Stored grain insect pests and their management: A review

Chapter · November 2022

CITATIONS
0

READS
215

3 authors, including:

M K Chandaragi
Sardarkrushinagar Dantiwada Agricultural University
11 PUBLICATIONS **9** CITATIONS
SEE PROFILE

Anand Prajapati
Navsari Agricultural University
6 PUBLICATIONS **1** CITATION
SEE PROFILE

₹ 760.00

ISBN 9789395369244

https://adventpublishing.in

ed by: Kamin A. & Pedge S.

Edited by
Dr. Kamin Alexander
Dr. Sudarshan Pedge

Advent Publishing

New
Ento

New Frontiers in Entomology - Vol. 1

Edited by: Kamin Alexander and Sudars

Authors: Lalsingh Rathod, Mamatha T,
Haider, Md. Humayoon Akhtar, Anju M
Angel Markush, Monika, Prajapati A. R

ISBN: 978-93-95369-24-4

First printing edition: November 2022

BD|#AP0240|826x117|00p|

Cover design by Mr. Jyotiram Shinde

Printed in Republic of India

Published by Advent Publishing

007, Aspen, Building No 01,
Mohan Highlands, Badlapur East
421503 (MS) INDIA

Phone: +91-92-092-80-738

E-mail: info@adventpublishing.in

Website: https://adventpublishing.in

New
Ento

Sam

Ka

This book explores tho
offers a foundation for a
management, including: env
coastal and estuarine manag
practice. As we all know that
intricately interwoven with
Physiology, Insect ecolog
Entomology, Bio-rational A
depth multidisciplinary resea
useful results for integrated
and rapidly evolving discipli
which include:

- Agriculture and insec
- Insect behavior.
- Biological control of
- Biological control of
- Food and forage crop
- Pest of Alfalfa, corn,
- Pest of sorghum, soyb
- Forensic entomology.
- Insect ecology.
- Population dynamics
- Microclimatic influen
- Trophic level relation
- Horticulture crops.
- Insect pest manageme
- Insect resistance to pe
- Insect systematic
- Insecticide toxicology
- Environmental toxico
- Insect genetics.
- Plant and insect intera
- Pollinator Health.
- Veterinary entomolog
- Biological control of
- Stored pest grains

These fields are Cultu
semiochemical-based strateg
Quarantine Entomology,
Conservation; Molecular En
indicative to a reasonable ext

Advent Publishing

CHAPTER EIGHT

Stored grain insect pests and their management: A review

M.K.Chandaragi[1], A. R. Prajapati[2] and Manisha Sindhe[3]

[1]*Cotton Research Station, Sardarkrushinagar Dantiwada Agricultural University, Talod, Sardarkrushinagar (Gujarat)*

[2]*Ph.D. Scholar, Department of Entomology, N. M. College of Agriculture, Navsari Agricultural University, Navsari (Gujarat)*

[3]*Agriculture in Polytechnic, Sardarkrushinagar Dantiwada Agricultural University, Deesa (Gujarat)*

Corresponding author(s) Email address: mallu3731@gmail.com

Abstract

India's agriculture production of food grains is not in proportion due to the country's population explosion, reduction of cultivable land along with post-harvest grain losses. According IGMRI, Hapur post-harvest losses of about 10 per cent of total food grains produced due to unscientific storage, insect pests, mites, birds, rodents and micro-organisms. Out of these post-harvest losses storage, insects alone accounted for 2.0 to 4.2 per cent. The main economic loss by storage insect pests includes grain consumption as well as by food contamination. There are several insect pests reported to be occurring on stored grains and cause different kinds of losses *viz.,* quantitative and qualitative loss, loss of seed viability and damage to storage structures, respectively. Hence, scientific management of stored insect pests is very crucial at every step starting from harvesting to processing. The details of different insect pests in storage and their management practices are discussed in this chapter.

Introduction

Typically stored grain pests refers any organism that can infest and cause damage to stored grains, foods, any other dried or processed foods, books, documents, fabric material, leather and wool in storage. These may be any micrio-organism (fungus, bacteria), arthropods (Insects and mites), mammals (rodents) and birds. The losses incurred by these pests accounted to 10 per cent of the total food grain produce in India. The infestation is carried to the storehouses from the infested field crops with the food grains and spread rapidly. A number of insect pests access to the grain storage at various stages of processing of food grains/ seeds *viz*., during the process of development and maturation of seeds/ grains, processing in threshing yards, during

New Frontiers in Entomology - Vol. 1 – Kamin Alexander *et al.* (Eds.) ISBN: 978-93-95369-24-4

transit or while in storage. Some insect pests initiate damage at the ripening stage of crops and continue during storage also. Major sources of infestations are old bags, storage structure, old containers, and cross over infestation (Pruthi and Singh, 1950). Further, damage is supported by environmental factors such as humidity, temperature and light. Storage insects belong to two orders namely Coleoptera (beetle pests) and Lepidoptera (moth pests). In storage, insects cause damage by feeding on grains causing weight loss and loss in quality as they deplete the nutrients. They contaminate the grains with their dead bodies, cast skins, excreta and with their webbings. The grains and grain products get bad colour, odour and taste, under severe infestation grains become unfit for consumption. Some of the storage insects are known to infest the grains in the field itself (eg. weevil, bruchids, angoumois grain moth etc). They may be grouped as internal feeders and external feeders. Although there are about one thousand insects are associated with stored grains all over the world (Srivastava and Subramanin, 2016) while only some are inflict severe damage to the grains leading to both in quantity as well as qualitative loss.

Insects cause different kinds of losses

Quantitative loss: Direct feeding insects cause loss in weight of the stored grains. A rice weevil will eat 14 mg out of 20 mg of a rice kernel during its developmental period. But commercially the whole grain is lost. A female weevil, through three generations per year, has the biotic potential to reproduce 1,500,000 offspring which will consume 1,500,000 kernel of rice (amounting 30 kg of rice). A gravid female of *Sitotroga cerealella* can destroy 50 g of rice completely in 3 generations.

(https://agritech.tnau.ac.in/crop_
rotection/crop_prot_crop_insect%20_storage_importance.html)

Qualitative loss: Direct feeding on the grain, chemical changes in grain content, contamination of grains with moult skin and body parts, spreading the pathogenic micro-organisms, loss of seed viability, Insects were found to cause the loss of viability of seeds to an extent of 3.6 to 41 per cent in paddy (https://igmri.dfpd.gov.in/igmri/storage).

Storage insect pests are broadly classified into 2 types:

I. **Primary insect pests:** These insects attack whole, sound and undamaged grain or seeds. Larvae of these insects are confined within one seed during its development

a) **Internal feeders**- Larvae of these insects are confined and feed inside the seed during its development

b) **External feeders**: Larvae of these insects are confined and feed outside the seed during its development

II. **Secondary insect pests:** These insects do not attack whole grains and fed mainly on broken or already damaged grains

I. Primary insect pests: Important primary storage insect pests, their bionomics, symptoms of damage were discussed.

A. Internal feeders

1. Rice weevil: *Sitophilus oryzae* Linnaeus (Curculionidae: Coleoptera)

They were cosmopolitan in nature and exist everywhere. Cereals like rice, wheat, maize, jowar, paddy, oat and linseed are severely damaged by it.

