Asian Journal of Advances in Research

5(1): 41-56, 2022

REVIEW ON MAJOR STORAGE INSECT PESTS OF CEREALS AND PULSES

ESUYAWKAL DEMIS [a*] AND WORKINEH YENEWA [a]

[a] Ethiopian Institute of Agricultural Research, Fogera National Rice Research and Training Center, Bahir Dar, Ethiopia.

AUTHORS' CONTRIBUTIONS

This review article was reviewed and prepared in collaboration with both authors. Both authors read and approved the final manuscript.

Received: 20 October 2021
Accepted: 30 December 2021
Published: 10 January 2022

Review Article

ABSTRACT

Insect pests are the most successful and diverse groups of animals on earth and are closely related to our lives and affect the welfare of humans in diverse ways. A vast number of pest species are related to stored commodities. From this pest species, storage insect pests are a major threat to grain storage and other stored products and they cause direct and indirect losses of grain on the storage. Cereals and pulses are attacked in stores by different insect pests and other storage pests. The three orders of insect Coleoptera, Lepidoptera, and Psocoptera contain species that are major pests on stored products. The two major groups Coleoptera and Lepidoptera insects harbor the most economically important post-harvest insect pests. Some of the storage insect pests which attack storage grains are rice weevil, maize weevil, lesser grain borer, granary weevil, Angoumois grain moth, khapra beetle, Indian meal moth, red flour beetle, and pulse beetles. *Callosobruchus chinensis*, *Callosobruchus maculatus*, and *Callosobruchus analis* are the three commonly known pulse beetle species in stored pulses. Hence the objective of this paper is to review the major insect pests of stored grains and their management methods. Insect infestation occurs in stored grains and grain products to a variable extent depending upon the storage conditions in developing countries. Under farmers' storage grain losses are further aggravated by poor post-harvest handling, inefficient storage facilities, and inadequate pest management systems. The stored grain pests infest grains during storage to fulfill their food and shelter requirements as a result they cause quantitative and qualitative losses. Globally, the quantitative losses of stored grain vary from developed countries to undeveloped countries. To reduce the losses management of storage insect pests by using physical, biological, botanical, chemical, host plant resistance, and integrated pest management methods are essential for the control of stored product insect pests.

Keywords: Storage insect pests; cereals; pulses; quantitative loss; qualitative loss.

1. INTRODUCTION

Insects are well-known to be the most thriving and varied animals in the world and they influence the wellbeing of people in various ways [1]. Many number of pest species are associated with stored commodities. Under storage, it may expect a permanent occurrence of several pest species [2]. Infestation of insects occurs in stored grains and grain products to a variable extent depending upon the storage conditions in developing countries [3]. In addition, they transfer bacteria and microscopic fungi of pathogenic importance [4].

**Corresponding author: Email: esuyawkaldemis@gmail.com;*

Cereals and pulses have great biological and nutritional value in developing countries [5]. They are usually attacked in stores by different insect pests and other storage pests. Some of the storage pests are carried from the fields into stores. Insects, bacteria, fungi, and rodents are the major groups of storage pests and they are contributing to storage losses apart from the losses that occur during handling and transportation, due to lack of appropriate storage facilities and pillaging of grains. Among all the pests, insect damage in stored grains alone may amount to 10-50% [6].

Stored grains are attacked by several insect pests. Stored grain pests infest grains to accomplish their food and shelter requirements for living as a result they cause qualitative and quantitative losses [7]. Many insect pests gain access to the grain storage at various stages of processing of food grains during the process of development and maturation of seeds, at the time of threshing yards, transportation, or while in storage. Some insect pests initiate damage at the ripening stage of crops and continue during storage [7]. Pulses contain 20-30% of protein, which is almost three times higher than that found in cereals. Post-harvest damages by insects have been recognized as an increasingly important constraint to pulse production. Pulse crops are commonly subject to long-term storage [8], and the storage conditions such as time, temperature, and moisture content induce physicochemical and biological changes leading to a significant effect on the nutritional composition, germination, and longevity [9].

The three orders of insect Coleoptera, Lepidoptera, and Psocoptera contain species that are major pests on stored products [10]. The two major groups Coleoptera (beetles) and Lepidoptera (moths and butterflies) insects harbor the most economically important post-harvest insect pests [11]. Crops damaged by Lepidoptera are only done by the larvae but; in the case of Coleoptera, both larvae and adults often feed on the crop and the two stages are responsible for the damage. Post-harvest insect pests may be primary, that is those which damage previously undamaged seed such as the genus Sitophilus, while secondary pests are those which cannot damage sound seed but attack seeds that are already damaged either mechanically or by primary insect pests [12].

Storage insect pests are a major threat to grain storage and other products and they cause direct and indirect losses of grain on the storage. The amount of loss due to insect damage is quite variable and depends on the storage period, storage conditions, storage structures, and varieties [13]. Globally, postharvest losses account for 24% of the total food produced and insect infestation contributes to a significant proportion of it. There are different proposals for the loss caused by insect pest infestations in grains; it varies from about 9% in developed countries to 20% or more in developing countries [14]. According to Wijayaratne *et al*. [15], the direct and indirect postharvest losses in humid regions are up to 50%. Other studies showed that insects are responsible for 10-60% of postharvest losses of grains in developing countries [16]. Due to these losses management of storage pests has an important option to reduce the damaged content of the stored products. Thus, to reduce damage due to these storage insect pests and to increase economic return, it is vital to use the appropriate management methods. Therefore, this paper is written to review the major storage insect pests of cereals and pulses and their management methods.

2. STORAGE INSECT PESTS OF CEREALS

2.1 Rice Weevil (*Sitophilus oryzae* L.)

Rice weevil is one of the most important destructive primary pests attacking many common stored grains and has cosmopolitan distribution found worldwide [17]. Among the stored grain pests, this weevil is one of the significant pests of stored rice causing both quantitative and qualitative losses to grain imparting severe economic loss [18].

Stored and milled rice grains are prone to attack by *Sitophilus oryzae* and the latter grains are mostly preferred causing heavy economic losses and both the larvae and adults feed on the carbohydrates in rice grains causing weight loss and contaminations [19]. It can infest many kinds of crops during storage such as rice, wheat, corn, sorghum, oat, barley, bean, sunflower seeds, nut, rye, macaroni, cereal products, and all types of stored grains. But, these insects do not bite nor damage the wood. Severely damaged lots of grains resemble moldy grains [7]. Enhancing the temperature and humidity of the infested grains, rice weevil activity also induces accelerated growth of the secondary pests and creates the most favorable conditions for pathogens and further infestation [20].
The entire life cycle completes from egg to adult in 28 days at 30°C and 14% moisture content. Rice weevil grows and develops inside infested rice grains. Both adults and larvae feed on the grains. Adult females lay an egg within 3 days after emerging from their pupa cocoons and those lay eggs in crevices of kernels or dust. They can lay 300-400 eggs in their lifetime and up to 7-8 eggs per day. The female inserts her ovipositor into the hole in a grain kernel to deposit eggs. The larvae hatch after 3-4 days at a temperature of 25^{o}C and 70% relative humidity. The developing

larva lives and feeds inside the grain causing irregular holes of 1.5 mm diameter on grains [21]. The larvae develop from the 3rd to the 4th instars in about 18-22 days, after which they pupate for about six days then, the insect emerges out as a developed adult. Adults are between 0.1 and 1.7cm long. They have three pairs of legs and their bodies are divided into three body segments which are head, thorax, and abdomen. Adults move and penetrate deeply into the bulk of grains and get widely distributed. The adults stay in the grain kernels for 3-4 days until they are hardened and mature [22].

Rice weevils have chewing types of mouthparts and the most significant identification feature of weevils is their snout, which is pretty long. The adult rice weevil is reddish-brown, with four light spots on its wing covers and irregularly shaped pits on its thorax. The head is an elongated snout [23]. The adult rice weevil *Sitophilus oryzae* can fly and is attracted to lights. The two sexes of rice weevil look superficially alike but when carefully examined, the males can be distinguished from the females by the form of the rostrum, which is short and broader in males [7].

