access the grains through openings or weak points in the storage containers. Examples include certain species of beetles and moths that feed on the surface of stored grains or infest grain heaps (Bhargava & Kumawat, 2010).

**b) Internal Feeder:** Larvae of internal feeders feed entirely within the kernels or stored material. They penetrate the outer layer of the grain and consume the interior, often causing significant damage that may not be immediately visible from the outside. Common examples of internal feeders include certain types of weevils and borers (Bhargava & Kumawat, 2010).

**Secondary Pests**

These pests infest grains that have already been damaged or cracked, accelerating spoilage. Species like the red flour beetle (*Tribolium castaneum*) and the lesser grain borer (*Rhyzopertha dominica*) fall into this category (Deshwal et al., 2020).

Each category of pest requires specific management strategies tailored to their feeding habits and lifecycle. Integrated pest management techniques, including sanitation, temperature control, and the use of chemical or biological controls, are often employed to mitigate losses caused by these pests and ensure the security of stored grains.

**Primary Pest of Stored Grains**

**1. Rice weevil - *Sitophilus oryzae***

**Distribution**

The rice weevil, scientifically known as *Sitophilus oryzae*, is a significant pest worldwide, particularly in India, where it inflicts severe damage to stored grains (Bhargava & Kumawat, 2010).

**Host**

It affects a variety of grains, including paddy, wheat, millet, maize, sorghum, and barley (Kumar, 2017).

**Bionomics**

1. The full-grown larvae are around 5mm in length, plump, fleshy, and legless.
2. The adult beetle is reddish-brown, approximately 3mm in length, with a cylindrical body and a long, slender, curved rostrum. Its elytra bear four light reddish or yellow spots.
3. Breeding occurs from April to October, with adults hibernating during winter inside cracks, crevices, or under wheat bags in storage facilities.
4. During the active season, females lay approximately 400 eggs on grains, sealing the hole with a gelatinous secretion (Bhargava& Kumawat, 2010).
5. Eggs hatch in 6 to 7 days, and the young larvae bore directly into the grain, where they feed and grow to maturity. Pupation also occurs inside the grain, lasting 6-7 days. (Deshwal et al., 2020).

**Damage Symptoms**

1. Both the larvae and adults cause damage to grains. They hollow out the grains, reducing them to powder.
2. Damage can start in the field itself, and adults cut circular holes in the grains, causing more destruction than consumption.
3. Developing larvae live and feed inside the grains, causing irregular holes approximately 1.5 mm in diameter (Kumar, 2017).

**Table 1:** Primary Pest of Stored Grains

| Common name | Scientific name | Order | Family |
|---|---|---|---|
| **Internal feeders** | | | |
| Rice weevil | *Sitophilus oryzae* | Coleoptera | Curculionidae |
| Lesser grain borer | *Rhyzopertha dominica* | Coleoptera | Bostychidae |
| Angoumois grain moth | *Sitotroga cerealella* | Lepidoptera | Gelechiidae |
| **External feeders** | | | |
| Red flour beetle | *Tribolium castaneum* | Coleoptera | Tenebrionidae |
| Indian meal moth | *Plodia interpunctella* | Lepidoptera | Phycitidae |
| Fig moth or Almond moth | *Ephestia cautella* | Lepidoptera | Phycitidae |
| Rice moth | *Corcyra cephalonica* | Lepidoptera | Galleriidae |
| Khapra beetle | *Trogoderma granarium* | Coleoptera | Dermestidae |

**Table 2:** Secondary Pest of Stored Grains

| Common name | Scientific name | Order | Family |
|---|---|---|---|
| Saw-toothed grain beetle | *Oryzaephillis surinamensis* | Coleoptera | Silvanidae |
| Long-headed flour beetle | *Latheticus oryzae* | Coleoptera | Tenebrionidae |
| Flat grain beetle | *Cryptolestus minutas* | Coleoptera | Cucujidae |
| Grain lice | *Liposcelis divinitorius* | Psocoptera | Liposcelidae |

## 2. Lesser grain borer - *Rhyzopertha dominica*

**Distribution**

The lesser grain borer is found in several regions, including India, Algeria, Greece, the United States, New South Wales (Australia), Japan, and China (Bhargava& Kumawat, 2010).