Fig.1
(Source: https://www.ipmimages.org/browse/detail.cfm?imgnum=5460611)

Fig.2
(Source: https://en.wikipedia.org/wiki/File:Sitophilus_oryzae_(Linn%C3%A9,_1763)_(3546202126).jpg)

Fig.3
(Source: https://www.ipmimages.org/browse/detail.cfm?imgnum=1435012#)

Bionomics

The female chews a tiny hole in the grain into which she lays her eggs, which are then covered by a secretion. Throughout her lifetime, a single female deposits 250–300 eggs. During the summer, the incubation period lasts around 2-3 days, while it lasts 6-9 days in the winter. The grub feeds within the grains, growing to maturity in 25-35 days. Grub has no legs and is whitish (Fig.1). Inside the grain, the fully grown grub pupates, and the pupal stage lasts 4-8 days in the summer and 14-20 days in the winter. The mature weevils (Fig 2) emerge from the grain by cutting its way out, and it survives for 21-28 days in summer and three months in winter. The adult has four reddish markings on its forewings and is a powerful flier. Its colour ranges from dark brown to black. Its antennae are formed like an elbow and have a protruding snout. Its length ranges from 3 to 5 mm. At the tip of the snout is a pair of mandibular jaws. Adults spend the winter months hiding out under go downs under rice bags or in gaps and crevices. At least three to five generations are completed each year (Jadav, 2006; Devi *et al*., 2017)

Symptoms of Damage

Both the adult and grub stages are harmful. It is a pest in both fields and warehouses. The female creates a small pit on the grain, lays an egg inside, and then tops the egg with gelatin. Grubs eat inside the seed by burrowing into it, hollowing out the grain. Within the grains, pupation occurs. The seeds develop holes when the adults emerge (Fig 3).

2. Lesser grain borer: *Rhizopertha dominica* (Fabricius) (Bostrychidae: Coleoptera)

Lesser grain borer is regarded as the second most significant pest of stored grains, after rice weevil. The insect's reflexed head, a characteristic of its family, makes it easy to identify it.

Fig.4 Grubs of *Rhizopertha dominica*

(Source: https://plantwiseplusknowledgebank.org/doi/10.1079/PWKB.Species.47191)

Fig.5 Adults of *Rhizopertha dominica*

(Source:https://en.wikipedia.org/wiki/Rhyzopertha)

(**Fig 6** Damage by *Rhizopertha dominica*

(Source: https://www.invasive.org/browse/detail.cfm?imgnum=1233134)

Bionomics

The eggs are attached singly or in clusters to the surface or interstices of the kernel. One female lays 300-400 eggs. Grabs are small and white in color (Fig 4). The grub period is 35-45 days. The pupal stage is 7-8 days. Within the kernel, these larvae pupate and later mature into adults (Fig 5) that emerge from the kernel through a hole. The beetle is small, dark brown, 3 mm long, and has a dark brown or black cylindrical body with roughened body units. The dwarf borers head is directed below the ribcage and is armed with powerful jaws for cutting and drilling wood. The antenna is sawn into three small, white pieces with curved bodies. The life cycle completed 42-60 days under optimal conditions. Five to six generations are noticed in a year. Antenna three segmented serrate, grub small and white in colour with bent body (Edde, 2012; Win and Rolania, 2020)

Symptoms of Damage

Both larvae and adult produce frass and cause weight losses by feeding on grains. These insects do not run fast and can easily hide in cracks and underneath damage flour (Tyagi *et al*., 2019)

3. Pulse beetle: *Callosobruchus chinensis* (Linnaeus) and *Callosobruchus maculatus* Fabricius (Bruchidae: Coleoptera)

Pulse beetles are widely distributed in temperate zones around the world. Infestation may start in the pods before harvest and carry over into storage where extensive losses may take place. These beetles exclusively feed on stored whole pulses *viz*., red gram, black gram, green gram, chickpea, horse gram, cowpea, pea etc.

Fig.7.Grubs of *Callosobruchus chinensis*

(Source: https://vikaspedia.in/agriculture/post-harvest-technologies/technologies-for-agri-horti-crops/storage-insects-and-their-management)

Fig 8. *Callosobruchus chinensis* adult

(Source: https://en.wikipedia.org/wiki/File:Callosobruchus_chinensis_(Linn%C3%A9,_1758)_male.jpg)

Fig 9. Damage by *Callosobruchus chinensis* on chickpea

(Source: http://agropedia.iitk.ac.in/content/pulse-beetle-callosobruchus-chinensis-chickpea)

Bionomics

Female lays 30-80 white eggs which are visible on grains. Egg period is 4-8days. Fresh eggs are translucent, orange cream in colour, changing to greyish white with age. Grub is fleshy, curved, white and creamy in colour, with black mouthparts (Fig 7). It molts four times. Larval period is 14-26 days and mature larva 6-7 mm long. Full grown grub lies at periphery next to seed coat and pupates in side seed. Pupa is oval in shape and white in colour while, pupal period is 4-12 days and having 2-3 mm length. The adult beetle measured about 3-4mm in length. Adults (Fig 8) are mostly good fliers so they can easily migrate from one go down to other. They are stout bodied beetles with serrate or pectinate antennae. Wings are short and exposing the tip of the abdomen uncovered (Pygidium). Adult period is 8-12 days. The average life span of an adult is 32-45 days. Around 7-8 overlapping generations are completed per year (Patel *et al*., 2005; Hosamani *et al*., 2018; Augustine and Balikai, 2019)

Symptoms of Damage

Adults do not feed but larvae of this pest can cause heavy damage. Infestation starts in the field itself. Grubs are responsible for the formation of cavities in seed kernels. The infested grain becomes completely hollow inside, leaving only a thin outer shell intact. Adults emerge and migrate across the surface of the grain, forming circular exit holes. Adults produce a considerable amount of frass, spoiling more than what they eat. If the container is poorly aerated, fungus and foul smell could also develop.

4. Groundnut bruchid or Tamarind beetle: C*aryedon serratus* Linnaeus (Bruchidae: Coleoptera)

It originates in Asia but has spread too many tropical and subtropical regions of the world**.** It is a large robust bruchid which is associated with groundnut when stored in their shells; it is also a pest of tamarind pods. Generally, infestation starts from field where the adults lay eggs on the pods and carried to storage.

Fig 10 Grubs of *Caryedon serratus*

(Source: https://d3i71xaburhd42.cloudfront.net/8e3ad36a744a71cf7b2248b00ddb50ae8040e399/3-Figure4-1.png)

Fig 11. *Caryedon serratus* adult

(Source: http://www.dicksonchemical.com/insects14.html)

Fig 12 Damage by groundnut bruchid

(Source:https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.11348)

Bionomics

Females lay about 80-100 eggs in pods or seeds. The incubation period 3-6 days. The grub is whitish and the head is brown. Grub period is 25 to 32 days. After hatching, the larvae break through the walls of the pod to reach the core and cause damage. Grubs (Fig 10) pupate inside silken cocoon, having pupal period of 11 to 13 days. Adults are 4-5 mm long, with reddish-brown bodies and dark spots. The prothorax is trapezoidal, densely covered with gray hairs and the hind legs are large. Adults are 4 to 7 mm long, reddish brown and have irregular black markings on the elytra. They are easily distinguished from other pests by their large, protruding eyes, wide femur of hind legs with conspicuous comb of spines. Adults live for 13-14 days. The entire life cycle is completed in 65-80 days (Sakhare *et al*., 2018; Oaya, 2020)

Symptoms of Damage

Primarily grubs are harmful stage. It is the key pest of groundnut in shell. The infested groundnuts lose their commercial values and eventually unfit for human consumption. First symptom of attack is appearance of windows cut into pod wall by larvae. After hatching, larvae burrow through pod wall and eat seeds (Fig 12).

5. Cigarette or tobacco beetle: *Lassioderma serricorne* (Fabricius) (Coleoptera: Anobiidae)

Although, the cigarette beetle is a cosmopolitan pest it generally prefers to be in warmer environmental conditions. It feeds on wide range of commodities, but prefers to feed on cigarettes, cocoa and chewing tobacco, chocolate, spices. The other hosts are paprika, dry dog food, beans, dried fruits, biscuits, grains, peanuts, rice and vegetables.