2.2 Maize Weevil (*Sitophilus zeamais* Motschulsky)

Sitophilus zeamais is the major storage insect pest causing the greatest damage in storage to maize grains in most parts of the tropics and sub-tropics among small-scale farmers [24]. They are regularly pests in the southern and temperate zones, in fields of cereal grains; however, if they get a chance, they will infest finished products. They prefer maize but have also been reported as a pest of cassava, rice, sorghum, and wheat. Minor hosts include taro, soybean, common beans, wheat, bean, and cowpea. These pests cause significant losses in maize or sorghum. Maize weevil *Sitophilus zeamais* are so destructive that damage ranging from 20 to 90% has been recorded in untreated maize [25].

The maize weevil has an average length of 3 mm [26]. It ranges in color from dull red-brown to black, with the elytra having four reddish stains on it [27]. It is a very vigorous flyer because it has well-developed wings with additional prominent legs. The adults are accomplished fliers, but cannot normally overwinter outside in the temperate zone. *Sitophilus zeamais* able to survive a few hours at freezing temperatures and will survive in heated storage facilities. The females lay their eggs by using their ovipositor to insert one egg into each seed or kernel. Eggs hatch in a few days, and the larvae will eat the inside of their kernel, pupating inside. Depending on the temperature the entire life cycle takes one to two months. Their life cycle takes no less than a month or so and is quite similar to the rice weevil. Maize weevils are larger and have better fliers than rice weevils. Larvae develop inside the grain and on emergence leaves a characteristic round hole that causes serious losses in weight, sensory and nutritional qualities [23].

The lifespan of the maize weevil varies with temperature. The life cycle is longer in cooler areas compared to warmer environments [28]. For instance, the life cycle of the maize weevil at 25°C is 37 days and that at 18°C is 110 days. Maize weevil *Sitophilus zeamais* infestation begins on-field and continues into storage. Infestation occurs when the adult female of the maize weevil creates a hole on the grain by chewing into the grain, laying its eggs, and sealing the hole created with a waxy (gelatinous) secretion [26]. The white elliptical-shaped egg hatches into a larva and continues through the four molting stages to adulthood in the grain. Under favorable environmental conditions, the normal growth of the maize weevil is 25 to 30^{o}C of temperature and 69 to 75% of relative humidity [29]. The fact that it completes its life cycle faster in warmer areas and the ability to fly very well, coupled with the fact that the female weevil is capable of laying 400 eggs in its lifetime under favorable environmental conditions account for its rapid increase in population and the ease with which it spreads, especially in the tropics [28].

The maize weevil is capable of destroying an entire grain which is sound and it is considered as the main storage pest [30]. The attack may start in the mature crop when the moisture content of the grain has fallen to 18-20%. Subsequent infestations in-store result from the transfer of infested grain into the store or from the pest flying into storage facilities, probably attracted by the odor of the stored grain. The reuse of sacks borrowed from neighbors or traders is a source of maize weevil. It is responsible for causing losses well above 80% in untreated maize grains and 20% in treated grains [31]. The adults and larvae of the maize weevil are strong feeders and can thus cause severe physical damage to the maize grains [32]. Both the grubs and adults are damaging stages [33]. The problem of maize weevils causing huge losses to stored maize is helped by the fact that a warm humid climate which promotes a very high insect activity throughout the year [34]. The more obvious consequence of the feeding of the maize weevil on the grains is a reduction in the weight of the grains due to the burrowing of the female into the grain and the feeding activities of the offspring once it has hatched. Another damage caused by *S. zeamais* reduces nutritional and market values and germination of the grain and seed. Maize grain is more vulnerable when stored at moisture content higher than 15% [35]. This lead to the introduction of mycotoxins by molds which normally develop on the grains at high relative humidity [36]. The health risk associated with consumption of weevil-infested maize grains as damaged grain is prone to contamination by aflatoxin [37, 38]. The presence of aflatoxins in the diet can lead to illness when consumed in small quantities but can eventually lead to death when large amounts are ingested [39].

2.3 Granary Weevil (*Sitophilus granarius* L.)

Among stored grain insect pests, granary weevil is also an economically important insect pest that damages stored cereal grains. This weevil is small, moderately polished. The insect resembles the rice weevil and is commonly confused. It prefers a temperate climate. Both the adults and larvae of granary weevil, *Sitophilus granarius* feed voraciously on a great variety of grains. Female make a scoop in grain and then deposits an egg and cover it with a gelatinous fluid. In warm weather, the *Sitophilus granarius* develops from the egg to the adult stage in about four weeks. Cold weather greatly prolongs the developmental period. The life cycle is similar to rice weevil [33].

The granary weevil, *S. granarius*, lives for one full year at 20-25^{0}C and relative humidity of about 15%. The biology of this species is also similar to the maize weevil, but it is unable to fly, thus restricted to the store. This species prefers softer grains like; wheat, barley, and rye as food and habitat. In addition, granary weevil has a high resistance to low temperatures; adults of this weevil can stay alive for up to two months at -5^{0}C. The *S. granarius*, female chews a small hole in a kernel into which she deposits an egg. The hole is sealed with a plug and the egg hatches. The legless larva feeds inside the kernel until pupation; then the new adult emerges after the completion of metamorphosis. A single female may lay as many as 250-400 eggs in a season. The egg is hatch 6-7 days and the young larvae bore directly into the grain is kept intact. At the end of the larval stage, they become covered by a covering called puparium inside the grain. The pupa stage starts with the cessation of eating, and the pupa stage persists for 6 to 14 days to become an adult. On emergence, the adult granary weevil, *S. granarius* cuts its way out of the grain and lives for about four to five months. The weevil completes three to four generations in a year [40]. This insect pest attacks all kinds of grain causing serious damage and contamination to the seed embryo. Development from egg to adult takes 25 to 35 days under optimal conditions of 26 to 30°C and 14% moisture content [23].

2.4 Lesser Grain Borer (*Rhyizopertha dominica* Fabricius)

Lesser grain borer is one of the destructive insect pests which infest many cereal grains at different pre and post-harvest levels [41]. It is a global insect pest, present both in the field at harvesting time and at the time of storage [42]. This insect is usually a polyphagous and cosmopolitan pest in tropical and subtropical areas, but it has also been found in the temperate regions of the world [43]. This insect pest originated from India and is now, spread throughout the world. Lesser grain borer, *Rhyizopertha dominica*, is regarded as second in importance to rice weevil as a destroyer of the stored grains. These insect pests resemble rice weevils in color but without snouts [7]. At one time this was often found in wheat packing’s but now it is the major pest of nearly all cereals. It is mostly found in warmer regions of the world and damages wheat, barley, maize, paddy, sorghum, and other products [44, 45].

The lesser grain borer is characterized as both an internal and external feeder and is a serious pest of both whole kernels stored grain and cereal products. Both adult and larvae cause serious damage, they bore into undamaged kernels of grain, reducing them to hollow husks. They can also survive and develop in the accumulated flour produced as the seeds are chewed up. This species is primarily a pest in stored corn and wheat but it can infest nuts, tobacco, beans, birdseed, cassava, biscuits, cocoa beans, dried fruit, spices, and dried meat and fish. It is a small, storage insect pest and was also commonly known as a wheat borer. The insect can be easily distinguished by its reflexed head, which is a typical character of its family. This beetle is tropically originated and most commonly encountered in India in cereal grains stored under a temperature range of 20-30°C, can ably survive 47°C [33].

Heavily infested grains become hollowed out and only thin shell remains. As many as four beetles can be present in the bigger grain like maize. Females of lesser grain borer lay up to 200-500 eggs in their lifetime [46]. The eggs are deposited in clusters on grain or singly among the frass produced by the insect. The oval-shaped egg is about 0.5- 0.6 mm in length and 0.2- 0.25 mm in diameter [47]. The life cycle of this insect was completed in four weeks at 35°C and seven weeks at 22°C. Eggs are laid either on the seed surface near the embryo end which is soft and easy for the young larva to penetrate or interstices of the grain or in other parts of the stores like on cracks and crevices, bags, walls, and others. Larvae of these insect pests are white to cream in color with three pairs of legs and biting mouthparts, undergoing four instars [46]. The larvae bore straight into the grain directly or fed on farinaceous material in the store for some time and then penetrated the grain in the first or second instar. The incubation period takes four to seven days. The newly hatched larva is active and campodeiform and undergoes five molts. The full-grown larva is dirty white with a pale brown head and curved abdomen covered with tiny hairs. Larva lasts for 35- 40 days. With a fall in temperature, it becomes less destructive. A single kernel of wheat provides food for five to six larvae. The pupal period is taken seven to eight days. Adults of *Rhyizopertha dominica*, are extended of 2 to 3 mm long [48] and sometimes up to about 5 mm long [49]. It has varying body colors such as reddish-brown, dark brown, or black with a somewhat roughed body surface [48]. No morphological difference separates the two sexes. The adults are powerful fliers and migrate from one go down to another, causing fresh infestation [21]. It prefers dark and dingy places. After severe infestation adults produce frass and spoil more than what they eat. The profuse powdery substance is the characteristic of its damage [7].

