Assessment of Maize Grain Storage Practices and Pests in Baka Dawula Ari District, South Omo Zone, Southern Ethiopia

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Office of Graduate Studies

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Assessment of Maize Grain Storage Practices and Pests in Baka Dawula Ari District, South Omo Zone, Southern Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Assessment of Maize Grain Storage Practices and Pests in Baka Dawula Ari District, South Omo Zone, Southern Ethiopia**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation

Sisay Girma

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RECOMMENDATION OF ADVISOR

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Assessment of Maize Grain Storage Practices and Pests in Baka Dawula Ari District, South Omo Zone, Southern**" prepared under my guidance by Sisay Girma Abebe submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Applied Biology (Applied Entomology). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr.Ofgaa Djirata

Major Advisor	Signature	Date

APPROVAL OF ADVISOR

I, the advisor of the thesis entitled "**Assessment of Maize Grain Storage Practices and Pests in Baka Dawula Ari District, South Omo Zone, Southern Ethiopia**" and developed by Sisay Girma Abebe, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr.Ofgaa Djirata

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APPROVAL OF BOARD OF REVIEWER

We, the undersigned, members of the Board of Examiners of the thesis by Sisay Girma Abebe have read and evaluated the thesis entitled "Assessment of Maize Grain Storage Practices and Pests in Baka Dawula Ari District, South Omo Zone, Southern Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Applied Biology (Applied Entomology).

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LIST OF ACRONOMYS

FAO- Food and Agricultural Organization of the United Nations

CSA- Central Statistical Authority

SSA- sub-Saharan African

SNPPR- Southern Nations, Nationalities, and Peoples' Region

ANOVA- Analysis of Variance

SAS- Statistical Analysis System

LSD-Least Significant Difference

SE- Standard Error

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Abstract

Maize plays a significant role in human nutrition in general and serves as a staple food in most parts of Ethiopia. However, maize crop in storage is constrained by a variety of pests in Ethiopia and other sub-Saharan African countries. This study was aimed at surveying the traditional maize storage practices and the efficacies of the storage structures in protecting the crop in the storage and investigating the species composition of relevant pests in selected Kebeles of Baka Dawula Ari District in southern Ethiopia. The study was conducted in four purposively selected Kebeles. A total of three maize cobs were taken from each type of storage structure in three replications from every study Kebele. The associated pests were collected from the samples, identified and their abundances were determined. Data on the efficacy of the storage practices, the level of the maize grain damage, and the weight loss were analysed by Proc ANOVA of SAS software (version 9). It was found that the levels of maize grain damage and loss were significantly different ($p<0.05$) among the storage structures in such a way that hanging over smoke was known to be the most effective in protecting the maize grains against pest attack. Likewise, the level of maize grain infestation varied significantly ($p<0.05$) among the study Kebeles in general, in which Bako Kebele exhibited a minimum level of pest infestation. The pest species found infesting the maize grain were members of the order Coleoptera and Lepidoptera with an Acarine species and an unidentified mold. The Larger Grain Borer, Prostephanus truncatus was found damaging the maize grain severely. P. truncatus was recorded infesting crops in Ethiopia for the first time. It is concluded that maize grain is severely damaged in the storage, mainly by the coleopteran pests already known to be cosmopolitan in Ethiopia. The introduction of the new pest may further exacerbate the already serious maize storage pest problem. It is recommended that intervention of the extension workers to introduce modern practices of maize grain storage facilities and management shall be implemented in addition to encouraging the use of smoke as an indigenous technique by the local people. Further study on the geographical distribution of the Larger Grain Borer and awareness creation about this newly introduced pest is also recommended.

Key words: Infestation, maize grain, pest, smoke, storage

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Cereal crops in general and maize (*Zea mays* L.) in a particular play, a significant role in human nutrition as food and also serves as feed for domestic animals (Bucklin *et al*., 2019). Maize is a member of the grass family, Poaceae (Gramineae). Maize is mainly grown for its grain, which is utilized for human consumption and forms about 50 - 70% of the constituent for livestock feeding (Longe, 2010). Maize is also known as the king of cereals because of its high-yielding potential (Nand, 2015). It is one of the major staple crops that provide energy for consumers, and also serves as a source of income. Besides it is the major staple food in Africa, contributing significantly to the agricultural sector (Tadele Tefera *et al*., 2011). In addition, it serves as a raw material for the production of starch, oil and protein, food sweeteners, alcoholic beverages, and more recently, fuel (FAOStat, 2021).

The world maize area amounts to 197 Million hectares, including substantive areas in sub-Saharan Africa (SSA), Asia and South America (Erenstein *et al*., 2022). Maize is the first cereal crops grown in over half of the countries in SSA, and one of the top two cereals in over three-quarters of these countries (Cairns *et al*., 2021). In Ethiopia, maize has a significant share among cereal crops in terms of production, productivity, distribution and adaptation (CSA, 2021). Among all cereals, maize is next to teff (*Eragrostis tef*) in area coverage with 2.5million ha (19.46% area allocated to all cereals) of land planted to maize; but first in productivity 4.6 tons per hectares with total annual production of 11.64million tons (CSA, 2021). In Ethiopia, maize is one of the major cereal crop grown for its food, feed, firewood and construction purposes (Waktole Sori, 2014; Tsedeke Abate *et al*., 2015).

The recent volatile food market and rising prices for most food crops may increase the importance of maize production. In addition, because of its productivity and wide adaptation, maize remains an important source of food with great potential to improve the livelihoods of most poor farmers in developing countries. But, its productivity is low due to several constraints; biotic and abiotic stresses.

The biotic constraints include insect pests, diseases, and weeds while the abiotic constraints include lack of farm inputs such as certified seeds, fertilizers, and chemicals, high prices of farm inputs, and high cost and unavailability of farm labor (Pingali & Pandey, 2001).

Post-harvest losses of food grains due to insect pests and mycotoxin contamination pose significant nutritional and economic losses to subsistence farmers in developing countries. The lack of improved storage structures for grains and the absence of storage management technologies force maize growers to sell their products immediately after harvest. Consequently, farmers receive lower market prices for the surplus grain they produced (Firdissa Eticha & Abraham Tadesse, 1999). Because of the great value of maize greater attention should be given to the crops during storage to make them available for use throughout the year (Longe, 2010).