**Hosts**

It attacks a wide range of stored grains and commodities, including wheat, rice, maize, sorghum, barley, lentils, army biscuits, ship biscuits, stored and dried potatoes, corn flour, beans, pumpkin seeds, tamarind seeds, and millets. (Kumar, 2017).

**Bionomics**

1. The larva is about 3mm long, dirty white, with a light-brown head and a constricted elongated body.
2. The adult is a small cylindrical beetle measuring about 3mm in length and less than 1mm in width. It is shining dark brown with a deflexed head, covered by a crenulated hood-shaped pronotum. There's no morphological difference between the two sexes.
3. Breeding occurs from March to November, with hibernation in December either as an adult or as a larva.
4. A single female can lay 300-400 eggs in 23-60 days at a rate of 4-23 eggs per day. Eggs are laid singly among the frass or glued to the grain in batches (Bhargava & Kumawat, 2010).
5. The incubation period is about 5-9 days. Larvae cut a circular hole in the pedicel end of the eggs to emerge.
6. Larval period lasts 23-50 days, pupal period 4-6 days, and adults live for about 40-80 days. There are typically 5-6 generations in a year (Deshwal et al.,2020).

**Damage Symptoms**

1. Both adults and larvae are voracious feeders, boring into grains and reducing them to mere shells with irregular holes.
2. Adults are capable of migrating from one storage facility to another, causing fresh infestations.
3. They produce a considerable amount of frass, spoiling more than what they eat.

4. Larvae eat their way into the grain or feed on the grain dust and can also attack grain externally (Kumar, 2017).

### 3. Angoumois grain moth - *Sitotroga cerealella*

**Distribution**

The Angoumois grain moth is found worldwide. In the Indian subcontinent, it is more abundant in mountainous areas or regions with mild climates (Ahmad et.al., 2021).

**Hosts**

It infests a variety of grains, including paddy, wheat, maize, sorghum, barley, oats, etc. (Kumar, 2017).

**Bionomics**

1. A full-grown larva is about 5 mm long, with a white body and a yellow-brown head.
2. The adult is a buff, grey-yellow, brown, or straw-colored moth with a wing expanse measuring about 10-12 mm. It has narrow, pointed wings fringed with long hair.
3. Breeding typically occurs from April to October. The insect overwinters as a hibernating larva and pupates in early spring as the season warms up.
4. Females lay eggs singly or in batches on or near the grain. The eggs are initially small and white, turning reddish later on. A single female lays, on average, 150 eggs, usually within a week after mating. The egg period is 4-8 days (Ahmad et.al., 2021).
5. The larval stage may last about 3 weeks. Before pupation, the larva constructs a silken cocoon in a cavity. The pupal period is 9-12 days, and the adult lives for about 4-10 days. During the active season, the life cycle is completed in about 50 days. Several generations are completed in a year (Deshwal et al., 2020).

**Damage Symptoms**

1. The damage is most severe during the monsoon season.
2. Only the larvae cause damage by feeding on grain kernels before harvest and in storage. They bore into the grain and feed on its contents.
3. Exit holes of about 1 mm in diameter, with or without a trap door, are observed on affected cereal grains. As the larva grows, it extends the hole, which partly gets filled with pellets of excreta.
4. Infested grains exhibit an unhealthy appearance and smell. In a heap of grain, the upper layers are most severely affected (Kumar, 2017).

### 4. Red flour beetle - *Tribolium castaneum*

**Distribution**

Worldwide (Ahmad et.al., 2021).

**Hosts**

Wheat flour, broken grains, mechanically damaged grains, dry fruits, pulses, and prepared cereal foods such as cornflakes (Kumar, 2017).

**Bionomics**

1. Eggs: Laid by females, typically about 25 in number, and take around 2 weeks to hatch.
2. Larvae: Initially yellowish-white and about 1 mm in length, mature into reddish-yellow larvae. They feed and develop for about 26-30 days in summer.
3. Pupae: Yellowish and hairy, pupation occurs in the flour, lasting 5-9 days.
4. Adults: Active during the breeding season from April to October (Deshwal et al.,2020).