Fig.13. Grubs of Lassioderma serricorne (Source: https://entnemdept.ufl.edu/creatures/urban/stored/cigarette_beetle.htm)

Fig 14. Adult beetle of *Lassioderma serricorne* (Source https://en.wikipedia.org/wiki/File:Lasioderma_serricorne_(Fabricius,_1792)_(28701262892).png)

Fig.15. Damage by *Lassioderma serricorne* on cigarettes (Source: https://www.researchgate.net/figure/Damaged-cigarettes_fig4_285322257)

Bionomics

Tobacco beetles are light brown oval shaped beetles with serrated antennae and strong humped appearance on the head and thorax. Egg-laying occurs either in the folds or crevices of the food material. The eggs are mostly oval or oblong, 0.29 to 0.50 mm long and white in colour, but become opaque before hatching. Females lay about 100 to 110 eggs, which hatch in 5-6 days. The larval stage lasts 20 to 25 days, followed by the pupal stage. Larvae (Fig 13) are smaller than adults and resemble worm like. They are known as cigarette beetles or tobacco beetles because they are found on tobacco and cause damage by forming small galleries. After 25 to 39 days of larval life, it forms a smooth cell on which it rests. Newly formed pupae are glossy white, but gradually turn reddish brown after a few days. Females are mostly larger than males. Adults (Fig 14) have a downwardly curved head and thorax with small hairs on the elytra (Edde, 2019).

Symptoms of Damage

Both adults and grubs of this pest enter into the tobacco products *viz*., cigarettes, cheroots, and chewing tobacco. A typical symptom of infestation by this pest is the presence of pin-sized round burrows in processed tobacco. The grubs are tunneling inside the cigarettes and after transforming to adults they exit leaving hole on commodities (Fig 15). The pest also attacks cocoa, wheat, ginger, chili peppers, turmeric and cottonseed.

6. Sweet Potato weevil: *Cylas formicarius* (Fabricius) (Curculionidae: Coleoptera)

Fig. 16. Grubs of *Cylas formicarius* tunneling on Sweet Potato (Source: https://www.insectimages.org/browse/detail.cfm?imgnum=5368079)

Fig. 17 *Cylas formicarius* Adult (Source; https://www.alamy.com/male-of-sweetpotato-or-sweet-potato-weevil-cylas-formicarius-fabricius-isolated-on-a-white-background-image449131350.html)

Fig 18. Damaging symptom of *Cylas formicarius* in stored root (Source: https://apps.lucidcentral.org/pppw_v10/text/web_full/entities/sweetpotato_weevil_029.htm)

Bionomics

Adult female makes small cavities on the tubers or stems and deposit eggs singly. Each female lays 100 to 200 eggs. Incubation period is 5-10 days. Grubs are apodous, pale-yellowish white in colour (Fig 16). Pupation takes place inside vine or inside tuber. Grubs and pupal stages last for 16 to 25 and 4 to 8 days, respectively. Adult weevils are ant-like, slender bodied having elongated snout-like bluish-brown head with non-geniculate antenna, bright red thorax and legs and brownish-red abdomen (Fig 17). Entire life cycle is completed in 28 to 39 days (Sutherland, 1986)

Symptoms of Damage

Grubs bore into stems, tunnels inside and feed on soft tissues (Fig 18). Grubs and adults bore into tubers both in field and storage godowns. Affected tubers develop dark patches, which later start rotting. This is dispersed from field to field through infested vines and is carried over from season to season by breeding in damaged tubers left in the fields after harvest.

7. Angoumois grain moth:*Sitotroga cerealella* (Olivier) (Gelechiidae: Lepidoptera)

The insect names come after its first notice during 1736 from Angoumois region of France. It is mainly found in a warm temperate climate and attacks both stored as well as fieldgrains. It causes enormous damage to the grains of paddy, sorghum, bajra, wheat, etc.

Fig. 19. Grub of Angoumois grain moth

(Source: https://en.wikipedia.org/wiki/Angoumois_grain_moth)

Fig. 20. Adult of Angoumois grain moth

Fig. 21. Larval damage of Angoumois grain moth on stored grains

(Source: https://www.forestryimages.org/browse/detail.cfm?imgnum=1435096)

Bionomics

Eggs are placed in grains, sacks and other godown items individually (up to 150 eggs) or in groups of 3-5 each. Incubation period is 4-8 days. The larvae are milky white with a reddish-brown head, about 5 mm long and have conical prolegs on the abdominal segments (Fig 19). The larva spins a silky cocoon inside the kernel and becomes a reddish brown pupae. Before pupating, the larva cuts circular opening in the silky covering of the shell and emerge out. The pupal stage lasts for 9-12 days. Cocoons are dense white and tough. Adult (Fig 20) is a pale grayish brown or straw coloured moth (Singh and Bindu, 2014; Srivastava and Subramanian, 2016).

Symptoms of Damage

Larva is the damaging stage which bores into a number of cereals including paddy. Larva (Fig 21) webs together the broken grains with silk and frass and feed on them. Grains like sorghum, rice, wheat, maize and milled products such as *soji*, oil cakes, dries fruits *etc.* are attacked. In case of whole grains, kernels are bound into lumps up to 2 kg. Pupation takes place silken cocoon among the infested grains.

8. Almond moth: *Cadra cautella* Walker (Pyralidae: Lepidoptera)

Almond moths are found around the world. Although it thrives best in tropical climates, it has spread too many regions around the globe due to its tendency to infest dry goods that are shipped internationally.

Fig.22: Adult moth of *Cadra cautella*

Fig.23 Damage by *Cadra cautella* on stored groundnut

(Source: https://en.wikipedia.org/wiki/Almond_moth)

Bionomics

Generally, adult female moths oviposit around 200 eggs at a time and it takes about 3 days for eggs to hatch. The larvae go through five instars over a period ranging from 17 to 37 days (Gordon and Stewart, 1988). Larvae are mostly gray with darker heads. The caterpillar is 12-15 mm long and identifiable by the pattern of spots along its back. The pupal stage completed around 7 days. Adult almond months are predominantly light brown in color (Fig 22), with smaller hind wings that are typically gray. When extended, its wingspan ranges from 14 to 22 mm. The back edges of the wings are lined with a short fringe (Subramanyam and Hagstrum, 1996). Adult females live on average for 10 days and adult males live for an average of 6 to 7 days. (McNamara *et al*., 2008)

Symptoms of Damage

Larva is pale white and attacks flour and broken grains (Fig 23). Dense webbing on the surface of affected products like dried fruits, vegetables products and cereals especially maize can be seen. Almond moths exists as a primarily pest, its habitat is often some kind of dry food product which is stored in a warehouse or similar industrial environment. Most commonly, they are found in dried fruits, but they have also been found in nuts, beans, flour, and other grains.

9. Mediterranean flour moth: *Ephestia kuehniella* Zeller (Pyralidae: Lepidoptera)

This moth is found throughout the world, especially in countries with temperate climates. It prefers warm temperatures for more rapid development, but it can survive a wide range of temperatures. The Mediterranean flour moth is frequently found in warm places with stored grain products, such as flour mills and bakeries, where it can breed year round.

Fig. 24 Adult moth of *Ephestia kuehniella*

(https://en.wikipedia.org/wiki/File:Ephestia_kuehniella_male.jpg)

Fig 25. Larva of *Ephestia kuehniella*

(https://en.wikipedia.org/wiki/File:Ephestia_kuehniella_larva.jpg)

Bionomics

Female's lay 116 -678 eggs in a food source, such as flour, to which the eggs often become attacked. When the eggs hatch, larvae spin silken tubes around themselves. Larva is pale white in colour and attacks flour and broken grains. They spend about 40 days maturing within these tubes. Full grown larvae disperse to new locations and spin silken cocoons in which they develop into pupae. Adult (Fig 24) are small gray coloured moths emerge in 8-12 days (Jacob and Cox, 1977).