The stored maize is attacked and damaged by several pests that lead to quality deterioration. Insects are most often considered the principal cause of maize grain losses (Abraham Tadesse, 1996; Khosravi *et al*., 2007; Alam *et al*., 2014). The most important insect pests that cause damage to maize in the field and storages are Lepidopterous stalk borers and Coleopterous weevils, respectively (Alam *et al*., 2018).

Storage is predominantly important in agriculture because agricultural supplies are required throughout the year but harvesting is limited with seasons. In these circumstances, storage is very important to meet average demand by storing excess supply during harvesting season for gradual release to the market during the off-season (Adejumo & Raji, 2007). Grain storage options include indoor, outdoor, and subsurface levels (Channal *et al*., 2004). Cereal crops in general and maize in particular are susceptible to infestations by a variety of stored product insects, such as weevils, when they are in storage (Fantu Bachewe *et al*., 2018).

As a result, there is an urgent need to maintain the quality of stored grains such as maize through proper management of stored grain insect pests (Upadhyay & Ahmad, 2011). There are not enough documents of studies regarding the traditional storage methods and practices that farmers use to protect stored maize against the respective pests, and related species composition, and status of insect pests of the stored maize grain and the associated damage and losses caused to the crop in the study area.

Therefore, this study is planned to find out efficient storage structure of maize grain against the respective pest, identifies the species, and the associated damage and losses by the pests for the sound management of the pests in the study area

1.2. Statement of the problem

Improving agricultural output and lowering crop losses in the field and after harvest could lead to increased food security. In most places, crops are grown seasonally and after harvesting, grains are stored for short or long periods as food reserves, and as seeds for the next season. As a result, it is crucial to store crops for future use (Thamaga-Chitja *et al.*, 2004). In addition to directly destroying grains through feeding and reproduction, the presence of pests has also had a direct impact on grains by raising the grain temperature and moisture levels. These cause the respiration rate to increase, resulting in a loss in grain quantity and quality. Grain damage by storage pests ranges from mild to severe post-harvest loss, which has been identified as a significant limitation. The post-harvest loss due to storage insect pests has been recognized as an important constraint, with grain damage ranging from 20-90% being reported for stored raw/untreated seeds (Tadele Tefera *et al.*, 2011).

Farmers and traders are also impacted by the irreparable harm. Adult weevils and larvae were internal feeders on the maize grain, which has an impact on seed viability and small-scale farmers' capacity to successfully plant their crops. Due to inadequate infrastructure, the greatest amounts of losses occur while harvests are stored.

In Ethiopia studies on grain storage practices and associated storage pests were limited to certain parts of the country. Information on the efficacy of storage types of maize grain against storage pests in common traditional grain stores was lacking. The lack of information has made it difficult to design and implement intervention strategies in the area.

Across the study area maize grain is the primarily produced, source of income, and highly consumed crops by the local people. But the maize grain consumed by the local people is highly damaged by the pests qualitatively and quantitatively. Moreover, in the ware house of merchants' local people buy damaged or holed maize grain in low price relative to undamaged maize grain.

Larger grain borer (*Prostephanus truncates*) occurrence in Ethiopia was not known until 2008 (Abraham Tadesse *et al*., 2012). Its presence in Ethiopia was confirmed in 2009 through pheromone trap deployed at the Moyale Ethio- Kenyan border using pheromones obtained from the International Center of Insect Physiology and Ecology (ICIPE). However, according to Abraham Tadesse *et al*. (2012) the pest was not reported to be found in any of the grain samples obtained from different stores and market places in suspected areas in the districts of Moyale, Bulo Hora and Arsi Negele. Therefore, the current study was intended to find the clear infestation and damage of maize grain in storage by the larger grain borer.

1.3. Objectives of the study

1.3.1. General objective

To assess the maize grain storage methods and the species composition of storage pests damaging stored maize grain for a sound management of the pests.

1.3.2. Specific objectives

- To identify the maize grain storage practices
- To identify the storage pest species of maize grain
- To determine the level of maize grain damage by the pests in the storage
- To evaluate the efficacy of locally available storage structures against maize grain storage pest

1.4. Research questions

- Which structure is the most commonly used for maize grain storage in the study area?
- Which storage pest species infest stored maize grain in the study area?
- What is the level of damage caused by the storage pests to stored maize grain?
- Which storage method is the most protective against maize grain storage pests in the study area?

1.5. Significance of the study

This study will provide adequate information on the major types of storage pests that may damage the maize grain, and identify and document the most effective methods of maize grain storage practices that would help to control the related storage pests in the study area. The maize-producing farmers in the study area will benefit from the finding of this study as it will help them improve their maize grain storage techniques. Moreover, the district bureau of agriculture in particular, and the scientific community and related stakeholders, will benefit from data on efficacy of the storage structure of maize grain against the respective pest, and the associated damage and losses by the pests for the sound management of the pests obtained through this investigation.

CHAPTER TWO

LITERATURE REVIEW

2.1. Global maize production

Maize can be cultivated in a wide range of agro-ecologies, including various temperatures, altitudes and latitudes, land and soil types, though with quite different yields per hectares (ha) (Bellon *et al*., 2005). From FAOStat (2021) the global maize area is primarily located in the America (36.1%), Asia (34.1%), Africa (20.9%), and Europe (8.9%) area coverage.

America contributes half of the global maize production followed by Asia (32%) and the remainder primarily by Europe (11%) and Africa (Table 1). There is a substantive heterogeneity within each of the continent's regions. The maize area in the America is split between Northern America (mainly USA) and Central and South America. Some two-thirds of Asia's maize area is in East Asia (mainly China with mostly temperate maize, compared to mostly tropical maize in South and South-East Asia).

