

Post-Harvest Insect Pest and Their Management Practice for Major Food and Export Crops in East Africa: Ethiopian case

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Simple Summary: Various Many important storage pests have been identified with regard to the major food and exports in Ethiopia and the losses incurred by these pests have been identified and documented. The effectiveness of the existing post-harvest management alternatives for the major food and export crop pests in Ethiopia were assessed. However, it is difficult to rank those different storage pest management methods based on the currently available data. The most commonly used methods discussed here include cultural practices, use of various botanicals available locally, varietal tolerance, different storage structures, and some significant entomopathogenic fungi. While most of the research outcomes discussed in this study include basic information rather than ready-made technologies, however, with certain slightly modifications the available technologies can be implemented. For example, the conventional underground pits can be slightly modified to avoid moisture, so that mold development can be managed and reduces the potential risks of storage pests. Additionally, direct use of the recommended resistance varieties can also plays an important role in avoiding field infestation and reducing loads of insects under storage conditions. Several botanical products have also proven successful so that farmers could directly apply them. Finally, it is important to emphasize on integrated approach of pest management system for its sustainability and effectiveness approaches for long-term storage of seed and grains under various conditions.

Abstract: Subsistence farmers in Ethiopia store grain crops in traditional ways, making them vulnerable to storage insects and molds, which can lead to contamination of staple grains. It is critical to have accurate knowledge of the insect species, infestation rates, storage loss, and storage conditions in the various types of farmers' grain stores in order to apply the most efficient and agreeable approach. With a focus on Ethiopia, this study conducted a thorough review of the literature on post-harvest insect and management strategies. In this study, weevils (*Sitophilus spp.*), lesser grain borer (*Rhyzopertha dominica*), rust red flour beetle (*Tribolium sp.*), sawtooth grain beetle (*Oryzaephilus sp.*), flat grain beetle (*Cryptolestes sp.*), indian meal moth (*Plodia interpunctella*), and angoumois grain moth (*Sitotroga cerealella*) are the most common insect pests of stored cereal. Flour beetles (*Tribolium sp.*), sawtoothed beetles (*Oryzaephilus sp.*), flat grain beetles (*Cryptolestes sp.*), and some moths have been identified as common stored product pests of stored oil seed, while bruchid beetles (*Callosobruchus chinensis*) and the moths (*Sitotroga cerealella*) were reported for pulses. Additionally, a total storage loss of 9%–64.5%, 13%–95%, 36.9%–51.9%, and 2–94.7% in maize, sorghum, chickpeas, and sesame respectively were caused by the storage pests in Ethiopia under various circumstances. Various pest population monitoring approaches for harvested produce and stores have been developed and recommended so that remedial measures can be taken before infestations or as soon as infestations are detected. In this regard, reducing post-harvest grain losses is becoming an issue to

ensure the country's future food security by improving food availability and accessibility for many smallholder farmers in Ethiopia.

Keywords: Post-harvest; storage pests; storage loss; pest management; food crop

1. Introduction

By 2050 world population has been estimated to reach 9.1 billion and this needs a 70% increase in food production which indicates the need to increase the food supply by 60% to meet the food demand in 2050 [1, 2]. Globally about 1.3 billion tons of food is wasted, however, in low-income countries most grains/food is lost well before reaching the consumer [1, 2, 3, 4]. Different biotic (pests and disease) and abiotic (heat, drought, natural ripening process, and improper handling) factors are the major constraints causing post-harvest losses and quality deterioration crops [1,5]. Those losses occur through the various post-harvest activities including harvesting, handling, storing, processing, packaging, transporting and marketing and the losses that occur at those different stages including on field, storage, processing and marketing in Africa are often estimated to be about 20- 40% [1,5]. Food deficit experiences in most Sub-Sahara countries and Ethiopia imports significant amount of food every year to alleviate this food shortage [2].

Most of the main sustainable crops, cereals, grain legumes and oilseeds , in Ethiopia are produced during the main crop season, which runs from June to October, while some crops are also planted during the short rains (March to May). In this case, food supply and food security are largely relay on good storage in situations. It is estimated that approximately 60 to 90% of the products are kept in the farm household and stored for 6 to 12 months [6]. This stock is then, subject to post-harvest losses and deterioration due to biotic and abiotic factors. Insect pests, fungi and rodents constitute the major biotic agents that cause serious problems in storage. Insects directly destroy grain by feeding on kernels and/or indirectly by contaminating the grain with its waste, webbing and parts of the body.