The insects can be either detected based on random sampling and record for the holes in the grains or by adults moving on grain. Grubs and adults feed on internal material and leave the husks and flour with sweet odor or fungus smell at severity. The insect outside the grain can be detected by sieving which discharges the adults to fall from the grain. Morphologically adults are dark reddish-brown. Grubs are whitish and are funneling inside the grains [33].

2.5 Angoumois Grain Moth (*Sitotroga cerealella* Olivier)

The Angoumois grain moth is a pest of various stored products. It damages maize, rice, wheat, sorghum, oats, barley, pearl millet, and rye. However, the grain moth is often found alongside other pests with which it may act synergistically. It is one of the most internal feeding destructors. Infestation starts from the field itself during the ripening or milking stage. However, in storage infestation restricts to the surface. Infestation produces abundant heat and moisture that may encourage mold growth and attract secondary pests [33].

It is a cosmopolitan pest, more abundant in warmer regions. However, in Indian conditions, the pest is abundant in milder conditions. It is found in all sub-Saharan regions of Africa. Larvae are the damaging stage only whole cereals are attacked. A full-grown larva angoumois grain moth is measured about 5 mm long, with a white body and yellow-brown head. The adult of this grain moth is a buff, grey-yellow, brown, or straw-colored moth, measuring about 10-12 mm in wing expanse. The presence of narrow pointed wings fringed with long hair is the characteristic feature angoumois grain moth. It overwinters as a hibernating larva and as the season warms up, it pupates in early spring. Females start laying eggs singly or in batches on or near the grain and the eggs are small and white when freshly laid, turning reddish later on. A single female lies on an average 150 eggs usually within a week after mating. The egg period is four to eight days. The larval stage may last about three weeks. Before pupation takes place, the larva constructs a silken cocoon in a cavity. The pupal period is 9-12 days and the adult lives for about four to ten days. During the active season, the life cycle of the angoumois grain moth is completed in about 50 days. Several generations completed in a year. Damage is at its maximum during the monsoon. Only the larvae cause damage by feeding on the grain kernels before harvest and as well in-store. The larva of grain moth bores into the grain and feeds on its contents. Exit holes of one mm diameter with or without a trap door, are seen on the affected cereal grains. As it grows, it extends the hole which partly gets filled with pellets of excreta. It imparts an unhealthy appearance and smell. In a heap of grain, the upper layers are most severely affected in storage [50, 7].

2.6 Khapra Beetle (*Trogoderma granarium* Everts)

Khapra beetle, *Trogoderma granarium*, is another important pest that causes major damage in bulk storage conditions. It has been described as one of the 100 worst invasive species worldwide [51]. It is a tropical and subtropical insect mainly found in hot and dry regions. It prefers low humidity and high temperature. It is an external feeder and none of the stages lives in the grain. It is a serious pest of wheat but can also damage rice, maize, sorghum, oilseeds, and pulses. This insect can be able to attack any dried plant or animal matter but it prefers mainly grain and cereal products. Generally, infestation occurs in external layers of grain as this insect pest is not able to enter beyond some depth into the grain but in case of heavy infestation, whole lots are damaged [7].

Adult khapra beetles have wings but do not fly. It is oval and has grey and pale brown markings. The head is essentially hidden beneath the hood like pronotum. Female lays eggs five to six days after breeding. A single female lies about 100-120 eggs on grain surface or crevices. At 35°C, the incubation period is four to six days but it can vary depending upon the temperature and humidity. The larva is brownish-white in color, body covered with bundles of long, reddish-brown movable and erectile hair on the posterior segments and forming a sort of tail in the posterior end. First stage larvae feed on broken grains and debris resulting from the feeding of older larvae as it cannot attack the whole grain. The larval period extends up to 20-25 days at 30^{o}C whereas the pupal period is four to eight days. The optimum temperature for development is 35°C. If the temperature falls below 25°C for some time or if larvae are very crowded, they may go into diapause. They can survive temperatures below -8°C. The larva is highly resistant to starvation. Under abnormal conditions, the larva can survive without food for a few years. Although it attacks almost all parts of the grain, it prefers the germ portion and as such the viability of the seed is lost long before any quantitative damage occurred. Severe infestation results in a reduction of entire grains to mere frass. Adults do not feed and are short-lived. The destructive stage is the larva [7].

Khapra beetle, *Trogoderma granarium* damages the grain starting with the germ portion, surface scratching, and devouring the grain. Excessive molting creates public discrimination, loss of market appeal due to insanitation caused by the cast skins. This insect can thrive at temperatures ranging from 23°C to 40°C. Under optimum conditions, the insect can complete about 12 generations in a year. On starvation, the larva molts and reduces in size, and becomes active again on the availability of grain. The insect hides in cracks and crevices and is most distinctive. It is very difficult to kill these hidden insects even with contact insecticides [52].

2.7 Indian Meal Moth (*Plodia interpunctella* Hubner)

Indian meal moth is a major economic insect pest of stored products and is found on every continent except Antarctica [10]. The Indian meal moth is also called the mealworm moth. Indian meal moth is a pest in flour mills, processing plants, animal feeds, dried fruit, and on the surface of all types of grains [53].

It is easily distinguished from other grain pests by the peculiar markings of its fore-wings, which are reddish-brown with a copper luster on the outer two-thirds but whitish gray on the inner or body ends. Hind wings are long silvery grey with silky fringes. Thorax is slightly darker and has reddish scales. Each female moth lays 100 to 300 eggs singly or in clusters, on or near the appropriate foodstuffs. The egg period is two days to two weeks depending upon the weather condition. Within a few days, the eggs hatch, and small whitish larvae or caterpillars emerge. The larva is white, often tinged with green or pink, a light-brown head-on reaching maturity, and it measures 8-3 mm in length. The larvae become full-grown in 30-35 days. The larva spins a silken cocoon and transforms into a light-brown pupa, from which the adult moth develops and later emerges. During warm weather, the Indian meal moth may pass through the egg, larval and pupal stages in 6 to 8 weeks. The adults of the Indian meal moth can fly from one bin to another and spread the infestation [7].

Indian meal moth is a cosmopolitan, it causes serious damage to the panicles and grain contaminates the grain with excrement, cast skins, webbings, dead individuals, and cocoons. The insect prefers to feed on the germ portion, hence the grains lose viability. It infests grains, meals, breakfast foods, soybean, dried fruits, nuts, dried roots, herbs, dead insects, maize, cereals, groundnuts, and cereal products. Damage is caused completely by the larvae feeding on the food source and spinning large amounts of silken webs. The webs serve to protect the larvae from desiccation, but they attract fecal pellets, debris from the damaged food source, and cast larval skins, leading to far greater contamination than by the feeding itself. The webbings can cause great nuisance at the time of grain processing and clogging of mill machinery. Infestation can also raise the moisture content and temperature of the stored products, attracting mold and other microorganisms. Most larvae are located in the top two to three inches of the stored product. Adult moths cannot enter closed packages and it needs an opening like a hole or a seam to reach the food source to lay their eggs. Adults of this moth feed on nectar and do not damage stored products. Adults mate in 2-3 days after emergence and eggs are laid directly on the food source. Larvae continue to feed within the food source, and can also move to other nearby sources. Pupation can also be within the food source, or in other distant locations. Duration of the life cycle is highly dependent on temperatures but is usually completed in 4-5 weeks under optimal conditions. Cold temperature is not favorable for the development of this insect [52].

2.8 Red Flour Beetle (*Tribolium castaneum* Herbst)

Red flour beetle is a cosmopolitan pest that distributes worldwide and it is the worst pest of flour mills. It feeds stored products and usually feeds on broken grains and results in dust formation. Infested flour emits a sour and pungent smell, which is due to some secretions of beetles [21].