Table 1: Share of worldwide maize production by region

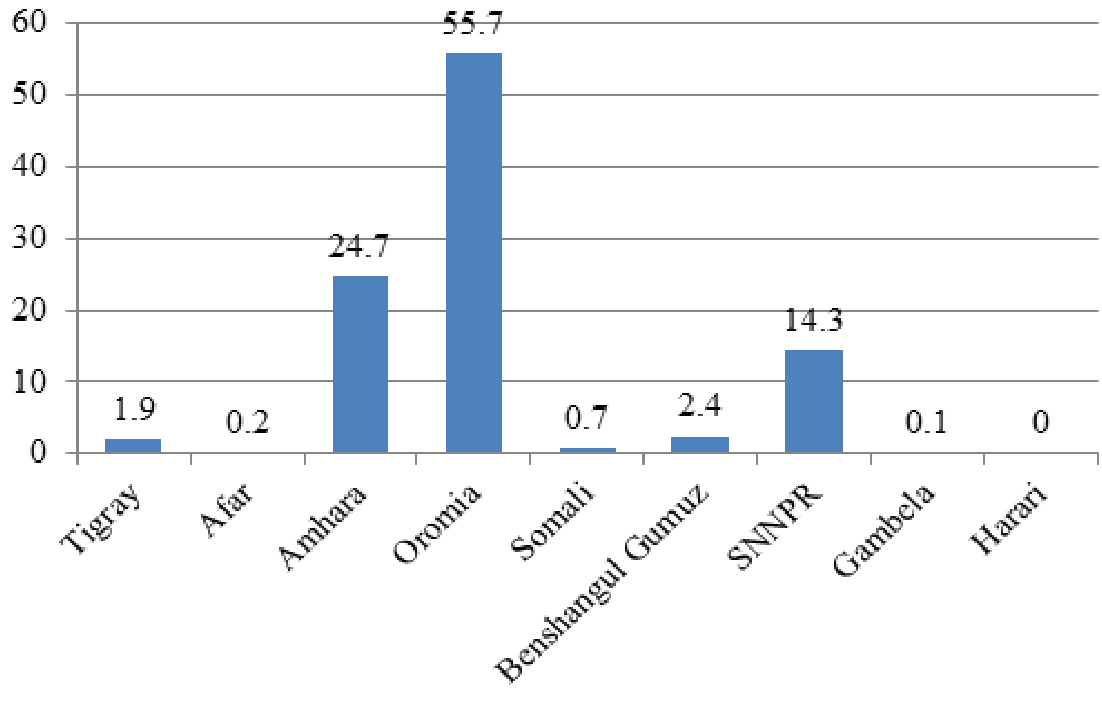
Region	**Productivity (%)**
America	49.6
Asia	32
Europe	10.9
Africa	7.4
Oceania	0.1
Total	100

Modified from (FAOStat, 2021)

Maize is the first cereal crop grown in over half of the countries in SSA, and one of the top two cereals in over three-quarters of these countries (Cairns *et al*., 2021). Because of its productivity and wide adaptation, maize remains an important source of food with great potential to improve the livelihoods of most poor farmers in SSA. Despite the importance of maize in SSA, yields remain low (Bekele Shiferawu *et al*., 2011) because of climate change and heavy postharvest losses.

Maize is an important crop for overall food security in Ethiopia. Regionally, maize is mostly grown in the south-western and western parts of Oromia, western and north-western parts of Amhara, parts of the Southern Nations, Nationalities, and Peoples' Region (SNNPR), and Benishangul-Gumuz regions. Available data shows that the Oromia regional state contributes half of maize production in the countries, while about one fourth of the maize comes from the Amhara regional state (CSA, 2018). Minor maize-producing regions include SNNPR, Benishangul-Gumuz, Tigray, Somali, Afar and Gambella as shown in (Figure 1). Over the last two decades, the maize sector in Ethiopia has experienced an unprecedented transformation. Maize yields have doubled from around 1.6 t/ha in 1990 to more than 3.7 t/ha in recent years, the highest level in sub-Saharan Africa after South Africa (FAO, 2019).

Important causes for the increased productivity include increased availability and use of modern inputs (e.g. modern varieties and Inorganic fertilizers), better extension services and increasing market demand (Tsedeke Abate *et al*., 2015).



Source: (CSA, 2018)

Figure 1: Maize production in Ethiopia by region

2.2. The economic importance of maize

Maize is very important because of a good source of minerals, vitamins, fibre, and oil present in maize (rich in embryo). This oil is used for cooking and soap-making companies. Maize starch is famous in pharmaceutical industries as a diluent and is also used in cosmetics. Its seeds are used to make alcohol while the stem is used for paper manufacturing.

Small-scale farmers are engaged with maize farming, because of its high nutritional value and affordable source of vitamins and minerals for people living in rural areas. Various local alcoholic drinks are prepared from maize. Maize grain is the third most consumed cereal as human food after rice and wheat (direct pathway, processed or unprocessed). Global human food consumption of maize amounts to 18.5kg/capita/year, 11% of the average annual cereal human consumption of 175kg globally (2014–2018), excluding beverages (FAOStat, 2021).

The use of maize as food is markedly more common in Low & Lower-Middle Income Countries (43% of production) and in Africa (54%), particularly in eastern and southern Africa (66%). Maize is consumed in 161 countries, with consumption levels exceeding 50 kg/capita/year in 22 countries, primarily in eastern and southern Africa (9 countries) and Latin America (7 countries) (FAOStat, 2021).

Generally, the majority of global maize production is used as livestock feed and a minor percentage for human consumption (Table 2). According to FAOStat (2021), maize plays a particularly important role as a staple food in the diets of millions of people in Africa, South Asia, and Latin America, whereas in Europe most maize is used as livestock feed.

Table 2: Global use of maize (average values of the years 2016 – 2018)

Global use	Amount in (%)
Feed	61
Bio fuel use	17
Food	13
Other use	9
Total	100

Modified from (FAO, 2019)

Maize is critical for food security in Ethiopia. More than 9 million smallholders grow maize on about 2 million ha (14% of the total land area in Ethiopia) and around 88% of their production is used for food consumption (Tsedeke Abate *et al*., 2015). In terms of calorie intake, maize is the most important staple crop for the rural, Ethiopian population (Guush Berhane *et al*., 2011).

2.3. Maize production and associated constraints

Maize yields have been on the decline as indicated by the yield gap between experimental research station plots and average yields that farmers typically realize on their farms (De Groote, 2002). The decline in maize production is attributed to biotic and abiotic stresses. The biotic constraints include insect pests, diseases, and weeds while the abiotic constraints include lack of farm inputs such as certified seeds, fertilizers, and chemicals, high prices of farm inputs, and high cost and unavailability of farm labour (Pingali & Pandey, 2001).

However, drought and declining soil fertility are frequently cited as the most limiting factors to maize production and productivity in the semi-arid tropics (Diallo *et al*., 2002). Additionally, the major constraints of maize production and productivity in tropical countries including Ethiopia are the damage caused by insect pests and fungal infestation both in the field and in the storage.