Minimizing post-harvest losses and degrading quality are therefore the most important points of action to increase food availability from established production, which could lead to improved food security and economic development in the community. In the case of major food and export crops, this paper provides a detailed literature review of post-harvest insect pests and their management practices with special emphasis on Ethiopia.

The overall objective of this work is understanding post-harvest insect pests of major crops and targeting of interventions options to minimize the losses, the specific objectives of this paper are;

To review type and kind of post-harvest insect pests in Ethiopia.

To evaluate the impact of post-harvest insect pests on major crops in Ethiopia.

To assess the effectiveness of the adequacy of existing post-harvest management options.

2. Post-harvest insect pests of major crops: worldwide overview

Different researcher outputs have identified a number of post-harvest insect pests. Insects like weevils (*Sitophilus spp.*), lesser grain borer (*Rhizopertha dominica*), rust red flour beetle (*Tribolium castaneum*) sawtooth grain beetle (*Oryzaephilus surinamensis*), flat grain beetle (*Cryptolestus minutus*), indian meal moth (*Plodia interpunctella*) and angoumois grain moth (*Sitotroga cerealella*) are reported as pests of cereal grains whereas flour beetles (*Tribolium confusum*), sawtoothed grain beetles (*Oryzaephilus surinamensis*)

and moths have been reported from stored oil seeds [7]. For pulses, bruchid beetle (*Callosobruchus chinensis*) was identified as pest for stored products [7].

There are two groups of stored grain insect pests, namely, “internal feeders” or “primary insect pest” if they feed within the kernels, otherwise they are referred to as “external feeders.” and “secondary insect pests” [8]. Insect pests that are able to penetrate and damage whole kernel of grain are grouped in primary insect pests. These pests include the rice weevil (*Sitophilus oryzae*), maize weevil (*Sitophilus zeamais*), granary weevil (*Sitophilus granaries*), lesser grain borer (*Rhizopertha dominica*), Khapra beetle (*Trogoderma granarium*), the pulse beetle (*Callosobruchus chinensis*) and angoumois grain moth (*Sitotroga cerealella*). On the other hand, insect pests like rust-red flour beetle (*Tribolium castaneum*), flat grain beetle (*Cryptolestus minutus*), sawtoothed grain beetle (*Oryzaephilus surinamensis*), grain mites (*Acarus siro*), and grain lice (*Liposcelis divinatorius*) which cannot damage the whole grain but feed on broken kernels and damaged grain are classified as secondary insect pests.

3. Importance of post-harvest insect pest on major food and export crops in Ethiopia

3.1. Maize

Pests affect maize production and productivity by attacking roots, leaves, ears, tassels, and the grain during storage [9]. Important storage pests have been reported in maize stores, including *Sitophilus zeamais*, *Sitotroga cerealella*, *Ephestia acautella*, *Plodia interpunctella*, *Tribolium spp.*, *Cryptolestes spp.*, *Carpophilus spp.*, *Anisopteromalus calandrae* and *Choetospila elegans* were reported as common pests in maize stores [10,11,12]. Similar reports indicated that maize was destroyed by a number of stored pests, of which the maize weevil followed by moth of grain, rice weevil and flour beetle were important storages pest in Jimma, Ethiopia [11]. Most of the loss assessment studies carried out on maize indicates significant loss of both grain and weight loss caused by different storage pest [10, 12, 13, 14,]. According to this assessment result a total grain damage ranging from 9 % to 64.5% and weight loss ranging from $8.3 \pm 0.2\%$ to 58.85 due to the maize weevil (*Sitophilus zeamais*), angoumois grain moth (*Sitotroga cerealella*), rice weevil (*Sitophilus oryzae*), flour beetle (*Tribolium confusum*) and large grain borer (*Prostephanus truncatus*) under traditional farmers’ storage practices were recorded (Table 1). The result of this analysis also indicates that most of the loss assessment studies were conducted on *S. zeamais* damage and it is reported as the most important maize storage pest causing significant quantitative and qualitative harm to both farmers and improved maize varieties in Ethiopia (Table 1). A comparative assessment study on maize storage pest in different site also indicated that the *S. zeamais* was the most abundant and distractive storage pests recorded in all the study sites and 53.85% on average estimated a grain weight loss during three-six months of maize storage was reported from this pest [9]. Research works carried out on improved Quality Protein Maize (QPM) varieties also showed a loss (37.76 - 53.05 %) in grain that could be explained as loss in nutritional value of the due *S. zeamais* was also reported [13]. Generally, the high post-harvest maize loss incurred despite the low overall agricultural productivity seeks an intervention to prevent the high quantitative, qualitative and economical losses causing by the storage pests during the storage periods of maize grain.