The generalized life cycle of the red flour beetle is that of a typical holometabolous insect that has egg, larvae, pupa, and adult. The individual female lays 400-450 eggs in her whole life. Eggs are sticky and are laid on the grains or debris of the grains. These are small, cylindrical, rounded at both ends, and of a whitish color. The larvae are minute, brownish-white, and when fully grown are 4 to 5 mm long, well sclerotized, campodeiform, cylindrical, slender, tinged yellowish with a thin appearance with six to seven instar stages [54]. Pupation takes place on the grain surface, which lasts for 6-8 days. Pupae are quiescent and not feeding as in all other holometabolous insect populations. It gradually gets yellowish then finally turns brown. It is dorsally covered with fine hairs, has dark wings, well-developed eyes, and sclerotized legs [55]. Adults are flat, 2.3-4 mm in length, and red-brown [56]. Both the larvae and adults cause damage. The larvae are always found hidden in the food. The adults, however, are active creatures, but mostly found concealed in flour products. Adult construct tunnels as they move through the flour and other granular food products [21].

Red flour beetle is a polyphagous feeding habit [57] and attacks a wide variety of stored products and their byproducts. It has been found on wheat and wheat flour and often causes serious damage in prepared cereal-based foodstuffs such as biscuits, nuts, beans, pasta, cornflakes, and even dried fruits. Wheat flour is the most preferred substrate [58]. It has also been reported to attack groundnut and other cereal like maize, rice, sorghum, and others [59]. Damage by this red flour beetle pest is usually manifested by a loss in both quality and quantity [57]. The damage leads to the loss in overall gain as a result of the loss of price and the extra cost needed for control in form of pesticides and expensive pest-proof packaging [60].

3. STORAGE INSECT PESTS OF PULSES

3.1 Pulse Beetles

All pulse pests belong to the family Bruchidae and order of Coleoptera. They are one of the major seed weevils or bruchids, have been associated with the seeds of leguminous plants through co-evolutionary processes [61]. The bruchids also usually referred to as pulse weevils or beetles and lay their eggs on the maturing pods in the field, or store dry whole pulses. *Callosobruchus maculatus*, *Callosobruchus chinensis*, *Callosobruchus analis*, *Callosobruchus rhodesianus*, *Callosobruchus dolichosi*, *Callosobruchus subinnotatus*, *Callosobruchus phaseoli*, *Acanthoscelides obtectus* and *Zabrotes subfasciatus* are some of the major pulse bruchids. Apart from bruchids, other insects attacking the stored beans are *Oryzaephilus surinamensis*, *Tribolium castaneum*, *Rhyzopertha dominica*, *Prostephanus truncatus*, *Sitophilus* spp., and nitidulids [62].

Pulse beetles are cosmopolitan pests and are widely distributed throughout the tropical and sub-tropical areas [63]. *Callosobruchus chinensis*, *Callosobruchus maculatus*, and *Callosobruchus analis* are the three commonly known insect species in stored pulses. They are generally differentiated based on the coloring pattern of the body. Adults are short-lived and their main purpose is to find a mate and lay eggs for the continuation of generation [33]. Most bruchids are short, stout-bodied beetles with a short forewing not reaching the tip of the abdomen. Adults are characterized by their compact hairy bodies and relatively long antennae. Larvae of most species feed within seeds and some develop in stored dry grains or legumes. All bruchids are phytophagous with most species able to avoid feeding on seed covers that contain toxins. Adult bruchids fly from infested stores to nearby fields. As the pod develops females lay eggs on it or within it. Eggs hatch and grub bore into soft developing pulses [7]. The pulse beetles are the major pest of economically important leguminous seeds, like mungbeans, field peas, chickpeas, soybeans, cowpeas, lentils, green gram, black gram, and others [19].

Callosobruchus chinensis is a cosmopolitan polyphagous pest in the wet tropics and subtropics. This species is reported to be the most damaging pest of legume seeds which are a major source of protein in many countries. Infestation may start in the pods before harvest and carry over into storage where significant losses may happen. The level of infestation may be high. The insects can cause damage in almost all types of stored pulses. They prefer whole grains for damage initiation [33]. Both adults and larvae are damaging stage. *Callosobruchus* spp. lays an egg on the grain surface; this presence of eggs is the first line of detection. After feeding the grain the exit holes caused by the adults was one more detection symptom. But by the time exit holes are visible; the insect completely infested the grain and is of no use. Eggs are laid on the surface of the seeds is stored or pods in the fields and larvae develop within seeds causing weight loss, decreased germination potential, and reduction in commercial value. The seeds may be almost completely hollowed out by feeding activities of the larvae and characteristic emergence holes are evident after the adult leaves the seeds. Thus, severe damage and significant weight loss in stored seeds are caused by larvae, which grow within the pulses and consume the seeds [64].

Pulse beetle *Callosobruchus maculatus* (Fabricius) is a very important pest of grain legumes both in storage and field, commonly in storage conditions. This species originated in Africa but is now found all over the tropics and sub-tropics. *C. maculatus* mainly attacks beans of various species and can alternatively attack other pulse crops. This species is a major pest of economically important leguminous grains, such as cowpea, lentil, green gram, and black gram [19].

The pest is an internal feeder that lays eggs on the seed surface in the field as well as during threshing which hatch during storage. The insect multiplies when the congenial conditions become available. The larva is whitish with a light-brown head. The mature larva is six to seven mm long. The larva feeds inside the beans and when numerous, may leave nothing but the shell thereby causing serious weight loss, reduction in quality, nutritive value, germinability [23]. The adult beetle measuring 3-4 mm in length is oval, chocolate, or reddish-brown and has long serrated antennae. A single female lays small, oval, scale-like 34-113 eggs at the rate of 1-37 per day. The egg period is 6-16 days; the larval period is 10-38 days. The pupal stage lasts 4-28 days. The average lifespan of an adult is 5-20 days. In its lifetime, adults never feed any pulses. *C. maculatus* infestation was dependent on the water content of the food, which is needed for fecundity and longevity [65]. Infested stored seed can be identified by the white eggs on the seed surface and the round exit holes with the flap of the seed coat [7]. The infested seeds are unfit for planting or human consumption [66].

4. LOSSES DUE TO STORED GRAIN PESTS

Storage losses due to insect pest infestations have been a problem of major concern among smallholder farmers who use traditional storage structures [67]. It is also a problem at the time of transportation and other stored products. Insects can damage the grains by direct feeding or indirectly by deterioration and contamination of grain by their fecal matter, exuviae, or secondary infestation. Direct feeding damage results in reductions in grain weight, nutritional value, germination, and market value. Whereas deterioration and contamination from the presence of insects result in the reduction of grain and market value due to insect parts, odors, molds, and heat damage [33].

Deterioration of stored grains results from the interactions of several factors such as physical, chemical, and biological variables existing in the overall chains from production to consumptions [68]. Deterioration of grain as a result of infestations of insects, fungi, and mites is the most important post-harvest factor affecting the nutritional quality and marketability of stored grain. Grain storage pests are a major concern for farmers worldwide but especially in developing countries because a large percentage of the crop may be lost to storages pests. Before any pest control interventions, it is vital to assess the pest status and extent of losses that have occurred or are likely to occur during storage [69].

Losses due to insect attacks are weight loss, quality loss, and quantity loss of the grain or other stored products. Weight loss of sacked grain is easily recognized by the appearance on the sack surface of frass resulting from the feeding activity of the insects. Quality loss is losses expressed by loss in nutritional quality, edibility, caloric value, and consumer acceptability of the products [70, 71]. Quality loss can also be due to contamination and foreign matter (insect fragments, excreta, and others) content [72]. Quantitative losses are losses that result in a reduction in quantity. The quantitative losses of stored grain in the global level estimates of postharvest losses vary in literature and global information for losses showed that 9-40% [71]. FAO and World Bank [73], reported that approximately 20-30% loss of grains occurred globally, with an estimated monetary value of more than US$4 billion annually. According to a study conducted by World Bank, 12-16 million tons of food grains are lost due to storage pests, which if prevented could feed one-third of the population [74]. Although other studies reported that approximately 50-60% losses of cereal grains during storage due to technical inefficiency [75].