Maize is attacked by many insect pests during all stages of growth from seedling to storage (Bekele Shiferaw *et al*., 2011). Insects and other pests are a major threat to maize production and are responsible for direct and indirect losses of maize on the farm and storage (Bankole & Mabekoje, 2004). Insects are responsible for 15-100% and 10-60% of the pre and post-harvest losses of grains in developing countries, respectively (Mihale *et al*., 2009).

2.4. Storage insect pests of maize

The stored maize is attacked and damaged by several pests that lead to quality deterioration forcing farmers to sell at reduced prices and below the production cost. Insects are most often considered the principal cause of maize grain losses (Abraham Tadesse, 1996; Khosravi *et al*., 2007; Alam *et al*., 2014). More than 37 species of arthropod pests are associated with maize grain in storage (Abraham Tadesse, 1996).

During the storage period, insect pests and diseases have been playing a significant role in reducing production and productivity coupled with germination potential (Mollah *et al*., 2016).

Two major groups of insects are economically important on stored maize grain: Coleopterans (beetles) and Lepidoptera (moths and butterflies) (Alam *et al*., 2018). Crop damage by Lepidoptera is only done by the larvae. In the case of Coleopterans, 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, i.e. those that 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 pests such as the grain borer and genus *Sitophilus.*

Crop losses and deterioration of product during storage are likely to occur unless adequate precautions are taken (Araya G/ Silassie, 2007). The common grain insect pests are; the lesser grain borer (*Rhyzopertha dominica*), maize weevil (*Sitophilus zeamais*), and red flour beetle (*Tribolium castaneum*) (Dowell & Dowell, 2017).

Additionally, *Sitophilus* (Curculionidae), *Tribolium* (Tenebrionidae), *Sitotroga cerealella* (Grain Moth), and Grain weevil *Sitophilus granarius* (L.) are primary storage pests in SSA (Dick, 1988; Holst *et al*., 2000). Above all of the earlier mentioned storage insect pests, in SSA, the chief grain storage beetle pest is the Larger Grain Borer (LGB) *Prostephanus truncatus* (Horn), (Bostrichidae), inborn in Mexico and Central America, which has been established in East and West Africa (Nyambo, 2008).

Maize weevil (*Sitophilus zeamais* Motschulsky Coleoptera; Curculionidae) is a major insect pest of stored maize and grain products in the tropics (Obeng-Ofori & Amiteye, 2005). The three main species attacking stored cereals are *Sitophilus oryzae*, *Sitophilus zeamais*, and *Sitophilus grannaries* (L). Although maize weevil is predominantly associated with maize, it can also breed on dried cassava and has alternate hosts like sorghum, rice, wheat, and other grains. The species has great ability and can therefore infest ripening crops in the field and establish in the grain before harvest (Haines, 1991). Maize weevil is an important post-harvest pest in stored maize, especially in the tropics (Victor & Ojaruega, 1993). The low presence of *Sitophilus zeamais* at the initial harvest stage and high infestation after several months of maize stocking (Tigar *et al*., 1994).

Infestation by the weevil commences in the field (Girma Demissie *et al.*, 2008), but most damage is done during storage.

The larger grain borer (LGB) *Prostephanus truncatus* is a member of the Bostrichidae (Coleoptera), or horned powder-post beetles, which is a group of primarily wood-boring insects. *P. truncatus* was first described as *Dinoderus truncatus* in 1878 by Horn. The Larger Grain Borer causes extensive damage to maize in storage and it leads to serious losses to many resource-poor farmers who store grains on farms for use as food and seed. *P. truncatus* is reported as a serious pest of maize on the cob in the field (with moisture content as high as 40-50%), in cribs/on platforms during drying, and in stores (Quellhorst *et al*., 2021). Prior to its spread into Africa, *P. truncatus* had already been known as a pest of field and stored maize in Mexico and parts of South America (Ramírez-Martínez *et al*., 1994). In addition, *P. truncatus* is an important pest of dried cassava (*Manihot esculenta*), including fermented and unfermented dried roots and bagged chips (Quellhorst *et al*., 2021).

2.5 Non-insect storage pests of maize

There is a group of pests other than insect pests, which cause considerable yield losses to stored crops, commonly called non-insect pests (Rodents, Mites, and disease from mycotoxin contamination). Bacteria prevalence in stored durable crops may be low. They may, however, invade an already damaged portion of the crop products during storage and their multiplications.

Rodents: pose a significant challenge in storage and, in some cases, they are the main storage problem (Brown *et al*., 2013; Mwangi *et al*., 2017; Edoh *et al*., 2018). The roof rat *(Rattus rattus*), the house mouse (*Mus musculus*), and the natal multimammate mouse (*Mastomys natalensis*) are the rodent species usually associated with postharvest losses in grain stores in East Africa (Makundi, 2009). However, attention to rodents seems to be minimal (Swanepoel *et al*., 2017). In Kenya, for instance, rodents contribute 30% of the total postharvest losses on maize stored in farmers' stores (Edoh *et al*., 2018) and 11% of the storage losses in off-farm stores (Mwangi *et al*., 2017). In the lowland tropical zone specifically, rodents are the greatest storage problem in on-farm stores, contributing 63% of their total postharvest losses (Edoh *et al*., 2018).

Fungi are well-known to cause a variety of deteriorating changes in grains and fresh produce, both before and after harvest (Sauer, 1988). It has been reported by many researchers that fungi grow faster under warm conditions than under cool conditions. The deterioration is increasing about 10 times faster at 25ºC than at 3ºC (Sauer, 1988; Suleiman *et al*., 2013). Storage duration and storage types play an important role and influence the aflatoxin contamination in maize. Several reports indicated that mycotoxins are common contaminants of stored maize in sub-Saharan Africa (Probst *et al*., 2014). Proper initial drying and subsequent moisture-proof storage are crucial in minimizing the growth of toxigenic fungi and toxins development (Bradford *et al*., 2020). However, in Africa, many factors include environmental conditions, pest infestation, pre and postharvest handling, influence of infection of stored products by toxigenic fungi, and contamination of maize by mycotoxins. Because of the traditional post-harvest practices and the prevailing environmental conditions in Ethiopia, the risk of maize grain contamination with fungi is expected to be high.