Table 1. Comparison in estimated storage losses and pests in major food and export crops in Ethiopia.

crop	Cause of loss	Estimated grain loss %	Estimated weight loss %	References
	<i>Sitophilus zeamais</i> , <i>Sitotroga cerealella</i> , <i>Sitophilus oryzae</i> , <i>Tribolium confusum</i>	64.50%	58.85%	[12]

maize	<i>S. zeamais</i>	NA	63.85	[13]
	<i>Sitophilus zeamais</i>	12-20	NA	
	large grain borer	9-45%	NA	[10].
	<i>Sitophilus zeamais</i>	25% - 46	NA	[13]
	<i>Sitophilus zeamais</i>	18.0 ± 3.4	8.3 ± 0.2	[13]
	Storage insect	37	NA	[2]
	Storage insect	13	NA	[2]
sorghum	Insects & molds	90-95%	NA	[4]
	insect	50%	NA	[14]
chickpea	<i>Callosobruchus chinensis</i>	36.9% -51.9%	NA	[18]
	<i>Callosobruchus chinensis</i>	50%	NA	[17]
		2 to 36	25	[21]
sesame		13%	26	[22]
	<i>Elasmolomuse sordiduse</i>	94.7%	23	[20]

NA= data not available; Source (analyzed by the author)

3.2. Sorghum

Regarding the sorghum storage pests, *Sitophilus zeamais*, *Sitotroga cerealella*, *Sitophilus spp*, *Tribolium confusum*, and *Oryzaephilus surinamensis* were the major insect pests identified in Africa including Ethiopia [14]. In maize, this crop has also been observed severely damaged mainly by weevils, including *sitophilus sp.* under different storage condition [15]. Based on data collected through survey and other standard methods, a total post-harvest loss ranges from 13 % - 95 % in different parts of Ethiopia under different farmers' storage conditions was assessed (Table 1). Although most Ethiopian farmers in various parts of the country mainly store their grain above ground bin locally known as "gotera," storing sorghum in traditional underground pits mainly to protect against burning, theft, insect pests and domestic and wild animals has also been recorded as a common storage practice for most sorghum growing farmers [16]. However, the underground pits in most cases leads to grain degradation due to mold infections [2,4]. Due to poor storage management system, significant sorghum grain and weight loss caused by *Sitophilus sp*, *Sitotroga sp.* and *Tribolium* species were reported under different farmers' sorghum storage condition and the damage was observed increasing with the extension of the storage period [15]. Beside to storage insects, sorghum grains stored in underground pits was also severely affected by molds damage [2, 4]

Generally, the high damage of sorghum-stored products was attributed to loss due storage insect and mold contamination and this could be resulted in a complete rejection of the grain under improper storage conditions (Table 1). Hence, considering different post-harvest loss management options along with other factors in the sorghum production-supply chain, should be the focus to alleviate the significance storage losses of sorghum grains, of which properly handled of the grain after harvest and before storage in order to reduce storage infection and infestation could be good actions to be taken.