Symptoms of Damage

Larva (Fig 25) attack stores of flour or other cereal grains as a source of food, but the most damage is done when they interfere with machinery in the mills. The web-like material that larvae spin clogs machines.

b) External feeders

10. Rust-red flour beetle: *Tribolium castaneum* (Herbst) and Confused flour beetle: *Tribolium confusum* Jacquelin du Val (Tenebrionidae: Coleoptera)

They are serious pests 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.

Fig.26. Developmental stages of the red flour beetle, *T. castaneum*.

(Source :Rosner *et al*., 2020)

Fig. 27. Larva of T. confusum

(Source: https://www.biolib.cz/en/image/id352445/)

Fig.28. Adult of *T. castaneum*.

(Source: https://en.wikipedia.org/wiki/Red_flour_beetle)

T. castaneum

Fig.29. Adult of *T. confusum*

(Source: https://www.intechopen.com/chapters/79822)

T. confusum

Bionomics

The rust-red flour beetle is 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. Beetles are small, elongate rust red coloured measuring 3-4 mm in length. Grub is flat, dull yellowish and body covered with setae. Antennal segments in the confused flour beetle increase in size gradually from base to tip (Fig 29) while in red flour beetle last three segments at the tip of the antennae are abruptly larger than the preceding ones (Fig 28). The two species occur together and they can be distinguished based on the antennae. Incubation period is 4 to 5 days and grub underwent seven instars. Grub is flat, dull yellowish and body covered with setae. Developmental period of the immature stages ranged from 70 to 83 days. Pupation takes place in the flour. The pupal period range from 6 to 9 days and the unmated male and female adult period range from 45 to 67 days and 75 to 89 days, respectively. The total life cycle of a beetle is 164-194 days (Devi and Devi, 2015).

Symptoms of Damage

Both adults and grubs are external feeders, feeding on broken grains, oilseeds, oil cakes, dried fruits, nuts and processed products like flours, soji, atta, maida etc. It also imparts bad smell to the commodity. 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 colour.

11. Khapra beetle: *Trogoderma granarium* (Everts.) (Dermestidae: Coleoptera)

It is more confined to extreme dry climate weather. It is highly destructive to wheat, also infesting maize, jowar, rice, pulses, dried fruits, oil seeds and their cakes.

Fig 30 Grub of kapra beetle (Source: https://apps.lucidcentral.org/pppw_v10/text/web_full/entities/khapra_beetle_483.htm)

Fig 31. Adult kapra beetle (Source:https://en.wikipedia.org/wiki/File:Khapra_beetle.jpg)

Fig 32. Damage of kapra beetle on stored grains (Source: https://entnemdept.ufl.edu/creatures/urban/beetles/khapra_beetle.htm)

Bionomics

Female fecundity is 13- 85 eggs with incubation period of 3- 5 days. Larva is brownish white in colour and body covered with bundles of long, reddish brown, movable and tactile hairs on the posterior segments forming a sort of tail at the posterior end. Larva campodeiform yellowish brown covered with long brown hairs (Fig 30). Grub period is 20-40 days. Pupation takes place in last larval skin among the grain. Pupal period is 4- 6days. Adult is oval in outline, having grey and light brown markings with no distinction of head, thorax and abdomen (Fig 31). Abdomen is large in size and antennae are club shaped. Males are smaller, darker and incapable of flying. It completes 4-5 generations (Hadaway, 1956)

Symptoms of Damage

Only grub is the damaging stage, feeds on many kinds of grains and other products of vegetable origin. Seed coat chewed up in an irregular manner in all cereals especially wheat, wheat products, oil cakes and peanuts (Fig 32).

12. Rice moth: *Corcyra cephalonica* Stainton (Pyralidae: Lepidoptera)

It is a very serious pest of stored paddy and other cereals ans widely distributed in all rice-growing regions. It develops well in humid and warm climates and also infests wheat, sorghum, maize, barley, oilseeds and sweet products. Rice moth is widely used for rearing of

natural enemies under laboratory and in field against crop pests as it is easier and cheaper to produce natural enemies on different stages of *Corcyra* for mass production (Lee *et al*., 1991; Gaffar *et al*., 2012)

(Fig 33. Larva and adult of *Corcyra cephalonica*

Source:

https://agritech.tnau.ac.in/crop_protection/crop_prot_crop_sto_insect_primary_pest_15.html)

(Fig 34. Damage of *Corcyra cephalonica* on groudnut

Source:

https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.15444)

Bionomics

Almost 200 eggs are laid by females which are small, oval, 0.4 mm long and are mostly laid on bags, walls. Incubation period is 4-7 days. Larvae having variable color forms such as white, green, and slightly bluish-gray. Fully grown larva is 11-15 mm long with short scattered hairs and no markings on body (Fig 33)). Pupae are pink, elongated and cylindrical with dark spots on the apical side. Pupal period is about 9-16 days but may extend to 40-50days to tide over winter. Adult is a pale grayish brown moth with a wing expanse of 2.5 to 3 cm. Larva is creamy white with reddish brown head and measures 2 cm. Females are larger than males. Adult life is usually for a week. The Head is provided with tufts of hairs (Devi *et al*., 2013)

Symptoms of Damage

Larva is the damaging stage which webs together the broken grains with silk and frass and feeds on them (Fig 34). Larvae feed on rice, jowar, wheat, maize, biscuits, candies, cocoa, and other kitchen foods. Besides these pests also pollute the environment with large quantities of frass and silken cocoons, webbing together the grains into large lumps occur.

2. Secondary pests

13. Saw toothed grain beetle: *Oryzaephilus surinamensis* Linnaeus (Silvanidae: Coleoptera)

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.

Fig 35 Larva of *Oryzaephilus surinamensis*. (Source: https://www.ipmimages.org/browse/detail.cfm?imgnum=5521099)

Fig 36 Adult of *Oryzaephilus surinamensis* (Source: https://en.wikipedia.org/wiki/File:Oryzaephilus_surinamensis_(Linn%C3%A9,_1758)_(14438947353).png)

Fig.37 Damage by *Oryzaephilus surinamensis* on maize (Source: https://www.npmcevre.com/index.php?page=zararlilardetay&zid=44)

Bionomics

Antennae are club shaped and elytra completely cover abdomen. Female can lay up to 300 eggs. Eggs are white in colour, laid loosely in cracks of storage receptacles and godowns. Hatching period is 3-17 days. Larvae are white in color with black markings (Fig 35), flat form, three pairs of legs and an abdominal proleg. Larval period is 14-20 days. 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. Pupal period is 8-15 days. Adult survive for 6 to 15 days and total life span 38 to 58 days. It is a dark red flat beetle with 6 teeth like projection on either side of the pronotum and hence the saw toothed grain beetle (Fig 36). There are 4-6 generations completed in a single year (Kousar *et al*., 2021)

Symptoms of Damage

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, as well as cocoon formation, is the primary indication of this pest infestation. They feed on grains, milled products, dried fruits, nuts, tobacco, dried meat etc (Fig37) . Adult stage is remained as resting stage.

14. Long headed flour beetle: *Latheticus oryzae* Waterhouse (Tenebrionidae: Coleoptera)

It is mainly attacks on broken grains, wheat, rice, corn, flour, barley and many other granaries, grocery stores and mills.

Fig 38. Larva of *Latheticus oryzae* (https://agritech.tnau.ac.in/crop_protection/crop_prot_crop_sto_insect_primary_pest_12.html)

Fig 39 Adult of *Latheticus oryzae* (Source:https://en.wikipedia.org/wiki/File:Latheticus_oryzae_Waterhouse,_1880.png)

Bionomics

Eggs are mostly smooth and translucent in color. Grubs are generally white in color with dark eyes. Body of larva is covered by pale-colored hairs (Fig 38). The life cycle is completed in 25–39 days. It is cosmopolitan, pale yellow, slender, flattened beetle, with slightly bulged antennae and the presence of can thus behind each eye. Beetle is light brown with elongated body measures about 2-3 mm long. Head is large having shorter antenna than head, 11 segmented with 5 clubbed apical segments (Fig 39).