Mites are the predominant biotic factor that reduces the quantity as well as the quality of stored grains. Under favorable conditions, mites, and insect pests can reduce global grain production by up to 9 % (Rahman *et al*., 2009). Mites are members of the Phylum Arthropods, Class Arachnids, and Subclass Acari. The majority of mite species found infesting stored food belong to the order Astigmata, and among the most economically important Astigmatic mites, the family Acaridae includes several species commonly found in a wide range of food products (Hughes, 1976). It is very problematic to detect their infestation in stored grain due to their microscopic size (Palyvos, 2017). Storage mites can be found wherever their living conditions are ideal, which includes micro climatic environmental factors such as temperature and relative humidity. Up to 30 generations can be produced annually under ideal conditions for rapid development, including 25°C ambient temperature and 90% relative air humidity. At less than 60% relative air humidity, they are practically unable to develop (Sánchez *et al*., 2017).

Infestations of stored grains by these storage mites cause three types of harm which include firstly damage to human health by contaminating food with allergens (Olsson & van Hage-Hamsten, 2000; Stejskal & Hubert, 2008). Second, as vectors of toxic fungus, these mites indirectly contribute to mycotoxin contamination of food and feed (Hubert *et al*., 2004). Third, mites reduce grain weight and germination ability (ŽĎárková & Reška, 1976).

Thus storage mites are becoming more important because of their increasing prevalence and interaction with fungi and insects, leading to the serious qualitative and quantitative deterioration of grains.

2.6 Crop storage

Crop storage plays a major role in supplying food. In most places, crops are grown seasonally and after harvesting, grains are stored for short or long periods as food reserves, and as seeds for the next season. According to Grover & Singh (2013), in developing countries such as India, about 50 – 60% of the cereal crops are stored in the traditional facilities at the household and farm level for consumption and for next season planting. The indigenous storage structures are made of locally available materials (grass, wood, mud, etc.) without any scientific design, and cannot guarantee to protect crops against pests for a long time.

Estimated losses as high as 59.48% in maize grains after storing them for 90 days in traditional storage structures (Granary/Polypropylene bags) (Costa, 2014). Storage losses can be classified into two categories: direct losses, due to physical loss of commodities; and indirect losses, due to loss in quality and nutrition. It is important to consider both damage and losses by the insects during storage. "Damage" can refer to physical evidence of deterioration, for example, holes in the grains. It mainly affects the quality of grains. "Loss", on the other side, is the total disappearance of the food, which can be measured quantitatively (Boxall, 2002). The loss in quality results in a value loss of the product, and sometimes leads to total market rejection also. The rejection rate depends upon the individual's economic status and cultural background. For example, a subsistence farmer may consume the damaged food to some extent, whereas wealthy consumers may reject even slightly damaged food.

The storage losses are affected by several factors, which can be classified into two major classes: biological conditions (insect pests, rodents, fungi) and physical conditions (temperature, humidity, rain) (Abedin *et al*., 2012). Moisture content and temperature are the most crucial factors affecting the storage life. Most of the storage molds grow rapidly at temperatures of 20 – 40^0C and relative humidity of more than 70% (Abedin *et al*., 2012). Low moisture keeps the relative humidity levels below 70% and limits mold growth.

In the traditional storage structure, temperature fluctuations due to weather changes cause moisture accumulation either at the top or bottom of the grains' bulk depending on the direction of air convection. This can be avoided by minimizing the temperature difference inside and outside the storage structure. Grains should be dried to about 13% of the moisture content before storage to minimize the losses. The quality of grains before storage is another critical factor affecting storage losses. Mechanical damage during harvesting and threshing can result in bruised areas on grains, which may serve as centres for infection and cause deterioration (Shah, 2013). The criticality of a factor depends upon the storage conditions.

In most developing countries, especially in Africa and South Asia, grains are generally stored in bulk or bags in simple granaries constructed from locally available materials (straw, bamboo, mud, bricks). Mud bins and pots, *bokharies* (straw structure), and plastic containers are common storage structures in Asia (Baloch, 1999). Gunny bags and Plastic/Polythene bags are commonly used for short-duration storage, and Steel/Plastic drums are used for long-duration storage. Various types of granaries are used in African countries.

In the house-smoked storage method, maize is stored within the dwelling in a space between the ceiling and roof over the cooking spot to receive the heat. In West Africa, grains are commonly stored in the home or field in jute or polypropylene bags, raised platforms, conical structures, and baskets (Hell *et al*., 2000; Abass *et al*., 2014). In East and Southern Africa, farmers use cow dung ash in small bags, wood cribs, pits, iron drums enclosed with mud, and metal bins for storing the grains (Wambugu *et al*., 2009). "*Nkokwe*" is one of the most commonly used storage structure used in Malawi and Kenya. This is a kind of cylindrical basket made up of interwoven split bamboo and covered with a conical-shaped roof of grass. The structure is raised off the ground on stilts (Schulten, 1982). Most of these structures are not scientifically designed and are made from locally available materials, and cause damage to stored grains due to biological, environmental, and other factors.

2.6.1. Ethiopian traditional maize storage

Storage plays an important role in postharvest food supply chains in Ethiopia, like in other African countries. Small-holder farms in Africa usually store their produce for home consumption or as seed until they sell it in local markets (Kumar *et al*., 2007). Various studies conducted in Ethiopia showed that farmers use different traditional storage containers (Abraham Tadesse and Basedow, 2004; Adugna Haile, 2006). There are different forms of traditional storage structures, generally made of locally available materials such as bamboo split, wooden walls, mud, and thatched grass roofs.

Underground storage (Pit)

Underground pit grain storage is common in dry lands of Ethiopia where there is a shortage of wood and other materials for the construction of above-ground storage bins, grains such as sorghum and maize are stored underground in some parts of Ethiopia, but it is unusual for teff to be stored in such pits (Boxall, 1974). The pit gate is covered with a combination of locally available materials such as strips of timber, stone, soil, animal dung, and mud (Mashilla Dejene, 2004).

It can be constructed outside or inside of farmers' houses. Farmers have different criteria that they use to select a place to make storage pits. These include closeness to residences; choice of a more raised place to avoid leakage or percolation of moisture during the rainy season; soil type and property (Negussie Efa *et al*., 2005). The average capacity of pits in East and West Hararghe Zones of Oromia Regional State varied from 0.4 to 3.08 tons (Mashilla Dejene, 2004). In Hararghe about 70-75% of the farmers used underground storage pits exclusively and 8-12% used it in combination with other storage methods (Boxall, 1974).