**Damage Symptoms**

1. Larvae: Cause damage by feeding on stored food products. They are usually concealed within the food.
2. Adults: Construct tunnels as they move through flour and other granular food products. They are mostly found hidden in flour.
3. Infestation Signs: Flour may turn greyish, moldy, and develop a pungent odor, rendering it unfit for human consumption (Ahmad et.al., 2021).
4. Affected Products: Damaged processed food, flour, Suji, meda (Kumar, 2017).

**5. Indian meal moth- *Plodia interpunctella***

**Distribution**

The Indian meal moth is indeed found worldwide, infesting various stored food products across different regions (Ahmad et.al., 2021).

**Host Range**

It infests a wide range of stored food products, including grains, meals, breakfast foods, soybeans, dried fruits, nuts, dried roots, herbs, and even dead insects.

**Bionomics**

1. The larva of the Indian meal moth is typically white, sometimes tinged with green or pink, with a light-brown head.
2. When mature, the larva can reach a length of 8-13 mm.
3. The adult moth has a wingspan of about 13-20 mm and exhibits a coppery lustre.
4. Breeding can occur throughout the year.
5. The female moth lays 30-350 whitish ovate eggs, singly or in clusters, on or near suitable food sources.
6. The egg period lasts 2 days to 2 weeks, depending on environmental conditions.
7. Larvae reach maturity in about 30-35 days, after which they pupate within a thin silken
8. The pupal stage can last from 4-35 days. In summer, the life cycle is completed in 5 or 6 weeks, with about 4-6 generations per year (Deshwal et al.,2020).

**Damage Symptoms**

1. Damage is primarily caused by the larval stage. Larvae crawl over the surface of stored grains and other food materials, webbing them together with silken threads.
2. Adult moths fly from one storage bin to another, spreading infestations (Kumar, 2017).

### 6. Fig moth or Almond moth or Warehouse moth - *Ephestia cautella*

**Distribution**

Widely spread in tropical and subtropical regions (Ahmad et.al., 2021).

**Host**

Wheat, rice, maize, jowar, barley, sorghum, Groundnut, soybean, Spices, dry fruits, oilseeds (Kumar, 2017).

**Bionomics**

1. Adult Moth: Greyish wings with transverse stripes, approximately 12 mm in wing expanse.
2. Egg Laying: Females lay whitish eggs indiscriminately in cracks and crevices of grain receptacles or on foodstuff.
3. Larval Stage: Larvae spin tubes within the food material while feeding. Full-grown larvae are white with a pinkish tinge, measuring about 1.5 cm, and take around 40-50 days to mature (Ahmad et.al., 2021).
4. Pupal Stage: Larvae pupate inside cocoons, with the pupal stage lasting about 12 days.
5. Life Cycle: Completed in about two months, with 5-6 generations in a year (Deshwal et al.,2020).

**Damage Symptoms**

1. Feeding Habits: Larvae primarily feed on the germ portion of grains, leaving the rest of the kernel undamaged.
2. Infestation Patterns: In bulk infestations, damage is typically limited to the peripheral top layer of stored grains.
3. Web Formation: Larvae may create webs that cover bags, floor space, and milling machinery, leading to clogging issues in mills (Kumar, 2017).

### 7. Rice moth -*Corcyra cephalonica*

**Distribution**

Widely distributed in Asia, Africa, North America, and Europe. It is an important stored-grain pest in both India and Pakistan, particularly in rice-growing areas (Ahmad et.al., 2021).

**Hosts**

Primary Host: Rice and stored paddy. Other Hosts: Sorghum, wheat, maize, gram, groundnut, cotton-seed, milled products, cocoa beans, and raisins (Kumar, 2017).

**Bionomics**

1. Activity Period: Active from March to November, overwintering in the larval stage.

2. Egg Laying: Females lay eggs singly or in groups of 3-5 on grains, bags, and other objects in storage facilities. Each female can lay 62-150 eggs during its 24-day lifespan (Ahmad et.al., 2021).
3. Larval Stage: Larvae hatch from eggs in 4-7 days and feed under silken web-like shelters, preferring partially damaged grains. They reach full size in 21-41 days, then make silken cocoons among infested grains.
4. Pupal Stage: Lasts 9-14 days, and adults live for about one week.
5. Life Cycle: Completed in 33-52 days, with approximately six generations in a year (Deshwal et al., 2020).