Losses resulting from poor post-harvest management of grains are among the key constraints to improving food and nutritional security in Africa, including Ethiopia [76]. In Ethiopia, grain is often not stored for more than eight months due to poor storage techniques and inadequate pest management systems [77]. Under farmers' storage grain losses are further aggravated by poor post-harvest handling, inefficient storage facilities, and inadequate pest management systems [77, 78]. The average grain losses due to storage pests in Ethiopia are estimated at 12% of the total grain produced, in some cases the losses could rise to 50% [79]. The average grain losses due to storage insect pests are estimated to be 10-30% [80].

5. MANAGEMENT OF STORAGE INSECT PESTS

5.1 Physical Method

Physical methods can be very simple methods that utilize renewable or local materials such as sun drying, sand layer application, repeated sieving, heating, mechanical heating system, ionizing radiation, and others [62]. Simple sieving and aspiration can also decrease the insect population. Frequent sieving of infested grains can lessen insect infestation. This method of storage insect pest management can be easily adopted by small-scale farmers and traders with smallholdings. Aeration and cooling are important management methods used to cool the grain to control insect infestations [81, 82]. Direct heating or cooling of grains is used widely to control stored product insect pests. Temperature management is also used to control the storage of insect pests. Increasing or decreasing the temperature can alter insect growth and metabolism. Above and below the optimum temperature insects are not active that will slow down the growth and continue to die. Using extreme temperatures can be lethal for insects at all stages. Passing of dry or wet heat in the storage system or refrigerated aeration yield better results. Even it can be achieved using high-frequency waves [33].

The use of inert dust like ashes, sand, and other mineral powders and small-sized grains in huge amounts is a barrier to insect movement through filling up the free space in grain bulks. Some inert materials are toxic to storage insect pests, resulting in mortality. Wood ash as inert dust induces insect mortality by its physical properties, it desiccates the insect cuticle and provokes suffocation in insects [83]. Inert materials, such as wood ash and sand are used for the management of bean beetle on stored chickpea by causing high adult mortality, a reduced egg laid, reduced the progeny emergence, resulting in low grain damage and low grain weight loss without affecting grain germination in stored chickpea grains [84].

Radiations in lower doses can able to kill or sterilize the common grain pests and even the eggs deposited inside the grains. Radiations like microwaves, X-rays, and others are utilized in several forms to treat the grains before storage to disinfect them. Ionizing radiation has been used in many countries as a pest control measure and a quarantine measure. It is used for achieving 100% mortality of insects in storage materials [62].

5.2 Hermetic Storage Control

It is a type of insect pest control method that seeks to reduce the concentration of oxygen in the container used while increasing the carbon dioxide concentration, eventually killing any insect pest present by reducing oxygen [85]. This is the storage of grains under airtight conditions. Airtight storage prevents pests from entering and causes the death of insects left in the store due to lack of O_2 and excess CO_2. Thus, modifying the atmosphere by reducing O_2 levels or rising CO_2 levels provided good control in stored grain pests [86]. Super grain bags have been developed as alternative methods for the storage of grains. Among the different strategies explored the use of modified atmospheres, which includes changing the extent of the ordinary air constituents of the store oxygen, nitrogen and carbon dioxide to form an air lethal to insects, has given especially promising results [87]. Airtight storage is an alternative to other methods of storage that ensures commodities from insects and molds [88]. Oxygen and dampness impermeable bags protect maize and sorghum superior to traditional storage structures and polypropylene sacks. It reduces storage loss from the current 25% at traditional storage to 2% in modern storage and promotes the ability of farmers to reduce grain loss [89]. It is suitable for protecting small quantities of grain materials but it is too expensive for use for food grains storage [83]. In Ghana, research was conducted on Triple-layer bagging without pesticides was found to be an effective, cheap, and environmentally friendly method of controlling the maize weevil [88].

5.3 Host Plant Resistance

Host plant resistance involves the plant protecting itself by employing physical barriers that restrict the feeding of storage insect pests [90]. It typically a relationship of plant species resistance with physical characteristics such as long tight husks which reduce attack by weevils and grain moths, the importance of the integrity of husks such as seeds with gaping or damaged husks which are more susceptible to attack, antibiosis in seeds of some plants which contain chemical substances unacceptable to certain insects, physical and nutritional properties of seeds such as hard seed coat or vitreous endosperm which contributes to resistance, definite oviposition preferences which exist among seed species and varieties [91].

Grain varieties and landraces vary among themselves in their susceptibility to stored grain insect pests. Such differences may be due to the existence of some levels of resistance in local grain varieties, which are attributed to the morphological or biochemical bases of resistance in grain varieties [92]. The grain coat thickness and grain hardness served as a barrier to the penetration of the endosperm by maize weevil, *Sitophilus zeamais,* and the varieties are proved to be less susceptible to infestation [93]. Resistance in stored sorghum to insect attack is attributed to the presence of toxic alkaloids or amino acids, enzyme inhibitors, pericarp surface texture, insect feeding deterrents, grain hardness, grain temperature, and moisture content [31, 94]. Other studies showed that grain hardness is the main resistance parameter for *S. oryzae* in stored sorghum [95].

5.4 Biological Control

Chemical pesticides are being phased out and novel biological methods are being developed, which can be adopted in integrated pest management practice to prevent insect damage of the grains. Biological control could be through the use of biotechnological intervention or using parasitoids or predators for the destruction of insects or the prevention of insect infestation [96]. Fungi and wasps are biological vectors released into grain storage facilities to control pulse beetles. These parasitoids feed on or infect the damage-causing insect pests. Many natural enemies are associated with stored product insects, adapted to human-based habitats, as are their prey and hosts. Several species of parasitoid wasps, predatory beetles, true bugs, and mites prey on any life stage of numerous species of stored product insect pests that they can subdue and consume [97]. *Trichogramma* spp. are especially promising as biological control agents on finished products because they attack the egg stage of the pests, thereby preventing invasion of products by first instars. This species has been evaluated against a range of stored product moths in bulk wheat storage, bulk groundnut storage, and bakeries, in addition to in warehouses and retail stores in Europe [98].

However, the control of these biological agents and their probable effect on the ecosystem has not been reported widely. Controlling insect pests in stored grain and grain products can be very difficult because of the variety of species that can infest grain and grain products. Research on the biological control of grains is still limited. It has to pass through various hurdles before being commercialized. It is still out of sufficient control of consequences; hence sufficient research is needed before adopting this practice [62].

5.5 Botanical Control

Botanicals are chemicals produced by plants that have insecticidal, repellent, or antifeedant and development inhibiting effects on storage insect pests. Various products of plants have a good degree of success as protectants against several stored grain insect pests [99, 100]. Botanical plants such as neem possess repellent, antifeedant, and feeding deterrent properties against storage insect pests. Plant extracts or products having insecticidal properties like neem leaf powder, black pepper, turmeric powder, and others were also proved their effectiveness in managing the stored grain pests.

The use of botanicals or phytochemicals has received much consideration and research in recent times because of the ever-increasing side effects of synthetic pesticides on human health. Botanicals have been in use for centuries by peasant farmers in Africa and Asia but are gaining prominence in recent times as a non-toxic and cheap alternative to synthetic pesticides [101]. Other advantages of botanicals are that they are freely degradable even under situations of overdose. Most all of them have no residual effects and are locally available and easily accessible to the peasant farmer [102]. Neem and Pyrethrum have been extensively studied and are well exploited commercially for the control of storage pests [103]. There have also been several studies evaluating the effectiveness of some of these plants alone and their combinations in the control of storage pests. Poor farmers in several developing countries who could not afford the synthetic pesticide against stored grain insect pests used botanicals as a traditional control method. Due to specific novel modes of action plant extracts and essential oils have an advantage over synthetic insecticides against the storage of insect pests to minimize the cross-resistance to specific target molecules [104]. These plant extracts and oils can produce fumigants. These fumigants play important role in eliminating the insect pest of stored grains with rapid degradation, low toxic effect, and local availability [105].

5.6 Chemical Control

The infestation of stored grain insect pests can be controlled by chemical methods. Chemical insecticides are applied to prevent or suppress insect pest infestations. Chemical treatments mostly encompass fumigants and contact insecticides. Fumigants are applied to eliminate infestations already present while protectants are mostly admixed with grain to prevent insect infestation from occurring at the time of the storage period. Before using the storerooms should be disinfested with approved residual insecticides preferably important for the management of stored pests. Synthetic insecticides are not recommended for food grains used for consumption. Only chemicals registered for direct application to grains should be used and these should be applied according to recommended doses [62].