Farmers justified that underground pit storage can protect the grain from fire, theft, insect pests, and domestic and wild animals. Indigenous underground pit storages are considered as cheap and cost-effective for storing grain for consumption (Abraham Mulu & Zelalem Belayneh, 2016)**.** Low cost of a pit dug or preparation was the major reason for choosing underground pit storage in areas where wood for aboveground bin construction was not available According to Mashilla Dejene (2004).

Above ground traditional storage structure

Gombisa (Gotera): *Gombisa* and *Gotera* are the same. *Gombisa*' in Afan Oromo and *Gotera*' is in Amharic. Studies conducted in various parts of Ethiopia indicated that *Gombisa* is one of the most common maize storage structures used by the majority of farmers across all agro ecological settings (Abraham Tadesse & Basedow, 2004).

Gombisa is an above-ground cylindrical shaped traditional storage bin used to store maize cob. It is a type of circular granary, made by interweaving locally available materials; mostly bamboo split by local artisans. It is an outdoor container made from split or whole bamboo poles or other plant sticks and its roof is thatched by dry grass/hay or corrugated iron sheet and usually raised off the ground on stones or a wooden platform.

The constructions of *Gombisa* differ according to locally available materials and traditions. The size of a *Gombisa* can vary depending on the volume of production, and the capacity is usually between one and four tons. *Gombisa* is used for the storage of shelled grain and maize on the cob. Plastered *Gotera* is used for shelled maize while without plastering is used for storage of unshelled maize.

Gumbi, Gota, Dibignit, Godo,* and *Gushgush are names given to similar types of containers (capacities may vary) in different parts of the country. *Gumbi* is a structure made from short cylindrical ring structures constructed from a mixture of mud reinforced with straw and fixed into one another using mud as a mortar to make a bigger container (Hengsdijk & de Boer, 2017)**.** It is used almost exclusively for the storage of shelled grain (Boxall, 1998). Their sizes vary, and they are usually kept indoors.

Kefo, Togogo, or Kirchat*:* are also similar to *Gumbi* but these are usually made up of split reeds, bamboo, or twigs, may be plastered with cow-dung from inside, and are kept indoors or outside abutting on the wall of the house (Abraham Tadesse *et al.*, 2006).

Bags and Polypropylene Sacks: Bags are flexible to store different types and different quantities of seed, the commodity can easily be removed for consumption, and the stores can be easily inspected. In Ethiopia and other African countries, the use of bags has been reported as the main storage container (Fantu Bachewe *et al*., 2020), which might be due to availability in the local market and cost. A polypropylene Sack is the other type of storage container to store shelled maize after treating it with either traditional or modern pesticides.

2.6.2 Traditional storage management practices

The grain borer and maize weevil in general results in ∼40% grain loss as they are most dangerous (Midega *et al*., 2016). To reduce the problem farmers use various techniques to minimize and avoid storage losses. The preference of farmers to select given techniques is based on the locally available materials, ease of use, effectiveness to control, and affordability of the price of the methods.

Cultural practice

Separation of apparently damaged and infested grain from the rest of the harvest is a common practice to reduce pest infestation. Rapid harvesting, separation of uninfected and infected grains, proper drying before storage and storage hygiene are the most important cultural practices reported for the management of storage pests (Abraham Tadesse & Firdissa Eticha, 1999). In South-western Ethiopia storage hygiene, exposing grain to the sun, treatment of grains with cow urine, and admixing with salt are frequently used cultural practices (Mendesil *et al*., 2007). Exposures to sunlight followed by sieving of the grains usually at monthly intervals are also well-known techniques among farmers and create an unfavourable environment for weevils. Farmers treat their maize seed by drying the seed before storing it and cleaning storage structures if the same previous storage was used (Girma Beriso, 2018).

Wood ash has been used since time immemorial as a botanical pesticide against maize storage insect pests. The abrasive nature of the ashes may desiccate the pests. Ash contains silica, which interferes with insect feeding and hinders fungal pathogen multiplication. Ash dust reduces the relative humidity of the storage condition and dries the seed surface. Egg laying and larval development of the storage pests could be hampered because ash dust covers the grain seeds (Karabhari Rekha Bhaskar & Kunde Padmakar C, 2014). Mixing ash with grain makes the entry of insects into grain a difficult task and causes physical and physiological injuries to the insects. As a result, the use of locally available Botanicals for stored-product protection is a common practice and has been believed to have more potential in subsistence and traditional farm storage conditions in developing countries like Ethiopia (Daniel Obeng-Ofori, 2008).

Mixing with sand and dust

Inert dust is chemically unreactive and thus, used for protecting insects from stored grains by physical means (Abd El-Aziz, 2011). Inert dusts act as a desiccant, absorbing water from the insect body, and may have an abrasive action. Water is lost because the dust removes the waxy layer of the cuticle of the exoskeleton by adsorption. Accordingly, insect pests coated with inert dust show massive dehydration and die very soon (Dhineshkumar *et al*., 2017). The use of chemically inert materials such as sand, wood ashes, or minerals in large amounts fills up the interstitial space in grain bulks and offers an obstacle to insect movement.

Treatments of local inert dust applied at the rates of 5% and 10% induced significantly higher protection of maize against maize weevils. Thus, this inert dust could be used in the management of maize weevils as a safe, ecologically sound, and cheap management alternative to synthetic chemicals under subsistence farmer's storage conditions in Ethiopia (Ali Mohammed & Abraham Tadesse, 2018).

Hanging over fire (Smoking)

Smallholder farmers usually store food grain crops above the kitchen fire in the farm hut or in the open where the high temperature due to direct solar radiation may also kill the developing larvae in the seeds. Farmers in most parts of Ethiopia, commonly hang heads of grain such as sorghum, barley, wheat, and cobs of maize mainly selected for seed from the where heat and smoke from the fire promote further drying and, possibly reduce insect infestation. Farmers believe hanging on fireplaces is keeping seed quality (Girma Beriso, 2018). Some farmers kept maize cobs over fires, especially those meant to be stored for longer periods such as seed for the following cropping season; these cultural grain preservation methods are common in eastern Africa (Tsedeke Abate *et al*., 2000). Farmers suspend a bunch of cobs in smoke over the fire and such stored maize was less damaged. Traditionally, smoke is used to minimize insect damage as well as to reduce the moisture content to a suitable level.