**Damage Symptoms**

1. Feeding Habits: Larvae damage grains of rice and maize by feeding under silken webs. High infestations can convert entire grain stocks into a webbed mass.
2. Odor: Characteristic foul odor develops in heavily infested grains, rendering them unfit for human consumption (Kumar, 2017)

**8. Khapra beetle- *Trogoderma granarium***

**Distribution**

The khapra beetle's origin in India and its spread to various regions, including Europe, Australia, North America, and other parts of the Indian subcontinent, highlights its adaptability. Its preference for extremely dry climates in regions like Punjab, Haryana, UP, and Rajasthan, with less prevalence in coastal areas, reflects its ecological niche (Bhargava & Kumawat, 2010).

**Host**

The Khapra beetle targets a wide range of dried materials, including grain and cereal products, wheat, barley, oats, rye, maize, rice, flour, malt, noodles and animal products like dead mice, dried blood, dried insects (Kumar, 2017).

**Bionomics**

1. Breeding: The insect breeds from April to October.
2. Egg Stage: Females lay white translucent eggs, usually singly or in clusters of 2-5, on grains. A female can lay 13-35 eggs in 1-7 days.
3. Egg Period: 3-10 days.
4. Larval Period: 20-40 days.
5. Pupal Period: 4-6 days.
6. Hibernation: Larvae hibernate from November to March in cracks and crevices.
7. Generations: Typically, there are 4-5 generations in a year.
8. Larva: Fresh larva is yellowish-white, about 4mm long, turning brown as it grows.
9. Adult: A small dark-brown beetle, 2-3 mm long, with a retractile head and clubbed antennae. The body is covered in fine hairs.
10. Flight: Adults are incapable of flying (Deshwal et al., 2020).

**Damage Symptoms**

1. Seasonality: The greatest damage occurs in summer, from July to October.
2. Feeding Habits: Larvae consume grain near the embryo or weak points, progressing inwards. They primarily target the upper 50 cm layer of grains in a heap or the periphery in a sack.
3. Extent of Damage: Infestation can lead to substantial loss, reducing the grain to mere frass.
4. Collection: Larvae can be collected by placing gunny bags on a grain heap due to their positive thigmotactic behavior (Kumar, 2017).

**Secondary Pest of Stored Grains**

1. **Saw-toothed grain beetle - *Oryzaephillis surinamensis***

**Distribution**

It is a common stored product pest found worldwide, particularly in temperate regions but can also survive in tropical and subtropical climates (Ahmad et.al., 2021).

**Host**

Saw-toothed beetles are commonly found infesting grains, including wheat, rice, oats, barley, corn, and other cereal grains (Kumar, 2017).

**Bionomics**

1. The saw-toothed grain beetle is characterized by its slender, dark, narrow, and flattened body shape.
2. Notably, it possesses a distinctive feature: a row of saw-like sharp teeth on each side of the prothorax, which gives it its name.
3. Its antenna is clubbed, and the elytra (hardened forewings) completely cover the abdomen, offering protection.
4. The female saw-toothed grain beetle lays approximately 300 whitish eggs, depositing them loosely in cracks or crevices of storage receptacles in places like warehouses or godowns.
5. The egg period ranges from 3 to 17 days, depending on environmental conditions.
6. After hatching, the larva emerges. It is slender, pale, and cream in color with slightly darker patches on each segment.
7. The larval period typically lasts from 14 to 20 days.
8. Following the larval stage, the beetle enters the pupal stage. It constructs a protective cocoon-like covering with sticky secretions (Ahmad et.al., 2021).
9. The pupal period varies from 7 to 21 days before the adult beetle emerges (Deshwal et al., 2020).

**Damage Symptoms**

1. Saw-toothed grain beetles primarily feed on grains, dried fruits, and other stored food products.

2. They cause damage by either scavenging the surface of grains or burrowing holes into them.
3. Common targets include rice, wheat, maize, cereal products, oil seeds, and dry fruits.
4. Their feeding activity can contaminate food products and reduce their quality, making them unfit for consumption and leading to economic losses for farmers, food processors, and distributors (Kumar, 2017).