Fumigants such as phosphine, cyanogens, ethyl formate, sulfuryl fluoride, and carbonyl sulfide rapidly kill all life stages of stored product insects in storage structures and are still one of the most effective methods for the prevention of stored product losses from insect pests[106, 62]. Methyl bromide and phosphine are the most commonly used chemicals for fumigation [107]. Phosphine fumigation is one of the commonly used insect pest control measures. At the time of storage, fumigation is the best method to control insects than treated bags [87].

5.7 Integrated Pest Management of Stored Grains

Integrated pest management method involves various components for efficient management of insect pests in stored grains. It relies on managing insect populations through host plant resistance, physical, biological, botanical, and chemical control techniques. This ensures the equilibrium of the population. It is an environmentally friendly method [91].

6. CONCLUSION

Cereals and pulses have great biological and nutritional value in developing countries, like Ethiopia. However, they are usually attacked in stores by different insect pests. Storage insect pests are a major concern for farmers worldwide, particularly in developing countries. They cause substantial losses in stored grains and grain products. So it is necessary to understand the behavior, type of insects, and their life cycle to reduce the losses. Stored insect pests cause losses on weight loss, quality loss, and quantity loss. The losses are huge and increase from time to time. Therefore, to reduce the losses management of storage insect pests has been important to decrease the damaged content of stored grains by applying the appropriate management methods of physical, biological, botanical, chemical, host plant resistance and integrated pest management in a timely. In addition to this to maintain quantity, attain high nutritional status, and improve stored insect pest management effective and efficient research on storage insect pests should be strengthened and promoted especially in developing countries like Ethiopia.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Chakravarthy AK. New horizons in insect science:Towards sustainable pest management. Springer, India. 2015;431.
2. Stejskal V, Hubert J, Luka J. Species richness and pest control complexity. In:Working Group Integrated Protection in Stored Products. Proc. Of the meeting in Lisbon, Portugal, IOBC Bulletin. 2002;25.
3. Bhargava MC, Kumawat KC. Pests of stored grains and their management. New India Publishing, New Delhi. 2010;264.
4. Hubert J, Stejskal V, Munzbergova Z, Kubatova A, Vanova M, Zdarkova E. Mites and fungi in heavily infested stores in the Czech Republic. Journal of Economic Entomology. 2004;97(6):2144-53.
5. Arthur FH, Throne JE. Efficacy of diatomaceous earth to control internal infestations of rice weevil and maize weevil (Coleoptera:Curculionidae). Journal of Economic Entomology. 2003;96:510- 518.
6. FAO. www.faostat.org. Accessed on 28th June 2012;2012.
7. Srivastava C, Subramanian S. Storage insect pests and their damage symptoms:An overview. Journal of Grain Storage Research. 2016;53-58.
8. Tiwari B, Gowen A, Mckenna B. Introduction in pulse foods:Processing, Quality and Nutraceutical Applications. Academic Press, Amsterdam, Boston. 2011;1-7.
9. Menkov ND. Moistuer sorption isotherms of chickpea seeds at several temperatures. Journal of Food Engineering. 2000;45:189-194.
10. Rees D. Insects of stored products. CSIRO Pub. Collingwood, Victoria, Australia; 2004.
11. Khare BP. Pests of stored grain and their management. Kalyani Publishers, New Delhi. 1994;304.
12. Marid T. Post-harvest loss of stored grain, its causes and reduction strategies. Food Science and Quality Management. 2020;96:26-35.
13. Mebeasilassie A. Studies on the pest status of bean bruchids and managements of major bruchids species in central rift valleys of Ethiopia. MSc. Thesis, School of Graduate Studies, Addis Ababa University, Ethiopia;2004.
14. Phillips TW, Throne JE. Biorational approaches to managing stored-product insects. Annual Review of Entomology. 2009;55(1):375-397.
15. Wijayaratne LKW, Arthur FH, Whyard S. Methoprene and control of stored-product insects. Journal of Stored Products Research. 2018;76:161-169.
16. Mihale MJ, Deng AL, Selemani HO, Kamatenesi MM, Kidukuli AW, Ogendo JO. Use of indigenous knowledge in the management of field and storage pests around Lake Victoria basin in Tanzania. African Journal of Environmental Science and Technology. 2009;3:49-71.
17. Grenier AM, Mbaiguinam M, Delobel B. Genetical analysis of the ability of the rice weevil *Sitophilus oryzae* (Coleoptera,

Curculionidae) to breed on split peas. Heredity. 1997;79:15-23.

18. Aslam I, Ozbek H, Kordali S, Calmasur O, Cakir A. Toxicity of essential oil vapours obtained from *Pistacia* spp. to the granary weevil, *Sitophilus granarius* (L.) (Coleoptera:Curculionidae). Journal of Plant Diseases and Protection. 2004;111:400-407.
19. Park IK, Lee SG, Choib DH, Park JD, Ahna YJ. Insecticidal activities of constituents identified in the essential oil from leaves of *Chamaecyparis obtusa* against *Callosobruchus chinensis* (L.) and *Sitophilus oryzae* (L.) Journal of Stored Products Research. 2003;39:375–384.
20. Hill DS. Pests of stored foodstuffs and their control. Kluwer Academic Publishers, Dordrecht;2002.
21. Rajat D, Visvash V, Nitin K, Ankit K, Rahul S. Stored grain insect pests and their management:An overview. Journal of Entomology and Zoology Studies. 2020;8(5):969-974.
22. Buatone S. Biological control of rice weevils (*Sitophilus oryzae* L.) in stored milled rice by the extracts of mint weed, kitchen mint and kaffir lime. PhD Thesis, Institute of Science, Suranaree University of Technology;2010.
23. Atanda SA, Agoda S, Ihionu GC, Usanga OE. Protection of grains and cereals- A Review. Applied Science Report. 2016;13(2):95-106.
24. Danho M, Gaspar C, Haubruge E. The impact of grain quantity on the biology of *Sitophilus zeamais* Motschulsky (Coleoptera:Curculionidae):oviposition, distribution of eggs, adult emergence, body weight and sex ratio. Journal of Stored Products Research. 2002;38:259-266.
25. Issa US, Afun JVK, Mochiah MB, Owusu AM, Braimah H. Effect of some local botanical materials for the suppression of weevil populations. Journal of Animal and Plant Sciences. 2011;11(3):1466-1473.
26. Siwale J. Comparative resistance of maize populations to the maize weevil, *Sitophilus zeamais* (Motschulsky). MSc Thesis, University of Zambia, Zambia;2007.
27. Alleoni B, Ferreira W. Control of *Sitophilus zeamais* Mots. and *Sitophilus oryzae* L. weevils (Coleoptera , Curculionidae) in stored rice grain (*Oryza sativa* L.) with insecticide pirimiphos methyl (Actellic 500 CE). In 9th International Working Conference on Stored Product Protection. 2006;1234-1241.
28. Cash F. Resistance to pyrethroids in the maize weevil, *Sitophilus zeamais*. Resistance to pyrethroids in the maize weevil, *Sitophilus zeamais*. University of Nottingham; 2011.
29. Tefera T, Mugo S, Tende R, Likhayo P. Mass rearing of stem borers, maize weevil and larger grain borer insect pests of maize. Nairobi:CIMMYT;2010.
30. Kanyamasoro MG, Karungi J, Asea G, Gibson P. Determination of the heterotic groups of maize inbred lines and the inheritance of their resistance to the maize weevil. African Crop Science Journal. 2012;20:99-104.
31. Abebe F, Tefera T, Mugo S, Beyene Y, Vidal S. Resistance of maize varieties to the maize weevil, *Sitophilus zeamais* (Motsch.) (Coleoptera:Curculionidae). African Journal of Biotechnology. 2009;8(21):5937- 5943.
32. Kim S, Kossou D. Responses and genetics of maize germplasm resistant to the maize weevil *Sitophilus zeamais* Motschulsky in West Africa. Journal of Stored Products Research. 2003;39(5):489-505.
33. Tyagi SK, Guru PN, Aarti N, Akhoon AB, Pulin P, Vandana M, Anju BK. Post-harvest stored product insects and their management. ICARAICRP on PHET, Central Institute of Post-Harvest Engineering and Technology;2019.
34. Baidoo P, Mochiah M, Owusu-Akyaw M. Levels of infestation on three different portions of the maize cob by the weevil *Sitophilus zeamais* (Motschulsky). Journal of Science and Technology (Ghana). 2011;30(3):21-26.
35. Dari S, Pixley KV, Setimela P. Resistance of early generation maize inbred lines and their hybrids to maize weevil [*Sitophilus zeamais* (Motschulsky)]. Crop Science. 2010;50(4):1310-1317.
36. Zunjare R, Hossain F, Muthusamy V, Jha SK, Kumar P, Sekhar JC, Guleria SK, Singh NK, Thirunavukkarasu N, Gupta HS, Tejada MM. Genetics of resistance to stored grain weevil (*Sitophilus oryzae* L.) in maize. Cogent Food and Agriculture. 2015;1(1):1075934.
37. Pingali P, Pandey S. Meeting world maize needs:technology opportunities and priorities for the private sector. In:Pingali P. (Eds.), CIMMYT 1999-2000 World Maize Facts and Trends. Meeting World Maize Needs:Technology Opportunities and Priorities for the Private Sector. Mexico City, Mexico;2001.