Symptoms of Damage

Milled products are fed by both grubs and adults as well. It is a secondary pest of milled products. Both larvae and adults feed on the commodity. Cereals flours, wheat, corn, barley, packaged food, rice and rice products, grains with excessive dust, broken grains and many other grocery stores and mills with high moisture contents are preferred.

15. Flat grain beetle: *Cryptolestes pusillus* (Schonherr) *Cryptolestes minutus* (Olivier) (Laemophloeidae: Coleoptera)

These are smallest beetle among the stored grain insect pests, both adults and larvae attack almost all types of grains and grain products including dried fruits, groundnut seeds and oilseed cakes. Rapid reproductions leads to increase in number and are generally found in association with many other stored insects like rice weevil, flour beetles etc.

Fig 40. Adult of Flat grain beetle (Source: https://en.wikipedia.org/wiki/File:Cryptolestes_pusillus_(Schoenherr,_1817)_(10959317805).png)

Fig 41 adult on the damaged grains (Source: https://www.weblio.jp/content/Cryptolestes+pusillus+%28Schonherr%29+%5BCucujidae%5D)

Bionomics

Eggs are laid in crevices or loosely amongst the food. It lays white eggs loosely in flour, grain or crevices. The egg period is 5-6 days. The larva is cigar like yellowish white with two reddish brown spots at anal segment. The larval period is 21 days. It pupates in a gelatinous cocoon. Adult is light to dark reddish brown beetle measuring 1.5 mm to 2.0 mm size, light to dark reddish brown in colour having filiform antennae little more than 1/2 the size of body (Fig 40). The life cycle is completed in 40-46 days.

Symptoms of Damage

Both grubs and adults feed on broken grains or on milled products. They are secondary pests and are unable to survive in sound uninjured grains. In case of heavy infestation it cause heating in grain and flour. Larvae feed on germ portion, endosperm and even on dead insects. Adults are only scavenger's and cause for heating in grain and flour in case of heavy infestation (Fig 41). It attacks rice, maize, wheat with excessive broken, different flours, ground nut particularly with high moistures and moldy grains are more preferable.

Management of storage insect pests:

Storage insect pests 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 their webbings. Therefore, stored products are unfit and unhygienic for human consumption due to the accumulation of insect detritus. 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. Management 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 either in storage or field conditions. These components with respect to management of stored grain pests are described here.

Use of inert dusts: Inert dusts like clays, sand, ash, minerals, silica (Silicon dioxide) are effective in managing the insects by moisture loss of the insect body by abrasion. Dusts that contain natural silica, such as diatomaceous earth (DE), are commercially available to manage or to improve fumigation efficiency. Activated clay (kaolin) has also been used in protecting grains from the attack of storage insects. Many researchers used inert dusts as grain protectants against different insect pests (table 1).

Table 1: List of different inert dusts used against storage insect pest

Inert dusts as grain protectants	Insect-pest	Reference
Diatomaceous earth	*C. maculatus*	Prasanthia *et al*. (2002)
	Rhyzopertha dominica	Kavallieratos *et al*. (2005)
	Tribolium confusum	Sabbour *et al*. (2015); Vayias *et al*. (2006)
	Tribolium castaneum	Sabbour *et al*. (2015)
	Sitophilus oryzae	Athanassiou *et al*. (2008) Poornima and Awakanavar (2008)
	Sitophilus zeamais	Jean*et al*. (2015)

Activated clay (Kaolin)	*Tribolium sp.*	Arthur and Puterka (2002)
	C. maculatus	Mahmoud *et al*. (2010)
	C. chinenesis	Mahmoud *et al*. (2010)
	Sitophilus oryzae	Kundu *et al*. (2018)
Ash	*Sitophilus zeamais*	Jean *et al*. (2015)
	Rhyzopertha dominica	Otitodun *et al*. (2017)
	Sitophilus oryzae	Otitodun *et al*. (2017)
Silica (Silicon dioxide)	*Tribolium confusum*	Aldryhim (1990)
	Sitophilus granaries	Aldryhim (1990)
	Rhyzopertha dominica	Aldryhim (1993)
	C. maculatus	Rouhani *et al*. (2013); Roy *et al*. (2017)
	Corcyra cephalonica	Vani *et al*. (2013)

Use of high and low storage temperature: Most of the stored insect pests will not tolerate extreme temperature, heating and cooling that leads high mortality. Grain temperature raised up to 55-65°C and for 10 to 12 h can effectively kill all life stages of stored grain pest in ware houses. Likewise, low temperature also give long term effect on stored seed and keeps them free from insect attack. Increasing or decreasing the temperature can alter the insect growth and metabolism. Optimal temperature for most of the storage insects is between 25 and 33º C any deviations from these points will slower down the growth and continuously to death as it can be seen from the table 1.

Table 1.Response To Stored Product Insects To Temperature (Fields, 1992)

Zone	Temperature (ºC)	Effects
Lethal	50-60	Death in minutes
	45-50	Death in hours
Sub optimal	35	Development stops
	33-35	Development slow
Optimal	25-33	Maximum Rate of development
Development stops	13-25	Development slow
	13-20	Development stops
Lethal	5	Death in week
	-10 to -5	Death in days
	-25 to -15	Death in minutes

Behavioral control by use of pheromones: Pheromones are female or male specific mainly used for surveillance and detection pests' infestation in stored grains. Some pheromones are identified and utilized to trap *Tribolium* spp., *Sitophilus* spp., *Stegobium paniceum* and *Lasioderma serricorne*. Apart from this, more effective manipulation and suppression of stored product insects, pheromones are used with entomopathogens. It is more practical method in which pheromone baited or light-baited device is used with an open reservoir containing a pathogen such as *Bacillus thuringiensis*. It helps to circulate a pathogen in stored insects (Tanaka and Takeda, 1993). In stored product protection, pheromones are normally exploited. As these chemicals are utilized in pest management as attractants, repellents, feeding and oviposition deterrents, mass trapping and mating disruption. Different types of traps were designed for their efficiency for dispensing synthetic lures to attract the stored grain insects.

Use of traps: Several types of traps to monitor the presence of stored grain pests are commercially available. Reliant on the type of pest, lures may include female sex pheromones or male aggregated pheromones or food attractants. In many times the interior of the grains masses can be monitored through the side access panel by using plastic tube traps, and sticky pheromone traps. These traps are inserted into the grain mass for specific period of time and then take out. These traps attract the insects and determine the presence of specific insect and number of insects present. Apart from these some other traps like Probe trap, Pulse Beetle Trap, Light traps, Sticky traps, Bait traps and Pheromone were also developed and tested in some of the countries.

Botanicals: Use of botanicals /plant derivatives is age old practice**.** They are utilized to manage insect pests in several ways like as repellents, antifeedants, chemo-sterilants growth regulators etc Plant extracts or products having insecticidal properties like neem leaf powder, black pepper, turmeric powder, Sweet Flag Rhizome powder etc were also proved their effectiveness in managing the stored grain pests. General dosage is 5-10g/kg of food grains. Different formulations like tablets, pellets, oils, etc are developing and are required commercialization (Adarkwah *et al*., 2010; Athanassiou *et al*., 2014; Said and Pasthe, 2015; Singh *et al*. 2021).