## 2. Long-headed flour beetle - *Latheticus oryzae*

**Distribution**

It is a common pest found worldwide, particularly in regions where grains are stored. Originally native to Asia, it has spread globally due to trade and transportation (Ahmad et.al., 2021).

**Host**

These beetles infest stored grains such as rice, wheat, barley, oats, corn, and various processed foods. They can be found in homes, food storage facilities, warehouses, and even grocery stores. They are particularly prevalent in warm and humid environments, but they can survive in a wide range of climates (Kumar, 2017).

**Bionomics**

1. Physical Description: The beetle is light brown in color with an elongated body, measuring 2-3 mm in length. Its appearance resembles that of *Tribolium castaneum*, commonly known as the red flour beetle (Ahmad et.al., 2021).
2. Reproduction: Female beetles lay approximately 400 white eggs individually on grains and seams of bags where grains are stored. The incubation period for these egg ranges from 7 to 12 days.
3. Larval Stage: The larvae, which are small, white, and highly active, feed voraciously on the inner portions of grains. The larval period lasts from 15 to 80 days, during which they undergo significant growth and development.
4. Pupal Stage: After the larval stage, the beetle pupates for 5 to 10 days, undergoing metamorphosis within a cocoon-like structure before emerging as an adult beetle.
5. Under optimal conditions of 35°C and 70% relative humidity, the entire life cycle of the long-headed flour beetle can be completed in approximately 25 days *(Deshwal et al., 2020).*

**Damage Symptoms**

1. Both larvae and adult beetles feed on milled products, causing damage to stored grains and packaged food and occur as secondary pests in stored grains (Kumar, 2017).

## 3. Flat grain beetle -*Cryptolestus minutas*

**Distribution**

The flat grain beetle, *Cryptolestus minutas*, is found globally, particularly in regions where grains are stored. It can be encountered in homes, food storage facilities, warehouses, and agricultural settings (Bhargava& Kumawat, 2010).

**Host**

This beetle infests a variety of grains and grain products. Its hosts include rice, maize (corn), wheat, various flours, groundnuts (peanuts), and other stored grains susceptible to infestation (Ahmad et.al., 2021).

**Bionomics**

1. Physical Description*:* *Cryptolestus minutas* is the smallest among stored grain insect pests, measuring 1.5 mm to 2.0 mm. It ranges in color from light to dark reddish-brown.
2. Reproduction: The female beetle lays white eggs loosely in flour, grains, or crevices. The egg period lasts approximately 5 days.
3. Larval Stage: The larva of *Cryptolestus minutas* is cigar-like and yellowish-white, with two reddish-brown spots at the anal segment. The larval period extends for about 21 days.
4. Pupal Stage: After the larval stage, the beetle pupates within a gelatinous cocoon *(Ahmad et.al., 2021).*
5. Life Cycle: The complete life cycle of *Cryptolestus minutas* spans approximately 42 days under favorable conditions.

**Damage Symptoms**

1. Both larvae and adults feed on broken grains or milled products, causing damage to stored grains and processed foods.
2. Heavy infestations can lead to heating in grain and flour, which can result in spoilage and reduced quality.

**4. Grain lice -*Liposcelis divinitorius***

**Distribution**

Grain lice are found worldwide, particularly in regions where grains are stored. They are commonly encountered in homes, food storage facilities, warehouses, and agricultural settings.

**Host**

Liposcelis divinatorius infests a wide range of starchy materials. Its hosts include various grains such as rice, wheat, maize (corn), barley, and oats, as well as processed grain products like flour and cereals.

**Bionomics**

1. Physical Description: Liposcelis divinatorius is pale grey or yellowish-white in color, small in size, resembling pinheads, with filiform (thread-like) antennae.
2. Reproduction: Females of Liposcelis divinatorius can lay approximately 7 to 60 eggs during their lifespan.
3. Metamorphosis: The metamorphosis of Liposcelis divinatorius is incomplete, meaning they undergo gradual development without distinct larval, pupal, and adult stages (Bhargava et. al., 2007).