38. Kankolongo M, Hell K, Nawa I. Assessment for fungal, mycotoxin and insect spoilage in maize stored for human consumption in Zambia. Journal of the Science of Food and Agriculture. 2009;89(8):1366-1375.
39. Akowuah JO, Mensah LD, Chan C, Roskilly A. Effects of practices of maize farmers and traders in Ghana on contamination of maize by aflatoxins:Case study of Ejura-Sekyeredumase Municipality. African Journal of Microbiology Research. 2015;9(25):1658-1666.
40. Singh NK, Tripathi RB, Akanksha P. Study on the life cycle and control of *Sitophilus granarius* (Coleoptera:Curculionidae) on wheat grain (*Triticum aestivum*) in laboratory condition. International Journal of Recent Scientific Research. 2019;10(08):34200-34202.
41. Edde PA. A review of the biology and control of *Rhyzopertha dominica* (F.), the lesser grain borer. Journal of Stored Products Research. 2012;48(2012):1-18.
42. Naseem MT, Khan RR. Comparison of repellency of essential oils against red flour beetle *Tribolium castaneum* Herbst (Coleoptera:Tenebrionidae). Journal of Stored Products and Postharvest Research. 2011;2(7):131-134.
43. Majeed MZ, Mehmood T, Javed M, Sellami F, Riaz MA, Afzal M. Biology and management of stored products' insect pest *Rhyzopertha dominica* (Fab.) (Coleoptera:Bostrichidae). International Journal of Biosciences. 2015;7(5):78-93.
44. Bashir T. Reproduction of *Rhyzopertha dominica* Fab. (Coleoptera:Bostrichidae) on different host-grains. Pakistan Journal of Biological Sciences. 2002;5(1):91- 93.
45. Suleiman M. Assessment of bioactivity of selected botanicals against the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera:Curculionidae) in stored sorghum, *Sorghum bicolor* (L.) Moench in northern Nigeria. PhD Thesis. University of Dares Salaam, Tanzania. 2018;308.
46. Mason LJ, McDonough M. Biology, behavior, and ecology of stored grain legume insects. In:Hagstrum D.W., Phillips T.W. and Cuperus G. (Eds.), Stored Product Protection. Kansas State University. 2012;7-32.
47. Kucerova Z, Stejskal V. Differential egg morphology of the grain pests *Rhyzopertha dominica* and *Prostephanus truncatus* (Coleoptera:Bostrichidae). Journal of Stored Products Research. 2008;44:103-105.
48. Rees D. Insects of stored grain a pocket reference. 2nd Edition. CSIRO Publishing. Australia;2007.
49. Robinson WH. Urban insects and arachnids. A Handbook of Urban Entomology. Cambridge University Press. Cambridge, UK. 2005;472.
50. Singh P, Satya S, Naik SN. Grain Storage insect-pest infestation- Issues related to food quality and safety. Internet Journal of Food Safety. 2013;15:64-73.
51. Lowe S, Browne M, Boudjelas S, De Poorter M. 100 of the world's worst invasive alien species:a selection from the global invasive species database. Auckland:Invasive Species Specialist Group;2000.
52. Sharma HC, Ashok SA, Ravinder RC, Jayaraj K, Varaprasad VJ, Varaprasad RK, Belum VSR, Rai KN. Management of sorghum and Pearl Millet Pests in Bulk storage. Global Theme on Crop Improvement. International Crops Research Institute for the Semi-Arid Tropics, Andhra Pradesh, India. 2007;20.
53. Matthew JG, Paul WF, James RN. Biological control of Indian meal moth (Lepidoptera:Pyralidae) on finished stored products using egg and larval parasitoids. Journal of Economic Entomology. 2006;99(4):1080-1084.
54. Devi MB, Devi N. Biology of rustred flour beetle, *Tribolium castaneum* (Herbst) (Tenebrionidae:Coleoptera). Indian Journal of Entomology. 2015;77(1):81-82.
55. Beeman RW, Haas S, Friesen K. Beetle wrangling tips:An Introduction to the care and Handling of Tribolium castaneum. Available online;2012.
56. Mahroof RM, Hagstrum DW. Biology, behavior, and ecology of insect processed commodity. In:Hagstrum D.W., Phillips T.W. and Cuperus G. (Eds.), In Stored Product Protection. Kansas State University;2012.
57. Bachrouch O, Jemaa JMB, Talou T, Marzouk B, Abderraba M. Fumigant toxicity of *Pistacia lentiscus* essential oil against *Tribolium castaneum* and *Lasioderma serricorne*. Bulletin of Insectology. 2010;63:129-135.
58. Kheradpir N. Food preference of Tribolium castaneum among four flour types. European Journal of Experimental Biology. 2014;4(1):436-439.
59. Ajayi FA, Rahman SA. Susceptibility of some staple processed meals to red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera:Tenebrionidae). Pakistan Journal of Biological Sciences. 2006;9(9):1744-1748.