Biological control: It is one of the sustainable options in the field crop pest management. However, in storage it has several limitations. The knowledge of behavior and biology of entomophagous insects attacking stored-grain pests was prerequisite for bio-control. But various parasitoids and predators used to manage the stored grain insects. Hymenopteran parasitoids are normally exploited to reduce infestation and damage caused by stored grain insect pests. Parasitic wasp, A*nisopteromalus calandrae* (Howard) (Hymenoptera: Pteromalidae) was reduced rice weevil infestation of spilled wheat by 90 per cent in a simulated warehouse. The parasitoid *Brecon hebetor* release suppressed almond moth, *Cadra cautella* populations up to 97.3 percent and egg parasitoid, *Trichogramma pretiosum* release against *Cadra cautella*, *Ephestia* spp. and *P. interpunctella* and *Trichogramma pretiosum* suppressed *C. cautella* up to 42 per cent and *P. interpunctella* up to 57 per cent (Murali, 2013). Release of larval parasitoid, *Bracon hebetor* caused 93.4 percent mortality in *Corcyra Cephalonica* larvae (Patel *et al*., 1982) and activity of *B. hebetor* in *Corcyra* rearing room was observed throughout the year except in April (Dabhi 2010).

Hermatic grain storage for control of stored insect pests: Hermetic storage creates low oxygen, high CO_2 atmosphere lethal to insects which are already present inside the container. It is used to prevent rodent penetration during storage and avoid the growth of molds as well as deterioration of the commodity by protecting it from the high outside relative humidity levels that prevails in hot humid climates (De Bruin, 2005). The storage insects can consume significant amounts of dry matter and spoil germination capacity of grains. The usually grains damaged by insects attract fungus under storage condition. Therefore, lower moisture content and storage temperature, problem of insects will be restricted. This can be easily achieved in hermatic grain storage. The insects under hermatic storage are killed due to very low oxygen and high CO_2 concentration. This technology is easy to use, cost effective and environmentally green technology without use of any insecticides. This can be used for protection of grains/seeds at farmers and consumers level in different sizes ranged from few kilograms to thousands of tones (Vinod *et al*, 2021)

Nanotechnology in stored grain pest management: In recent years consumer awareness on health hazards from residual toxicity and insect resistance to the pesticides has led the researchers go for alternatives. Insect normally bears wide range of lipids on the cuticle to defend the water barrier on their body and avoid death due to dehydration. A mechanism by used by nanoparticles that become absorbed into the cuticle lipids by physisorption thus causing death of insect by exclusively by physical ways (Barik *et al*., 2008). Nano-emulsions are type of emulsions in which size of the particle is even and extremely small ranges from 20-200 nm. Nano pesticides would be an innovative approach to combat insect pests and curbing the negative effects of synthetic insecticides on the environment. Polyvinyl alcohol is a water soluble polymer derived from petroleum that has distinguishing qualities *viz*., transparency, gloss, anti-electrostatic properties, chemical resistance and toughness. Due to its water solubility, reactivity and fast biodegradability, it can be incorporated in agricultural as water treatment applications. This strategy will be useful to control the stored product insects I storages (Kitherian, 2017, Wakeil *et al*., 2017). There are many forms of nano particles are used against stored grain pests silver nanoparticles like Ag NO_3, Silica like diatomaceous earth, Synthetic silica (Sio2), sands, silica Aerogel, Aluminium oxide (Al_2O_3), Zinc Ozide (ZnO), Copper Oxide (Cu2O), Titanium dioxide (TiO_2). The metal nanoparticles are utilized for making such formulations and can be used as insecticides. The unique type nano-material prepared from silica is nanosilica. These nanoparticles could be used in novel insecticide compositions to combat a variety of insect species (Barik *et al*., 2008, Zahir *et al*., 2012 and Yousef *et al*., 2019).

Chemical Control: The fumigants like carbon disulphide, methyl bromide, carbon tetrachloride, EDCT, chloropicrin (tear gas) sulphur dioxide, methyl format used at different concentrations for treating the stored grains in godowns in the past. 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. The fumigant requires airtight condition to achieve full efficacy. Relative Humidity and temperature in storage, moisture content of seeds and air tightness were important factors influencing efficacy of fumigation. The fumigant methyl bromide is ozone-depleting compound is being

phased out by regulatory bodies, instead of this aluminium phosphide (phosphine) is used to protect the food grains which is available in the form of tablets or powder formulation. Generally recommended 3 tablets per ton of food grains (each tablet weigh 3 g and release 1 g of phosphine gas). The fumigation period is 7 days.

References

Adarkwah, C., Obeng-Ofori, D., Büttner, C., Reichmuth, C. and Schöller, M. 2010. Bio-rational control of red flour beetle *Tribolium castaneum* (Herbst)(Coleoptera: Tenebrionidae) in stored wheat with Calneem® oil derived from neem seeds. *Journal of pest science*, 83(4): 471-479.

Ahmed J., Maleque, M. A., Islam M. S. and Bhuiyan M. A. H. L. 2016. Evaluation of indigenous plant powder against pulse beetle (*Callosobruchus chinensis* L.) on stored chickpea. *Journal of Sylhet Agricultural University*. **3**(2): 215-221.

Aldryhim Y. N. 1990. Efficacy of the amorphous silica dust, Dryacide, against *Tribolium confusum* Duv. and *Sitophilus granarius* (L.)(Coleoptera: Tenebrionidae and Curculionidae). *Journal of Stored Products Research*, *26*(4): 207-210.

Aldryhim Y.N. 1993. Combination of classes of wheat and environmental factors affecting the efficacy of amorphous silica dust, Dryacide, against *Rhyzopertha dominica* (F.). *J. StoredProd. Res*., 29; 271-275.

Ali F., Khan J., Zada A., Faheem B., Khan I., Salman M., and Khan K. 2019. Bio-insecticidal efficacy of botanical extracts of citronella and cinnamon against *Triboliumcastaneum*, *Sitophilus oryzae* and *Drosophila melanogaster* under laboratory conditions. *Fresenius Environ. Bull.*, 28, 3104-3109.

Arthur F. H., and Puterka G. J. 2002. Evaluation of kaolinite-based particle films to control *Tribolium* species (Coleoptera: Tenebrionidae). *J. Stored Prod. Res.*, 38(4): 341-348.

Athanassiou C. G, Kavallieratos N. G., Vayias B. J. and Panoussakis E. C. 2008. Influence of grain type on the susceptibility of different *Sitophilus oryzae* (L.) populations, obtained from different rearing media, to three diatomaceous earth formulations. *J. Stored Prod. Res*., 44: 279-284.

Athanassio,. C. G., Kontodimas D.C., Kavallieratos N. G. and Anagnou Veroniki M. 2005. Insecticidal effect of NeemAzal against three stored-productbeetle species on rye and oats. *J. Eco. Entom*., 98: 1499–1505.

Athanassiou, C. G., Rani, P. U. and Kavallieratos, N. G. 2014. The use of plant extracts for stored product protection. In *Advances in plant biopesticides*). Springer, New Delhi. PP. 131-147

Augustine, N. and Balikai, R. A. 2019. Biology of pulse beetle, *Callosobruchus chinensis* (Linnaeus) on cowpea variety DC-15. *J. Entomol. Zool. Stud*, *7*(1): 513-516.

Barik, T. K., Sahu, B and Swain, V. 2008. Nanosilica from medicine to pest comtrol. Parasitol. Research. 103: 253-258

Bett, P. K., Deng A. L., Ogendo J. O., Kariuki S. T., Kamatenesi-Mugisha M., Mihale J. M., and Torto B. 2016. Chemical composition of *Cupressus lusitanica* and *Eucalyptus saligna* leaf essential oils and bioactivity against major insect pests of stored food grains. *Industrial Crops and Products*, 82: 51-62.

Dabhi, M.R. 2010. A Ph. D. thesis submitted to Anand Agricultural University, Anand, pp: 94.

Daglish, G. J. 2008. Impact of resistance on the efficacy of binary combinations of spinosad, chlorpyrifos-methyl and s-methoprene against five stored-grain beetles. *Journal of Stored Products Research*, 44(1): 71-76.