**Damage Symptoms**

1. Grain lice primarily act as scavengers, affecting the germ portion of grains in heavy infestations. They feed on insect fragments, broken grains, and other organic matter present in stored grains.
2. They can thrive on a variety of starchy materials, including grains and processed grain products.
3. Damage symptoms caused by grain lice may include reduced grain quality, contamination of stored products, and economic losses due to spoilage.

**Management of Stored Grain Pest**

The management of stored grains refers to the various practices and techniques employed to ensure the safe storage, preservation, and quality maintenance of harvested grains over an extended period. It involves controlling environmental conditions, minimizing pest infestations, and preventing spoilage to maximize the economic value of the stored grains. Effective management of stored grains is essential for sustaining food security, minimizing post-harvest losses, and supporting agricultural livelihoods. It requires a combination of knowledge, resources, and ongoing monitoring and adaptation to mitigate risks and optimize storage outcomes.

With the vulnerability of stored grains to pest attacks and the reliance on chemical pesticides for control (Stejskal et.al., 2014), there's a pressing need to explore alternative and sustainable pest management strategies. While organophosphorus and pyrethroid insecticides, as well as fumigants like methyl bromide and phosphine (Yadav & Tiwari, 2018), have been effective in controlling pests, their continued use raises concerns about human health, environmental impact, and the development of pesticide resistance among pests. Key aspects of grain management include:

1. Traditional pest management approaches
2. Modern pest management approaches

**Traditional Pest Management Approaches**

Traditional pest management practices for stored grains involve a range of cultural, physical, and chemical methods that have been used for generations (Hajam & Kumar, 2022). These traditional pest management practices are often low-cost, accessible, and suitable for small-scale farmers (Manish et.al., 2011), but they require careful planning and implementation to be effective. Here are some key strategies:

**1. Storage in Sealed Containers**

Using containers that are sealed tightly helps prevent insect pests from accessing stored grains. Materials such as triple-layer plastic bags with airtight seals or containers treated to resist pests can effectively suffocate pests by depriving them of oxygen (Negi, & Solanki, 2016).

**2. Sand/Ash**

Mixing inert materials like sand or ash with stored grains acts as a physical barrier to insects and can suffocate them. Fine ash or powders can be particularly effective at preventing adult insects from laying eggs on grains (Negi & Solanki, 2016).

### 3. Harvesting Time

Harvesting grains at the right time, when they are fully matured and developed, can reduce the risk of pest infestations (Manish et.al., 2011). Delaying harvesting can deter adult insects from laying eggs on uncovered seeds, thus lowering infestation rates.

### 4. Alternate Hosts

Eliminating alternate host plants that pests can use when the primary crop is not available helps reduce pest populations. This can involve removing wild plants that serve as hosts for pests (Hajam & Kumar,2022).

### 5. Intercropping

Growing compatible crops together can help reduce pest infestations. For example, intercropping beans with maize has been shown to decrease infestations of bean pests in some regions (Yadav and Tiwari, 2018).

### 6. Cleanliness

Keeping storage areas and equipment clean helps prevent pest infestations (Manish et al., 2011). Proper cleaning of sheds, vehicles, and storage containers reduces the risk of introducing pests to stored grains.

### 7. Smoking

Using smoke from materials like cow dung (Ahmad et.al., 2021) can repel insects and reduce infestations without harming the grains. Smoke has been found to be effective in controlling pulse beetles and can be a low-cost alternative to chemical insecticides (Yadav and Tiwari, 2018).

### 8. Gaseous Effects

Manipulating the storage environment to alter gas concentrations, such as increasing carbon dioxide levels, can be lethal to insect pests (Yadav and Tiwari, 2018). High carbon dioxide levels can kill adult beetles and inhibit the development of pest larvae (Manish et.al., 2011).

### 9. Vegetable Oils

Coating grains with vegetable oils can deter pests by inhibiting egg laying and causing high mortality rates in larvae and adults. Crude and non-edible oils are often more effective and have ovicidal properties without affecting the quality of the grains (Hajam & Kumar,2022).