3.3. Chickpea

Chickpea productivity in Ethiopia is far below its potential due to different biotic and abiotic factors. Storage insect pest including *Callosobruchus chinensis*, *C. maculatus*, *C. analis*, *Acanthoscelides obtectus* and *Bruchus incarnatus* were reported to cause a significant loss in chickpea grain [17]. Sever infestation of chickpea post-harvest insect pests frequently leads to complete grain loss where large amounts of chickpea are stored under very poor conditions vulnerable to insect pest infestation [18]. Subsistence farmers in Ethiopia, mostly store their chickpea grain in traditional stores, which are not in-

sect-proof, hence, the grains are vulnerable to attack by storage pests [17]. Severely damaged chickpea grains shows both quality and quantity losses during the storage time. The assessment made on chickpea sored products indicated a total weight loss ranging from 36.9% -51.9% due to *Callosobruchus chinensis* damage in Ethiopia (Table 1). Besides the actual loss, *Callosobruchus chinensis* damaged chickpea grain is not suitable for planting (because of poor germination) or for food or feed (because of spoilage, bad smell and toxin production [20]. A laboratory experimental result also showed a weight loss of 50% caused by *C. chinensis* on chickpea products stored for eight month in central Ethiopia [19]. Direct physical losses and losses of quality in legumes in general and chickpea in particular affects both the nutritional value and the export value of the crop, which has a direct impact on the food security issue of the country. To alleviate this huge loss occurred in chickpea storage products, conventional storage systems along with the improve storage technologies can lead to a significant reduction in post-harvest loss damage in chickpea sored products.

3.4. Sesame

Sesame (*Sesamum indicum* L.) locally caled 'Selit' is an economically important export oil crops in Ethiopia. Similarly, it is also known to be attacked by many insect pests at both pre and post-harvest stages around the world. In Ethiopia sesame seed bug, *Elasmolomus sordidus* (F), is the most disastrous post-harvest insect pest. Some studies indicated that sesame seed bug causes both quality and quantity damage to sesame and groundnut seeds at the field as well as in warehouse conditions [20, 21]. A significant sesame weight loss, a maximum of 94.7% and a minimum of 2% due to *Elasmolomus sordidus* attack during harvesting, and threshing and storage time was recorded in Ethiopia [Table 1]. Beside the quantitative grain loss, 4 to 43% reduction in oil content and 0.44 to 1.51% increase in free fatty acids was also reported due to these noxious pests [22]. An experiment conducted in Sudan also showed that the highest crop loss due to sesame seed bug on sesame was recorded with 60 days of infestation and a significant loss in oil content was also recorded as a result this pest damage [22,]. Considering the increasing importance of this cash crop to the Ethiopian agricultural economy, alleviating the post-harvest management bottlenecks is key for reducing the damages caused by this important pest during pre and post-harvest operational activities.

4. Post-harvest insect management practice in Ethiopia

4.1. Cultural practice

While the use of improved storage technologies and various insecticides is successful in controlling the enormous storage damage caused by a number of storage pests, most farms have also used various conventional or cultural methods since time immemorial to manage pre-and post-harvest infestations of insects. This practice includes the use of improve varieties, proper hygiene and sanitation, proper harvesting time, improved storage structures and drying efficiency. Farmers in Ethiopia have been observed storing their seed grain above the kitchen to keep the grain dry. Similarly, among a various cultural methods tested in Ethiopia, solar heating of maize caused a significantly mortality (70- 100%) of maize weevil under 55–60°C heating for two to three hours using solar heat absorbance beds [23]. The Similarly, heat treatment of *C. chinensis* for about an hour in an obtuse-base-angle box heater glued with aluminum foil was also reported completely killing adult of *C. chinensis* and cause failure to lay eggs in chickpea [23]. Generally, our assessment result indicated that even though there are many different cultural practices used in different parts of the Ethiopia, the most common traditional approaches used by many farmers to reduce post-harvest loss include drying grains to maximum moisture before storage to prevent mold infection, avoiding mixing of infected and safe grains, heating at certain temperatures, adding some inert powder to prevent damage to pests, cleaning before storage, smoking traditional storage with locally avail-

able plant materials and others indigenous practices (Table 5). The ability of those widely used traditionally practices to control storage insect pest infestation as well as mold under both field and storage conditions was off-course different. Hence, Farmers and other actors along the value chine of a given crop can therefore use various cultural methods based on research result recommendations.

Table 5. Comparison analysis on effectiveness of storage pest controlling methods in in Ethiopia.