Storing unshelled maize

Maize cobs that are fully covered by the intact husk are less infested than those whose tips are slightly exposed (Ivbiljaro, 1981). Farmers believed that storing maize in grain form increases the susceptibility of the products to pest attack, especially in polypropylene bags, and storing maize in unshelled form with the husk intact can minimize pest attack (other than larger grain borer) (Midega *et al*., 2016).

2.6.3 Losses of maize in traditional storage structure

Many insect pests attack maize during all stages of growth from seedling to storage. However, a high percentage of post-harvest loss of maize is associated with storage pests. Approximately 30% of the losses in maize grains in Africa are a result of postharvest insect pests, which cause nearly 40% weight loss in maize (Boxall *et al*., 2002; Tadele Tefera *et al*., 2011). Estimates of loss up to 59.5% in maize grain after storage for 90 days in traditional storage structures (grain/ polypropylene bags) (Costa, 2014).

Insect attack has been reported to contribute significantly to the loss of maize grains. Traditional storage facilities may predispose the grain to different deterioration agents and cannot guarantee the protection of stored grains for longer durations (Kumar & Kalita, 2017) thus, such grain losses are considered as one main cause of food insecurity for smallholder farmers in developing countries (Manandhar *et al*., 2018). This suggests a need for improved storage systems such as hermetic silos, and Purdue Improved Crop Storage (PICS) bags, which help reduce grain storage losses and maintain grain quality (Kumar & Kalita, 2017). Similarly, studies by (Olayemi *et al*., 2012; Agada & Ijih, 2019) indicated that farmers experienced serious postharvest losses due to insect/rodent attacks and spoilage attributed particularly due to improper storage structure. High temperatures and poor storage conditions, according to farmers and experts, may encourage insect infestations, while the presence of spilled grains and rubbish near grain storage facilities may facilitate rodent infection. Traditional storage structures in southwest Ethiopia did not protect the stored maize from external environmental conditions and pest problems making the grains liable to develop insect pests and mold during the rainy season.

As a result, this leads to quality and quantity loss, which is a challenge for food security in the country. Besides this contamination with fungi and mold during traditional storage, methods may impose the occurrence of aflatoxin that can impose health problems during consumption.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Description of the study area

The study was conducted in the South Nations, Nationalities and Peoples Regional State (SNNPRS), South Omo Zone; Baka Dawula Ari District (Figure 2). Four administrative Kebeles (smallest administrative unit) namely Bako, Kaysa, Bayitsemal, and Giste, were considered for this study. The study Kebeles laid over different altitudes above sea level i.e., Bako from 2232 to 2339, Giste from 1342 to 1451, Kaysa from 1446 to 1488, and Bayitsemal from 1331 to 1439 (recorded by the investigator). The District is geographically located between 5° 46' 0" and 5° 54' 30" latitude and longitude 36° 27' 0" and 36° 40' 30". Classification of the agro-ecology of the District is in reference to the Ethiopian traditional agro-ecological classification. Accordingly, Highland (Dega) lies between (2,300 –3,200)), middle highland (Woina-dega) (1,500 –2,300), and lowland (Kola) (500 –1,500 metre above sea level (masl) (MoA, 2000). The study site gets a bimodal rainfall pattern with a shorter rainy season from March-May and the longest rainy season from August to November. The long-term mean annual rainfall is 1342.03mm and the maximum and minimum monthly average temperatures of the study area is 27.61 and 16.3°C, respectively (Biruk Gezahegn *et al*., 2018).

The study was conducted in one of the potential maize-producing Districts, Baka Dawula Ari District, South Omo Zone of the SNNPRS. According to data obtained from Baka Dawula Ari Districts, Plan and Development Office Bureau (2022), there are 14 Kebeles in the district. The four selected kebeles have a total of 3715 households/farmers. The main source of income in these kebeles is agriculture, of which the major crop is maize farming.