## Modern Pest Management Approaches

### 1. Chemical control

Stored grain pest infestation can be effectively managed through various methods, with fumigation being one of the most commonly employed techniques. Fumigation exposes insect pests to toxic gases generated by applying grain fumigants, effectively eliminating them from buildings, warehouses, small bags, soil, seeds, and stored products (Upadhyay & Ahmad, 2011). These fumigants enter the insect's body through their spiracles and spread to their trachea and tracheoles, ultimately binding to components of their hemolymph.

The Planta RBS, Vol.-6, Issue-1, April 2025: 1759 – 1775 // ISSN: 3048:8494
Pande et.al. (Series Chapter No. – 193 // ISBN: 978-81-965701-4-9)
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Historically, synthetic fumigants have been widely used to eliminate stored grain insect pests. Pyrethrins (Rajendran, 2016), for instance, are utilized to control specific pests like *Corcyra cephalonica*, while natural and synthetic cyanohydrins have shown effectiveness against various stored product pests.

A range of fumigants, including ethylene dichloride, carbon tetrachloride, ethane dinitrile, and others (Rajendran, 2016), are employed to combat pests like termites, cockroaches, mites, and stored grain insects. Phosphine gas, generated by metal phosphide preparations, is commonly used to fumigate public storehouses and inhibit the development of eggs in stored product pests. Additionally, fumigation with HCN gas, produced by metal phosphide preparations (Rajendran, 2016), effectively controls stored insect pests.

**2. Physical Control**

Physical control methods such as temperature, heat, and pressure play crucial roles in managing stored grain pest infestations.

Temperature treatment is a highly effective physical method that can kill various life stages of insects in stored grains. Extreme temperatures, both high and low, can cause heavy mortality in stored product insects. Superheating grains to temperatures between 55-65°C for 10 to 12 hours (Upadhyay & Ahmad, 2011) can effectively eliminate all life stages of stored grain pests in warehouses. Similarly, maintaining low temperatures can provide long-term protection against insect infestation, as it reduces insect development and eventually leads to insect mortality. Insects become inactive and die below 12°C (Stejskal, 2014), making long-term storage feasible and economical. Temperature also influences the reproductive performance of stored grain pests. For example, *Tribolium castaneum* exhibits reduced fecundity (Stejskal, 2014), egg-to-adult survival, and adult progeny production at lower temperatures. Additionally, moderate temperatures, up to 25°C (Upadhyay & Ahmad,2011), can accelerate the rate of increase of stored product mite populations.

Low pressure represents a nonchemical alternative to fumigants like methyl bromide and phosphines for controlling pests such as bruchids (Hajam & Kumar, 2022). Eggs and young larvae are particularly susceptible to high temperatures, while adults of certain species, like the rusty grain beetle, respond faster to higher temperature gradients.

The movement and distribution of adult insects within grain provide valuable information for pest detection and simulation of their distribution in grain bins (Hajam & Kumar, 2022). Acoustic techniques are effective in detecting hidden infestations of stored-product insect larvae, especially when larvae are highly active. Heat treatment can increase larval activity, enhancing the speed and reliability of acoustic detection under adverse conditions.

**3. Microbial Control**

Microbial control offers an effective alternative to synthetic pesticides, utilizing microbial insecticides in the form of spores and toxins. This approach is safer and more specific, with highly targeted toxins that can effectively control stored grain pests. One of the most effective microbial strains is *Bacillus thuringiensis* (Rajendran, 2016), which produces toxins that are lethal to stored grain insects. Entomopathogens, such as various fungi and viruses, are commonly used for controlling stored grain pests. These organisms infect and kill pests, providing a natural and sustainable method of pest control. For example, mustard oil combined with fungi like *Paecilomyces formosoroseus* or *Nomuraea rileyi* has been shown to reduce oviposition and adult emergence in *Bruchidius incarnatus*. Similarly, fungal species like *Beauveri abassiana, and Lecanicillium lecanii*, (Rajendran, 2016) are used to control the Indian meal moth.

## 4. Biological Control

Biological control methods employ various living organisms or their products to suppress populations of stored grain insects. These strategies have become widely accepted as effective means of managing stored grain pests. Several types of biological agents, including parasitoids, predators, and pathogens, are utilized in natural conditions to control insect populations.