Control methods	Crop/trait	treatment	Target pest	Measurement scale	Efficiency	References
Cultural	maize	Solar heating (55–60°C)	<i>Sitophilus zeamais</i>	Mortality rate%	70%-100	[23]
		G1			59.15±8.13 a	
		G2			12.78±1.44 c	
	maize (husk level)	G3	<i>Sitophilus zeamais</i>	NWPEAM	15.85±7.76 c	[35]
		G4			32.45±8.09 b	
Variety screening		G5			10.55±1.94 c	
Botanicals	Maize(Bio chemical level)	Pratap makka-5	<i>Sitotroga cerealella</i>	Grain loss%	7.21	[40]
		PMH-1	<i>sitotroga cerealella</i>		31.12	
	haricot beans	Orange powder (96 hours)	<i>Zabrotes subfasciatus</i>	Mortality rate	65.9	[31]
		Orange essential oil (hours)		Mortality rate %	67.4	
	Sorghum	Neem seed oil	<i>Sitophilus zeamais</i>	Mortality rate %	91.25-100	[35]
		citrus seed oil			83-100	
Entomopathogenic fungi	Maize	Cooking oils			54.54	[27]
		Triplex chemicals	<i>Sitophilus zeamais</i>	Mortality rate%	92.66	
		control			100	
		Metarhizium anisopliae & B. bassiana	<i>Sitophilus zeamais</i>	Mortality rate %	24.2	[39]
		13 isolates of	<i>Prostephanus truncatus</i>		92-100	
					98-100	
Inert dust	maize	Silicosec rates (15 days)	<i>Sitophilus zeamais</i>	Mortality rate %	100	[28]
		Filter cake rates			100	
		Wood ash rates			98.7	

(NWPEAM= number of adult weevils per ear after a month storage) ; Source (analyzed by the author)

4.2. Storage structure

Grain in Ethiopia is stored mainly in traditional grain stores such as “gotera”, bags (made of polyethylene, sisal or goatskin), “gumbi”, earthen pots and some others [35]. “Gotera” (above ground bin) is the most commonly used storage container in most parts of the country storage. It is made of bamboo, which is plastered internally and externally with mud and cow dung and mostly placed outdoors is [24]. “Gumbi” on the other hand, is made of mud, cow dung and straw of crop residue such as tef, *eragrostis tef*, and with a layered structure of rings stacked one over the other. Another traditionally made storage structures including baskets, pots, *gusgusha*, barrels and *goggo* were also used to store ‘teff’ in different parts of the country [24]. A study conducted in South East Ethiopia indicated that about 81% the farmers stored sorghum in “gotera”, while the 17% and 1% use clay pots and “gumbi” for storing their sorghum products after harvest respectively [16]. Similarly dried maize cobs were also stored in ‘gotera’ while, after shelling and winnowing, farmers store maize in polypropylene or jute bags [25].

A comparison study for different storage structures indicated that, bag in the house (46%) and the traditional “gotera” (39%) were selected by most farmers to store cereals while the improved storage methods such as the metal silo (< 1 percent) was list chosen method, which could be correlated with cost and its easily accessibility (Table 2). Likewise, cone-shaped underground pits with an average depth of 165.8 cm, 62.1 cm mouth diameter and 152.0 cm bottom diameter were also used for sorghum and corn storage in Eastern Ethiopia, Harar, (Fig 1) [16,25] A survey study conducted in in, Harar, indicated that about 70 % of the farmers store their sorghum, in the traditional underground storage pits till it is consumed or sold [23]. However, sstorage of sorghum in underground pits was less effective method to maintain the quality due to the myco-toxin contamination [24]. A comparative study on different storage structure indicates that the most critical system used by farmers to store cereals was a bag in the house that is used to store about 46% of their grain produces followed by the conventional “gotera,” (39%) while the improved storage methods, metal silo, (< 1 percent) was the list preferred (Table 5). The later may be due to its cost and accessibility implications. Similar survey study conducted on major food crop producing areas of Ethiopia identified traditional stores including, gotera (grain pits), bags (made of polyethylene, sisal or goat skin), earthen pots and some others [26]. According to this study, more than 70% of the respondents store their crop products in polyethylene bags and sacks followed by the traditional gotera (67.8 %) in which the later is mostly preferred to store large quantity for longer period of time (Table 2).

Table 2. Post-harvest storage methods in Ethiopia expressed as % of the total number of storage methods used for each cereal type.