Devi M. B., Devi N. V. and Singh S.N, 2014. Effects of six botanical plant powder extracts on the control of rice weevil, *Sitophilusoryzae* L. in stored rice grains. *Int. J. Agri. Inno. Res*., 2(5): 683-686.

Devi, M. B. and Devi, N. V. 2015. Biology of rust-red flour beetle, *Tribolium castaneum* (Herbst)(Coleoptera: Tenebrionidae). In *Biological Forum,* 7(1): 12-15.

Devi, M. B., Devi, N., Devi, S. R. and Singh, P. R,. 2013. Biology and morphometric of rice moth, *Corcyra cephalonica*. *Annals of Plant Protection Sciences*, 21(1): 87-89.

Devi, S. R., Thomas, A., Rebijith, K. B. and Ramamurthy, V. V., 2017. Biology, morphology and molecular characterization of *Sitophilus oryzae* and *S. zeamais* (Coleoptera: Curculionidae). *Journal of Stored Products Research*, 73:135-141.

De Bruin, T. 2005. Seeds in Store. Asian Seed and Planting Material, February

Edde, P. A., 2012. A review of the biology and control of *Rhyzopertha dominica* (F.) the lesser grain borer. *Journal of Stored Products Research*, 48: 1-18.

Edde, P. A. 2019. Biology, ecology, and control of *Lasioderma serricorne* (F.)(Coleoptera: Anobiidae): A review. *Journal of economic entomology*, 112(3): 1011-1031.

Fields, P. G., 1992. The control of stored-product insects and mites with extreme temperatures. *J. stored Prod. Res*., 28(2):89-118

Gaffar, S., El-Naggar, M. E. and Mikhail, W. Z. 2012. A novel technique for commercial mass production of natural enemies. *Egyptian Journal of Agricultural Research*, 90(3): 1245-1255.

Gordon, D. M. and Stewart, R. K. 1988. Demographic characteristics of the stored-products moth *Cadra cautella*. *The Journal of Animal Ecology*, 627-644.

Hadaway, A. B. 1956. The biology of the dermestid beetles, *Trogoderma granarium* Everts and *Trogoderma versicolor* (Creutz.). *Bulletin of Entomological Research*, 46(4):781-796.

Hosamani, G. B., Jagginavar, S. B. and Karabhantanal, S. S. (2018). Biology of pulse beetle,*Callosobruchus chinensis* on different pulses. *Journal of Entomology and Zoology Studies*, *6*(4): 1898-1900.

Jacob, T. A. and Cox, P. D. 1977. The influence of temperature and humidity on the life-cycle of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). *Journal of Stored Products Research*, 13(3): 107-118.

Jadhav, K. 2006. Biology and management of rice weevil, *Sitophilus oryzae* L. in pop sorghum. M.Sc.(Agri.) thesis submitted to University of Agricultural Sciences, Dharwad (Karnataka).

Jean, W. G., Nchiwan N. E., Dieudonné N., Christopher S. and Adler C. 2015. Efficacy of diatomaceous earth and wood ash for the control of *Sitophilus zeamais* in stored maize. *J. Entomol. Zool. Stud.*, 3(5): 390-397.

Jesser, E. N., Werdin-González J. O., Murray A. P. and Ferrero A. A. 2017. Efficacy of essential oils to control the Indian meal moth, *Plodia interpunctella* (Hübner)(Lepidoptera: Pyralidae). *Journal of Asia-Pacific Entomology*, 20(4): 1122-1129.

Kavallieratos, N. G., Athanassiou C. G., Pashalidou F. G., Andris N. S., Tomanovic Z. 2005. Influence of grain type on the insecticidal efficacy of two diatomaceous earth formulation against *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae). *Pest Management Science*, 61: 660-666.

Kitherian, S. 2017. Nano and bio-nanoparticles for insect control. Research Journal of Nanosciences and Nanotechnology, 7:1-9

Khashaveh, A., Ziaee M. and Safaralizadeh M. H. 2011. Control of pulse beetle, *Callosubruchus maculatus* (F.)(Coleoptera: Bruchidae) in different cereals using spinosad dust in storage conditions. *Journal of plant protection research*, 51(1): 77-81.

Kousar, T., Zaib-un-Nisa Memon, H. A., Sahito, W. M. M., Jatoi, F. A. and Shah, Z. H. 2021. Biology, morphology and varietal distribution of Saw-toothed grain beetle, *Oryzaephilus surinamensis* (L.) on date palm dry and semi-dry dates at district: Khairpur, Sindh-Pakistan. *Pure and Applied Biology (PAB)*: 10(3): 539-548.

Kundu, B., Okram S., Hath T. K. and Chakraborty D. 2018. Potentiality of some inert materials as grain protectant against rice weevil, *Sitophilus oryzae* (L.) on stored wheat grains.*J. Entomol. Zool. Stud.*, 6(3): 1271-1274.

Lee, C., Lin, F., Lu, C. and Wang, C. 1991. Natural enemies and their use in the bio-control of insect pests in Taiwan. In *Proceedings of International Seminar on Enhancement of Functional Biodiversity Relevant to Sustainable Food Production, Tsukuba, Japan. MARCO, Tsukuba, Japan*.

Mahmoud, A. G., El-Sebai O. A., Shahen A. A. and Marzouk, A. A. 2010. Impact of kaolin-based particle film dusts on *Callosobruchus maculatus* (F.) and *C. chinenesis* (L.) after different storage periods of treated broad bean seeds. *Julius-Kühn-Archiv*, (425): 638.

McNamara, K. B., Elgar, M. A. and Jones, T. M. 2008. A longevity cost of re-mating but no benefits of polyandry in the almond moth, *Cadra cautella*. *Behavioral Ecology and Sociobiology*, 62(9): 1433-1440.

Mensah, G. W. K. and Watters F. L. 1979. Comparison of four organophosphorus insecticides on stored wheat for control of susceptible and malathion-resistant strains of the red flour beetle. *Journal of Economic Entomology*, 72(3): 456-461.

Murali, S. 2013. Management of stored-product insect pests through biorational approaches. A Review. *Trends in Biosciences* 6 (2): 133-137.

Oaya, C. S. 2020. Study on the biology of groundnut bruchid, *Caryedon serratus* Olivier [Coleoptera: Bruchidae] on stored groundnut in Ganye area, Adamawa State, Nigeria. *Agricultural Science and Technology*, 12(3): 272-276.

Odeyemi , O. O. and Ashamo M. O. 2005. Efficacy of neem plant (*Azadirachta indica*) extracts in the control of *Trogoderma granarium*, a pest of stored groundnuts. *Journal of Plant Diseases and Protection*, 112(6): 586-593.

Ogendo, J. O., Deng A. L., Belmain S. R., Walker D. J. and Musandu A.A.O. 2004. Effect of insecticidal plant materials, *Lantana camara* and *Tephrosiavogelii*, on the quality parameters of stored maize grains. *J. Food Tech. Afr*., 9: 29- 36.

Otitodun, G. O., Opit G. P., Nwaubani S. I. and Okonkwo E. U. 2017. Efficacy of rice husk ash against rice weevil and lesser grain borer on stored wheat. *African Crop Science Journal*, 25(2): 145-155.

Paikaray, S. S., Satapathy S. N., Mohapatra A., Swain D., Priyadarshini P. and Ranjan S. 2021. Bioefficacy of botanicals on pulse beetle (*Callosobruchus chinensis* L.) of stored green gram seeds.*The Pharma Innovation Journal,*10(10); 1513-1515.

Patel, V. K., Chaudhuri, N. and Senapati, S. K. 2005. Biology of pulse beetle (*Callosobruchus chinensis* Linn.) as influenced by feeding of different grain pulses. *Agricultural Science Digest*, 25(4): 254-256.