Hymenopterans are commonly employed to reduce infestations and damage caused by stored grain insects. Parasitoids like *Bracon hebetor* and *Venturia canescens* are used to suppress populations of pests like *Ephestia cautella.* Additionally, predators such as hemipteran bugs, like *Xylocoris flavipes*, (Rajendran, 2016) and anthocorid bugs are frequently used to control stored grain pests in warehouses. These predators prey on various stages of insects and can significantly reduce populations, particularly of Coleoptera and Lepidoptera insects. Parasitoids play a crucial role in biological control by relying on other parasites to maintain low population levels of stored grain insects.

For controlling specific pests like the Indian meal moth, egg and larval parasitoids such as *Trichogramma deion* and *Habrobracon hebetor* are employed. Similarly, parasitoids like *Apanteles flavipes* (Rajendran, 2016) are used to control pests like the bean weevil. These parasitoids complete their life cycles inside the bodies of their hosts, effectively suppressing pest populations.

## 5. Cultural Control

Ensuring the cleanliness and proper maintenance of food grain storage facilities is crucial for preserving the quality and safety of the stored grains. Regular cleaning is essential to remove dirt, eggshells, dead larvae, and any other debris from the storage area. Broken and infested grains should be promptly removed and destroyed by burning before new grains are stored to prevent the spread of pests. All cracks and crevices in the walls and ceiling of the storage facility should be sealed with cement to prevent pests from entering or escaping. Proper labelling ensures these areas are identified for maintenance. The storage area should be whitewashed or painted with repellent paint to further deter pests. Coal tar can be used for painting purposes. Superheating the godowns with burning charcoal can effectively disinfect the area by raising the temperature to about 150°F (Upadhyay & Ahmad,2011). This process helps kill pests and their eggs. During this treatment, doors should be tightly closed for 48 hours, after which the godowns should be allowed to cool and cleaned before storage. Sulfur can be burned on charcoal to fumigate the godowns, releasing sulfur dioxide gas, which acts as a fumigant. Before supplying food grains, disinfestation measures should be carried out to ensure the grains are free from pests. Proper storage methods should be adopted in warehouses, including dusting the walls, floors, and ceiling with insecticidal specks of dust like BHC or DDT to disinfect the storage space. Commercial smoke generators can also be used for disinfection if the area can be made reasonably airtight (Upadhyay & Ahmad,2011).

## 6. Behavioral Control by Using Pheromones

Behavioral control using insect pheromones is a promising strategy for managing stored grain pests. Pheromones, which are chemical signals emitted by insects to communicate with each other, can be used in various ways to disrupt mating, monitor populations, and trap insects (Ahmad et.al., 2021). Disruption of mating with pheromones can lead to suppression of insect populations. For example, pheromones of insects like *Trogoderma* and the black carpet beetle (Hajam & Kumar, 2022) are used in bait traps to capture large numbers of these pests. Synthetic pheromones have also been developed for monitoring populations of stored grain insects, including species like Tribolium and Sitophilus (Upadhyay & Ahmad,2011).

Pheromones are also used in combination with entomopathogens, such as *Bacillus thuringiensis*, (Upadhyay & Ahmad,2011) for more effective pest control. Pheromone-baited traps containing insect pathogens can distribute the pathogen among stored-product insects, leading to increased mortality. This method is particularly promising for long-term control of insect pests, as it can suppress subsequent generations of pests through spore transfer and pathogen transmission.

**Conclusion**

The study highlights the practices of hill farmers who rely on traditional knowledge to construct eco-friendly grain storage structures. These farmers utilize indigenous methods for pest management, incorporating Integrated Pest Management (IMP) techniques. Effective control measures can significantly reduce the degree of infestation. Understanding the life cycle of pests, monitoring their activity, and assessing the damage they cause is crucial for better pest management in stored grains. External feeders, pests that consume grain from the outside, are easily noticeable. However, internal feeders, which damage grains from within, may not be apparent until significant damage has occurred. To prevent further infestation, heavily infested grain should not be stored in the godowns (storage facility). If infested material does enter the godowns, it should be kept separate until it can be fumigated. These practices aim to preserve grain quality and minimize losses due to pests.

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