S.No	Type of structure	Respondents (%)	Grains sored (%)	References
1	Bags	70.5	46	[2],[26]
2	gotera	67.8	39	[2], [26]
3	pots	9.4	NA	[37]
4	underground pits	0.3	NA	[26],
5	Metallic silo	NA	<1	[2]
6	Others	19.1	14	[2],[26]

NA= data not availabale;Source (analyzed by the author)



Figure 1. Large traditional underground pit for sorghum in Fedis, Ethiopia. Source; taken from FAO, 2017 [36]

To conclude, even though there are many storage technologies available for different grains, the choice of the specific technology could depend on different factors including the scale of production, crop type, prevailing climatic conditions, duration of storage time, the farmers' ability and willingness as well as the price affordability to buy or implement the storage structure for a given quantity of crop produces. Therefore, based on those and other factors which could potential affect the capacity of safe storage, extensive research works to improve the capacity and efficiency of the widely used traditions storage structures as well as providing improved technologies to the community could enhance the post-harvest management approach for a given crop under specific storage conditions.

4.3. Botanical Control

Plant products are seen to be effective and suitable for smallholder farmers to protecting stored grain from insect damage. Treatment with leaves of *Eucalyptus globulus*, *Schinese molle*, *Datura stramonium*, *Phytolacca dodecandra*, *Lycopersicum esculentum*, *Milletia ferruginea*, mexican tea powder, triplex, filter cake and neem seed were observed to cause high adult weevil mortality, reduced progeny emergence and low grain damage of *S. zeamais* [27,28,29,30]. In a study on, "Management of Adzuki bean beetle (*Callosobruchus chinensis* L.) suing botanicals, inert materials and edible oils in stored Chickpea" traced out that, *Chenopodium ambrosioides* caused a high adult mortality while, the use of *Brassica juncea*, *Linum. usitatissimum* and *Guizotia abyssinica* seed oils at rate caused reduction in progeny emergence [29]. Study conducted for determining the effective doses of Neem seed powder, citrus peel powder and their oil extracts for their resistance to maize weevil on Sorghum varieties found neem seed oil (NSO) and citrus seed oil (CSO) caused adult weevil mortality in the range of 91.25-100% and seed protection of 83-100% [Table 3]. For the same botanical oil rates, the study also revealed that, weevil emergence; seed damage and weight losses were statistically at par with the synthetic insecticide (Table 5). Similarly, Beans treated with sun-dried powder of orange peel and essential oil killed 65% and 67% of *Z. subfaciatus* after 96 hours respectively [31].

Table 3. Effect of NSO and CSO on weight loss, damage and germination.

Treatment	Rate(ml or g/0.1kg)	Weight loss %	Damage %	Germination %
CSO	1.50 ml	0.3f	1.1f	70.3bc
	1.00 ml	1.6e	4.7e	73.3b
	0.75 ml	1.9e	5.6e	62.5bc
	0.50 ml	3.1	8.5d	64.8bc
	0.25 ml	5.9c	14.6c	65.8bc

NSO	1.50 ml	0.0f	0.0g	59.8bc
1.00 ml		0.0f	0.0g	73.8b
0.75 ml		0.3f	0.9f	77.0b
0.50 ml		7.6b	20.6b	55.8bc
0.25 ml		9.6a	25.5b	56.0cd
Malathion5% dust	0.05 g	0.0f	0.0g	92.3a
Acetone treated	2.00 ml	10.7a	31.9a	47.8c
CV	5.22	10.4	8.6	
SE	0.01	2.10	22.8	

Means in columns with same letter are not significantly different at $\alpha = 0.01$. Mean separation was analyzed by SNKT; CSO= Citrus Seed Oil; NSO= Neem Seed Oil; Source; Kifle et al [35]

Generally, this assessment study suggested that, the locally available plant products with insecticidal properties are playing a vital role in controlling storage pest damage under different conditions, hence, small- scale farmers could be encouraged to these locally available, biodegradable and inexpensive plant products for controlling the high infestation of storage pests. However, adequate information on formulation and application methods, possible residual effects, toxicity to non-target species and easy accessibility of those selected plant botanicals for their practical use against the target storage pests is necessary to provide to the target group.