Patel, R.C., Yadav, D.N., Saramma, P.U. 1982. Effectiveness of Bracon hebetor against Corcyra cephalonica infestation in go down. *GAU Res J* .7(2):121-123.

Pathania M. and Thakur A. K. 2012. Efficacy of insecticides against pulse beetle, *Callosobruchus chinensis* (L.) on black gram seeds. *Indian Journal of Entomology*, 74(4): 402-403.

Pathania, M. and Thakur A. K. 2020. Effect of plant products on oviposition, adult emergence and weight loss of pulse beetle, *Callosobruchus chinensis* (Linn.) in stored blackgram grains. *J. Entomol. Zool. Stud.*. 8(3): 2070-2073.

Prasanthia, B. D. R., Reichmuth C. and Buttner C. 2002. Effect of diatomaceous earth on the reproductive performance of *Callosobruchus maculates* (F.) Coleoptera: Bruchidae).Proceeding of the 8th International Working Conf. on Stored Product Protection. York, UK. (Pp. 22-26)

Pruthi, H. S. and Singh, M. 1950. Pests of Stored Grain and their Control. *Indian Journal of Agricultural Science*, 18 (4):88

Poornima, V. and Avaknavar, J. S. 2008. Effect of temperature and relative humidity on efficacy of diatomaceous earth on mortality of rice weevil, *Sitophilus oryzae*. *Karnataka J. Agric. Sci.*, 22: 99-103.

Rosner, J., Wellmeyer, B. and Merzendorfer, H. 2020. *Tribolium castaneum*: a model for investigating the mode of action of insecticides and mechanisms of resistance. *Current pharmaceutical design*, 26(29): 3554-3568.

Rouhani, M.; Samih M. A. and Kalantari S. 2013.Insecticidal effect of silica and silver nanoparticles on the cowpea seed beetle, *Callosobruchus maculatus* F. (Col.: Bruchidae). *J. Entomol. Res*., 4:297-305.

Roy, N., Mukherjee M., Mondal S., Biswas D. andDas D. 2017. Pulse beetle, *Callosobruchus maculatus* Fabr.(Coleoptera: Bruchidae) management by physical means. *JAST*, 3(01): 14-27.

Sabbour, M. M., Abd El-Aziz S. E. and Shadia E. 2015. Efficacy of nano-diatomaceous earth against red flour beetle, *Tribolium castaneum* and confused flour beetle, *Tribolium confusum* (Coleoptera: Tenebrionidae) under laboratory and storage conditions. *Bull. Environ. Pharmacol. Life Sci.*, 4(7): 54-59.

Said, P. P. and Pashte, V. V. 2015. Botanicals: The protectants of stored grains pests. *Trends in Biosciences*, 8(15); 3750-3755.

Sakhare, V. M., Mutkule, D. S. and Kharade, V. G. 2018. Biology of groundnut bruchid, *Caryedon serratus* (Olivier) on different groundnut varieties. *Journal of Entomology and Zoology Studies*, 6(4): 1577-1580.

Salem A. A., Hamzah A. M. and El-Taweelah N. M. 2015. Aluminum and zinc oxides nanoparticles as a new methods for controlling the red flour beetles, *Tribolium castaneum* (Herbest) compared to malathion insecticide. *Journal of Plant Protection and Pathology*, 6(1):129-137.

Sehgal B., and Subramanyam B. 2014. Efficacy of a new deltamethrin formulation on concrete and wheat against adults of laboratory and field strains of three stored-grain insect species. *Journal of economic entomology*, 107(6): 2229-2238.

Sehgal B., Subramanyam B., Arthur F. H. and Gill B. S. 2013. Variation in susceptibility of field strains of three stored grain insect species to spinosad and chlorpyrifos-methyl plus deltamethrin on hard red winter wheat. *Journal of economic entomology*, 106(4): 1911-1919.

Singh, K. D., Mobolade, A. J., Bharali, R., Sahoo, D. and Rajashekar, Y. 2021. Main plant volatiles as stored grain pest management approach: A review. *Journal of Agriculture and Food Research*, 4:100-127.

Singh, M. P. and Bindu, S. P. 2014. Studies on the biology and host preference of the angoumois grain moth, *Sitotroga cerealella* (Olivier). *Indian Journal of Entomology*, 76(1): 8-11.

Srivastava, C. and Subramanian, S. 2016. Storage insect pests and their damage symptoms: an overview. *Indian Journal of* Entomology, 78: 53-58.

Subramanyam B. and Hagstrum D. W. 1996. Integrated management of insects in stored products. *M. Dekker., New York.*(https://www.worldcat.org/title/32853462)

Sutherland, J. A. (1986). A review of the biology and control of the sweetpotato weevil, *Cylas formicarius* (Fab). *International Journal of Pest Management*, 32(4): 304-315.

Tanaka, Y and Takeda S., 1993. Ecdysone and 20- hydroxyecdysone supplements to the diet affect larval development in the silkworm, *Bombyx mori* differently. *Journal of Insect Physiology*; 39(10):805-809.

Tyagi, S.K., Guru P.N., Aarti Nimesh, Akhoon Asrar Bashir, Pulin Patgiri, Vandana Mohod andAnju B. Khatkar (2019). Post-Harvest Stored Product Insects and Their Management. ICAR-AICRPon PHET, Central Institute of Post-Harvest Engineering and Technology, Ludhiana(Punjab) Technical Bulletin No.: AICRP on PHET/ Pub/ 2019/02. (https://krishi.icar.gov.in/jspui/bitstream/123456789/31390/1/Post-Harvest%20Stored%20Product%20insects%20and%20their%20management.pdf)

Vani, C. and Brindhaa U. 2013. Silica nanoparticles as nanocides against *Corcyra cephalonica*(S.), the stored grain pest.*Int. J. Pharm. Bio. Sci*., 4(3) (B) :1108-1118.

Vayias, B. J., Athanassiou C.G., Kavallieratos N. G. and Buchelos C.Th. 2006. Susceptibility of different European populations of *Tribolium confusum* (Coleoptera:Tenebrionidae) to five diatomaceous earth formulations.*J.Econ.Entomol*., 99: 1899 -1904.

Vinod, T. A., Krantidip R. P. and Sujit C. P. 2021. Hermetic Storage Technology for Food Grains: New Beginning of Organic and Safe Storage for Farmers and Consumers: A Review. *Bhartiya Krishi Anusandhan Patrika*, 36(4): 299-303

Verma, S. C.; Banshtu T. and Gupta P. R. 2010. Effect of edible plant powders on quality characters of treated pea seeds damaged by *Callosobruchus chinensis* Linnaeus. *Journal of Insect Science*,23(2): 176-179.

Wakeil, El N., Alkahtani, S and Gaafar, N. 2017. Is Nanotechnology a Promising Field for Insect Pest Control in IPM Programs? In: New Pesticides and Soil Sensors, Grumezescu, A.M. (Ed.). Chapter 7, Academic Press, New York, USA., pp: 273-309

Win, N. and Rolania, K. 2020. Influence of seasonal variation on the biology of lesser grain borer, *Rhyzopertha dominica*(Fabricius) on wheat. *J. Entomol. Zool*, *8*(5): 285-290.

Yousef, D.A., Bayoumi, A.E., Dimetry, N.Z., Amin, A.H. and Hoballah, E.M. 2018. Evaluating effect of pepper mint oil (mentha pipreta) and its nano-formulations on some enzymatic activities and bionomics of cotton leaf worm *spodoptera littoralis* (boisd.). *Arab Universities Journal of Agricultural Sciences*. 26(2C): 1977-1991

Zahir A.A., Bagavan, A., Kamaraj,C. Elango, G. and Rahuman A.A. 2012. Efficacy of plant mediated synthesized silver nano-particle against *Sitophilus oryzae*. *Journal of biopesticide*. 5:95-102.