60. Lale NES, Yusuf BA. Insect pests infesting stored pearl millet *Pennisetum glaucum* (L.) R.Br. in northeastern Nigeria and their damage potential. Cereal Research Communications. 2000;181-186.
61. Sales MP, Gerhardt IR, Grossi-de-Sá MF, Xavier-Filho J. Do legume storage proteins play a role in defending seeds against bruchids? Plant Physiology. 2000;124:515-522.
62. Mohapatra D, Kar A, Giri SK. Insect pest management in stored pulses:an Overview. Food and Bioprocess Technology. 2015;8(2):239-265.
63. Giga DP, Smith RH. Comparative life history studies of four *Callosobruchus* species infesting cowpeas with special reference to *C. rhodesianus* (Coleoptera:Bruchidae). Journal of stored Products Research. 1983;19:189-198.
64. Chakraborty S, Mondal P, Senapati K. Evaluation of relative susceptibility of *Callosobruchus chinensis* Linn. on five different stored pulse seeds. Asian Journal of Plant Science and Research. 2015;5(10): 9-15.
65. Nattudurai GC Arulvasu K, Baskar S, Maria P. An overview of pulse beetle, *Callosobruchus* spp. Entomol Ornithol Herpetol. 2017;6:4.
66. Somta C, Somta P, Tomooka N, Ooi PC, Vaughan DA, Srinives P. Characterization of new sources of Mungbean (*Vigna radiata* (L.) Wilczek) resistance to bruchids, *Callosobruchus* spp. (Coleoptera:Bruchidae). Journal of Stored Products Research. 2008;44(4):316-321.
67. Mendesil E, Abdeta C, Tesfaye A, Shumeta Z, Jifar H. Farmers' perceptions and management practices of insect pests on stored sorghum in southwestern Ethiopia. Crop Protection. 2007;26(12):1817-1825.
68. Dubale B, Waktole S, Solomon A, Geremew B, Setu MR. Influence of Agro-ecology, traditional storage containers and major insect pest on stored maize (*Zea mayas* L.) in selected woreda of Jima zone. Asian Journal of Plant Science. 2012;11:226-234.
69. Togola A, Seck PA, Glitho IA, Diagne A, Adda C, Toure A, Nwilene FE. Economic losses from insect pest infestation on rice stored on-farm in Benin. Journal of Applied Sciences. 2013;13(2):278-285.
70. Buyukbay EO, Uzunoz M, Bal HS. Post-harvest losses in tomato and fresh bean production in Tokat province of Turkey. Scientific Research and Essays. 2011; 6(7):1656-1666.
71. Hodges R, Bernard M, Rembold F. APHLIS-Postharvest cereal losses in Sub-Saharan Africa, their estimation, assessment and reduction;2014.
72. Brown PR, McWilliam A, Khamphoukeo K. Post-harvest damage to stored grain by rodents in village environments in Laos. International Bio Deterioration and Biodegradation. 2013;82:104-109.
73. FAO and World Bank. Food and Agricultural Organization of the United Nations. Reducing post-harvest losses in grain supply chains in Africa:Lessons learned and practical guidelines;2010.
74. Sharon M, Abirami CV, Alagusundaram K. Grain storage management in India. Journal of Post-Harvest Technology. 2014;2(1):12-24.
75. Kumar D, Kalita P. Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods. 2017;6(1):8.
76. Midega CA, Murage AW, Pittchar JO, Khan Z.R. Managing storage pests of maize:Farmers' knowledge, perceptions and practices in western Kenya. Crop Protection. 2016;90:142-149.
77. Demissie G, Tefera T, Tadesse A. Importance of husk covering on field infestation of maize by *Sitophilus zeamais* Motsch (Coleoptera:Curculionidea) at Bako Western Ethiopia. African Journal of Biotechnology. 2008;7:20.
78. Tefera T, Mugo S, Likhayo P. Effect of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil, *Sitophilus zeamais* and the larger grain borer, *Prostephanus truncates*. African Journal of Agricultural Research. 2011;6(10):2249-2254,
79. Gabriel AH, Hundie B. Farmer's post-harvest grain management choices under liquidity constraints and impending risks:Implications for achieving food security objectives in Ethiopia. Proceedings of the international association of agricultural Economists Conference, August 12-18, Gold Cost, Australia;2006.
80. Tadesse A. Arthropods associated with stored maize and farmers' management practices in the Bako area, Western Ethiopia. Pest Management Journal of Ethiopia. 1997;34:71-89.
81. Navarro S, Noyes RT. The mechanics and physics of modern grain aeration management. CRC Press, Boca Raton, FL;2001.

82. Navarro S, Noyes RT. Cassada M, Arthur FH. Aeration of grain. pp. 121-134. In:Hagstrum D.W., Phillips T.W., Cuperus G. (eds.). Stored Product Protection, Chapter 11, Kansas State Research and Extension as Publication; 2012.
83. Jean WG, Nchiwan NE, Dieudonne N, Christopher S, Adler C. Efficacy of diatomaceous earth and wood ash for the control of *Sitophilus zeamais* in stored maize. Journal of Entomology and Zoology Studies. 2015;3(5):390-397.
84. Tabu D, Selvaraj T, Singh SK, Mulugeta N. Management of Adzuki bean beetle (*Callosobruchus chinensis* L.) using some botanicals, inert materials and edible oils in stored chickpea. Journal of Agricultural Technology. 2012;8(3):881-902.
85. Yakubu A, Bern CJ, Coats JR, Bailey TB. Hermetic on-farm storage for maize weevil control in East Africa. African Journal of Agricultural Research. 2011;6(14):3311-3319.
86. Dowell FE, Dowell CN. Reducing grain storage losses in developing countries. Quality Assurance and Safety of Crops & Foods. 2017;9:93-100.
87. Demissie G. Field infestation of maize by *Sitophilus zeamais* (Mostch.) (Coleoptera:Curculionidae) at Bako and its management on stored maize. MSc Thesis, Haramaya University, Ethiopia; 2006.
88. Anankware PJ, Fatunbi AO, Afreh-Nuamah K, Obeng-Ofori D, Ansah AF. Efficacy of the multiple layer hermetic storage bags for bio-rational management of primary beetle pests of stored maize. Academic Journal of Entomology. 2012;5(1):47-53.
89. Tadele T, Abass AB, Adebayo A. Improved postharvest technologies for promoting food storage, processing, and household nutrition in Tanzania. 2012;1-20.
90. Kasozi LC. Genetic analysis and selection for weevil resistance in maize. African Centre for Crop Improvement. PhD Thesis, University of KwaZulu Natal, Pietermaritzburg, South Africa;2013.
91. Odeyemi OO, Daramola AM. Storage practices in the tropics:Food storage and pest problems. First Edition, Dave Collins Publication, Nigeria. 2000;1:235-247.
92. Mboya R. Study of the effects of storage methods on the quality of maize and household food security in Rungwe District, Tanzania. PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg. 2011;255.
93. Zakka U, Ndowa ES, Odidika CU. Evaluation of the performance of different maize varieties against *Sitophilus zeamais* Motsch. (Coleoptera:Curculionidae) infestation in the Niger Delta Region of Nigeria. Jordan Journal of Biological Sciences. 2013;6(2):99-104.
94. Goftishu M, Belete K. Susceptibility of sorghum varieties to the *Sitophilus zeamais* Motsch. (Coleoptera:Curculionidae). African Journal of Agricultural Research. 2014;9(31):2419-2426.
95. Bamaiyi LJ, Dike MC, Onu I. Relative susceptibility of some sorghum varieties to the rice weevil *Sitophilus oryzae* L. (Coleoptera:Curculionidae). Journal of Entomology Sustainable Agriculture. 2007; 4(5):387- 392.
96. Scholler M, Prozell S, Al-Kirshi A, Reichmuth C. Towards biological control as a major component of integrated pest management in stored product protection. Journal of Stored Product Research. 1997;33:81-97.
97. Abrol DP, Kakroo SK, Putatunda BN. Stored product mite *Tyrophagus longior* (Gervais) with hive bees in India. Current Science. 1994;66:105.
98. Grieshop MJ, Flinn PW, Nechols JR, Schoeller M. Foraging success of three species of *Trichogramma* (Hymenoptera:Trichogrammatidae) in a simulated retail environment. Journal of Economic Entomology. 2007;100:591-598.
99. Shukla R, Srivastava B, Kumar R, Dubey NK. Potential of some botanical powders in reducing infestation of chickpea by *Callosobruchus chinensis* L. (Coleoptera:Bruchidae). Journal of Agricultural Technology. 2007;*3*(1):11-19.
100. Srinivasan G. Efficacy of certain plant oils as seed protectant against pulse beetle, *Callosobruchus chinensis* L. on pigeon pea. Pesticide Research Journal. 2008;20: 13-15.
101. Issa US. Susceptibility of some maize varieties to the maize weevil *Sitophilus zeamais* (Motschulsky), (Coleoptera:Curculionidae) and effect of some local botanical materials for the suppression of weevil populations. MSc Thesis, Kwame Nkrumah University of Science and Technology;2015.
102. Saxena HO, Tripathi YC, Pawar G, Kakkar A, Mohammad N. Botanicals as biopesticides :Active chemical constituents and biocidal action. Familiarizing with Local

Biodiversity. Indian Council of Forestry and Education. 2014;222-240.

103. Dubey NK, Srivastava B, Kumar A. Current status of plant products as botanical pesticides in storage pest management. Journal of Biopesticides. 2008;1:182-186.

104. Betancur RJ, Silva AG, Rodriguez JM, Fischer GS, Zapata SM. Insecticidal activity of Peumus boldus Molina essential oil against *Sitophilus zeamais* Motschulsky. Journal of Agricultural Research. 2010;70(3): 399-407.

105. Kerdchoechuen O, Laohakunjit N, Singkornar S. Essential oils from six herbal plants for bio control of the *S. zeamais*. Journal Horticultural Science. 2010;45(4):592-598.

106. Donahaye EJ. Current status of non-residual control methods against stored product pests. Crop Protection. 2000;19(8-10):571-576.

107. Shaaya E, Kostijukovski M, Eilberg J, Sukprakarn C. Plant oils as fumigants and contact insecticides for the control of stored-product insects. Journal of Stored Products Research. 1997;33:7-15.