4.4. Use of Inert Dusts

Inert substances such as wood ash, lime powder, sand and other mineral dust is a time-honoured practice used for storing grains and seeds. Reports on efficacy of different inert dusts, indicated that that use of Silicosec at 0.1% w/w, filter cake at 1% w/w, wood ash at 2.5 to 10% w/w and sand at 30% - 70% were suggested as an alternative options for minimizing the damage of maize weevil in storage condition (Table 4). Similarly, coffee husk and wood ash at different rate was also showed a good effect against the maize weevil [32]. An experiment done on grain wheat treated with ash and sand showed less grain and weight loss by *Sitotroga cerealella* and *Tribolium* spp. than the untreated grains [16]. A test conducted at Gambella region also indicated significant effect of wood ash on managing bruchids on cowpea and 90% reduction in F1 progeny of *C. chinensis* [33]. Similarly, cotton and Ethiopian mustard seed oils exhibit strong toxic activity against Angoumois grain moth under laboratory experimental condition [34]. To conclude, the increasing side effect associated with the use of synthetic chemicals against stored product insects necessities the development of safe repellents against product pest. While the various inert dusts like wood ash and various admixed crops offered effective protection against insect pests in storage, the need to use inert dust in large quantities causes some difficulties. Therefore, attention should be paid to alternative materials that might be effective at acceptably lower rates.

Table 4. Main effects ($\pm$ SE) of inert dust (Silicosec, filter cake, and wood ash) and their rates on percent mortality of adult maize weevil 3, 7 and 15-days after exposure.

Main effect	Inert dust/rate (% w/w of grain)								
	Silicosec rates			Filter cake rates			Wood ash rates		
	0.05	0.1	0.2	1.0	2.5	5.0	2.5	5.0	10
3-days after exposure									
Rate	98.8 $\pm$ 1.3a	99.1 $\pm$ 0.4a	99.5 $\pm$ 0.9a	87.4 $\pm$ 2.4c	92.3 $\pm$ 7.8bc	97.8 $\pm$ 7.5a	65.0 $\pm$ 6.9f	73.2 $\pm$ 12.7ef	79.6 $\pm$ 5.5de
Inert dust		99.1 $\pm$ 0.43a			92.5 $\pm$ 1.58b			72.6 $\pm$ 3.29c	
7-days after exposure									
Rate	99.4a	100a	100a	95.8 $\pm$ 0.67ab	98.5 $\pm$ 1.33ab	99.6 $\pm$ 4.22a	84.7 $\pm$ 6.57c	89.0 $\pm$ 8.04c	93.7 $\pm$ 5.22c
Inert dust		99.8a			97.9 $\pm$ 0.64b			89.1 $\pm$ 1.61c	

15-days after exposure									
Rate	100	-	-	100a	100a	100a	97.6±1.1 1b	99.3±2.0 ab	99.3±0.6 7ab
Inert dust		100			100a			98.7±0.3 7b	

Means with the same letter in a row are not statistically significant at $p < 0.05$. “-” Data not available as all treated insects died. Source: Girma et al. [11]

4.5. Resistant varieties

Different storage pest species react differently to different crop varieties for feeding and reproducing. Experiments conducted with hybrid maize varieties showed different levels of resistance to maize weevil and large grain borer [10]. In this case, maize genotypes such as AW8047, INT-A, Pob-62TLWF-QPM, TUXEPENO C6, USB, and Golden Valley were reported comparatively resistant to the maize weevil and these technologies can be used by the resource-poor farmers [10]. Maize varieties with tight and complete husk cover was selected by most farmers for its advantage to protect filed infestation of the grain better than those with bare tipped ears [35]. Similarly, significant differences in storage resistance of haricot bean varieties to insect pests was also reported [36]. Likewise, based on dobie susceptibility index and the selection index, 21 maize varieties were recently tested for resistance to maize weevil in the Bako Agricultural Research Center and the results of this study indicated that, based on the selection index, 6 were classified as resistant, 5 were rated as moderately resistant and 8 were rated as moderately susceptible [37]. Currently, one weevil-resistant maize variety has been released by the National Maize Research Center [37]. In this approach, it is important to note that, for effective use of resistant varieties against storage pests, use of Marker Assisted Selection (MAS) methods can enhance the speed of resistant cultivars developments. Therefore, these developed resistance varieties could be implemented as a cheap and ecologically sound method to reduce the post-harvest loss along the storage time of the grains. In addition, the resistance varieties can be also used as important component of an integrated pest management strategy against storage pests.

4.6. Use of Entomopathogenic Fungi

Currently, many farmers and growers in the developed countries are familiar with the use of predators and parasitoids for biological control of arthropod (insect and mite) pests, but it is also possible to use specific microorganisms that kill arthropods. These include entomopathogenic fungi, nematodes, bacteria and viruses. There are about 750 species of fungi that cause infections in insects or mites [38]. As a group, they attack a wide range of insect and mite species, but individual species and strains of fungus are very specific. Different experimental results in Ethiopia indicated that isolates of the two most common entomopathogenic fungi, *Beauveria bassiana* and *Metarhizium anisopliae*, showed a significant difference in mortality, survival time for a number of pests including sesame seed bug, and maize weevil (Table 5). Efficacy of 13 isolates of entomopathogenic fungi (*Beauveria*, *Metarhizium* or *Paecilomyces* spp.) was assessed against *Sitophilus zeamais* and *Prostephanus truncatus* using a total immersion bioassay technique in the laboratory [39]. The obtained result that all isolates tested were virulent to *P. truncatus* (98-100% mortality) while *Metarhizium anisopliae* and *B. bassiana* were virulent to *S. zeamais* (92-100% mortality); isolate of *Paecilomyces* sp. was found to be the least virulent against *S. zeamais* (26.32 ± 4.29% mortality). However, the pathogenicity and virulent level varies with the concentration and strain of the isolated tested [39]. According to this study, *P. truncatus* was proved more susceptible to the entomopathogenic fungi tested than *S. zeamais* under Ethiopian condition.

In general, farmers and growers are under immense pressure to reduce the use of chemical pesticides. As result, looking alternative control methods against storage pests

are needed. In this case, the research outs assessed so far can indicate , using research based entomopathogenic fungi could be a promising alternative method to control pests of stored-products under specific storage condition. Besides, this method could be also incorporate as part of the Integrated Pest Management (IPM) strategies.

4.7. Integrated Pest Management (IPM)

Integrated pest management emphasizes the integration of disciplines and control measures such as varietal resistance, cultural methods, physical control, insecticidal plants, natural enemies, and pesticides into a total management system to prevent pests from reaching damaging levels. However, only some report on integrated management of post-harvest pests in Ethiopia has been available so far. In Ethiopia, integrated use of varieties, chenopodium plant powder, botanical triplex, silicoses and filter cake against maize weevil was reported [29]. Generally, because of costs and feasibility implications to use specific control methods, none of the various methods listed above can ensure safe storage. Hence, it is very important to integrate the available pest control methods including, resistant genotypes, biological control, cultural methods, and other non-polluting methods, in order to achieve an economical and sustainable post-harvest loss management approaches.

5. Conclusion

The issue of post-harvest losses is the primary agenda in an effort to improve food security mainly in the low-income countries of the world including Ethiopia. Many important storage pests have been identified with regard to the major food and exports in Ethiopia and the losses incurred by these pests have been identified and documented. The effectiveness of the post-harvest management options now available for Ethiopia's key food and export crop pests was evaluated. However, based on the information that is currently available, it is challenging to rank those various storage pest management techniques. Cultural techniques, the use of various locally accessible botanicals, varietal tolerance, various storage structures, and several significant entomopathogenic fungi are among the most often utilized strategies discussed here. Although the majority of the research findings covered in this study consist of fundamental knowledge rather than ready-made technologies, the current technologies can still be used with a few minor alterations. For instance, the traditional subterranean pits can be slightly altered to prevent moisture, so controlling the growth of mold and lowering the risk of storing pests. A further key factor in preventing field infestation and lowering insect loads in storage environments is the direct use of the specified resistant types. Several herbal remedies have also been successful, allowing farmers to use them right away. Last but not least, it's critical to highlight the integrated pest management system's viability and effectiveness as a strategy for long-term storage of grains and seeds under a variety of circumstances.

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