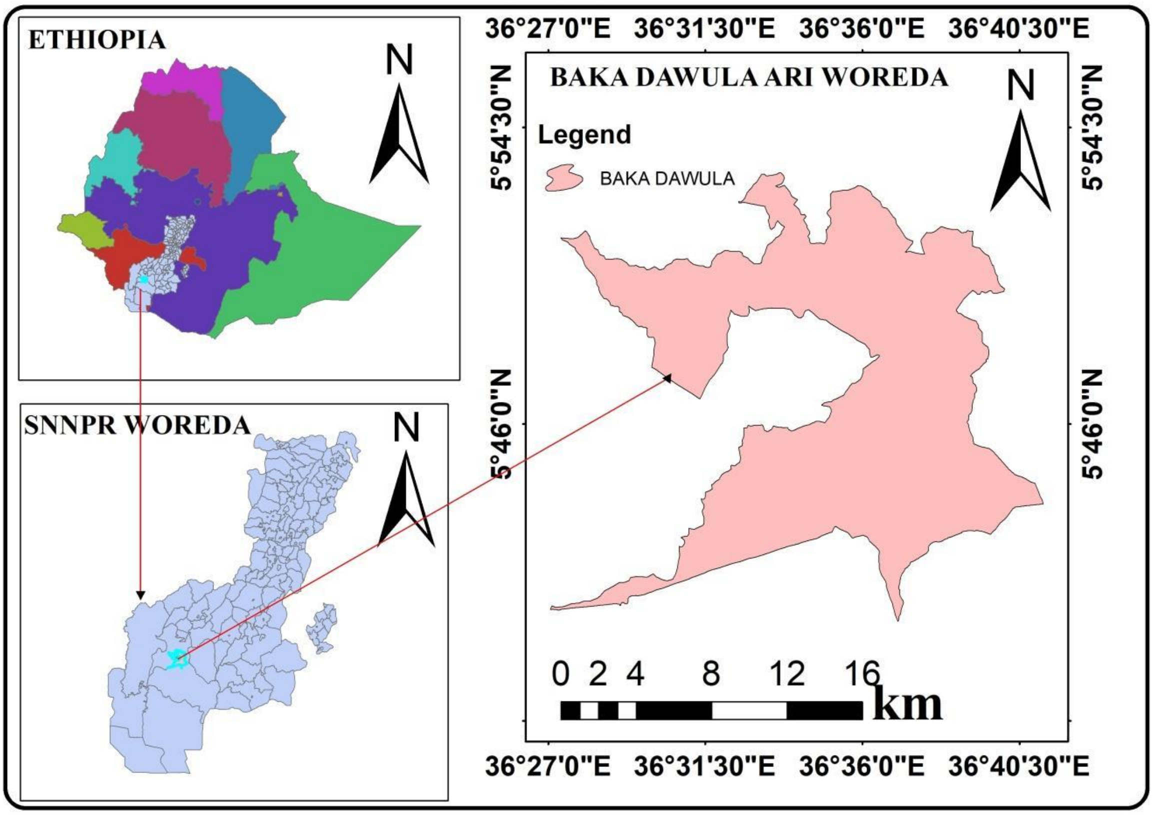


Figure 2: Map of the study area (ArcGIS 10.4 version 21)

3.2. Study design and sampling technique

The selection of the Kebeles was based on a preliminary survey conducted. Accordingly, the study Kebeles were selected based on the abundance of maize production (personal communication with Woreda Agricultural Development Office). A community-based cross-sectional survey was conducted from January 01, 2023 up to March 31, 2023. The study was conducted through systematic observation of storage facilities, sampling of damaged maize cobs, collection of insect pests in the storage structures, and baseline information gathering from the farming community.

Pertaining to logistic limitations, other social factors in the study area, and shortage of time, it was decided to address a total of eighty-four (84) respondents from the four Kebeles, and to each Kebele proportional sample size was assigned. From each Kebele, the households that participated in the study were selected by lottery methods (Table 3).

Table 3: Number of household and the sample size considered from the Kebeles

	Name of Kebele	Household number	sample size
1	Bayitsemal	2350	53
2	Kaysa	612	14
3	Giste	403	9
4	Bako	350	8
	Total	3715	84

3.2.1. Maize grain storage practice

Data regarding the maize grain storage methods, storage problems, storage treatments, and related aspects were collected from the selected households by systematic observation and semi-structured questionnaires (Appendix 9-12)**.**

3.2.2. The storage pests of the maize grain

A total of three maize cobs were taken from each type of storage structure in three replications from every study Kebele. The maize cobs were collected from the bottom, middle, and upper parts of the *Gotera*, and the middle and from both end sides for the hanging over smoke and hanging without smoke.

The collected maize cobs from each storage method were placed in separate plastic jars, labelled, and taken to the Laboratory of Entomology and Vertebrate Zoology of Arbaminch Plant Health Clinic for identification of pests**.**

A total of three hundred grams of maize grains were shelled from each sample and the grains were sieved through a 3mm sieve and later a 4.5mm sieve to separate the insect pests from the maize grains and the flour produced by the insect. Following the sieving, the grains were inspected by hand lens, and the pests that remained in the damaged maize grains were removed and included in the sample.

The insects were preserved in a 75% alcohol, until the investigation, observed under a binocular microscope, and numbers were counted and identified with the aid of insect identification keys and coloured plates (Rees, 2007; Hagstrum & Subramanyam, 2009). The grains were kept aside and used later for activity 3.2.3 below.

For assessing insect pest infestations, the main variables included were abundance, relative abundance, and frequency of species found in samples as suggested by (Bueno & Souza, 1991). Abundance refers to the total number of individuals of a species divided by the total number of samples and it is expressed by the following formula:

$$Abundance\ of\ species\ = \frac{Total\ number\ of\ individuals\ of\ species}{Total\ number\ of\ samples}$$

The relative abundance of species is expressed by the percentage of individuals of the species in a total number of observed individuals as shown in the following formula:

$$Relative\ Abundance\ of\ species\ = \frac{number\ of\ individuals\ of\ species}{Total\ number\ of\ observed\ individuals} * 100$$

The frequency of occurrence is obtained by the relationship between the number of samples containing the species and the total number of samples. It is expressed by the following formula.

$$Frequency\ = \frac{Number\ of\ samples\ in\ which\ the\ species\ occurred}{Total\ number\ of\ sample} * 100$$

3.2.3. Efficacy of locally available storage structures against maize grain pests

Using a hand lens and visual inspection technique, the damaged and undamaged maize grains were identified, and counts were recorded. The level of the maize grain infestation by each pest in the storage structures were compared and presented.

In the meantime, different estimate methods were used to determine the damage level of the grain, and the weight loss to the pests to test the efficacy of locally available storage structures. These included the Count and Weight Method (A) (Harris & Lindblad, 1976) and the method of insect-damaged grain percentage (B).

$$\%\, weight\ loss \ = \frac{(UNd) - (DNu)}{U(Nd+Nu)} * 100 \quad \text{........ (A)}$$

Where U = weight of undamaged seed, D = weight of damaged seed, Nd = number of damaged seed, and Nu = number of undamaged seed

$$\%\, insect\ damaged\ grain \ = \frac{Number\ of\ damaged\ grain}{Total\ number\ of\ grains} * 100 \quad \text{......... (B)}$$

3.3. Data analysis

Data on the storage methods were summarized by Microsoft Office Excel. Descriptive statistics (means and percentage) were used to investigate species compositions, abundance, their relative abundance, and distribution (frequency of occurrence) of the insect pests of the stored maize. Data on the efficacy of the storage practices level of the maize grain damage and the weight loss were analysed by Proc ANOVA of SAS software (version 9). Significant means were separated by Fisher's Least Significant Difference (LSD) at a 5% error level.

CHAPTER FOUR

RESULTS

4.1. Maize grain storage practices

Gotera (Riqa) is a traditional storage structure that is commonly practiced across the study area. The majority of the respondents said that they used *Gotera* alone and some of the farmers used *Gotera* with hanging practices (hanging over smoke and hanging without smoke**)** (Table 4). *Gotera* wall comes in different forms: plastered, unplastered, or partially plastered (Table 5) (Figure 3). The roofs of *Gotera* were constructed either from corrugated metal sheets or thatched grass with wooden or bamboo walls (Figure 3).

Table 4: Storage structures used for storing maize

Storage structure	Frequency	Percentage
Gotera (Riqa)	69	82.1
Riqa with hanging	15	17.9
Total	84	100

Table 5: Forms of the *Gotera* walls

Form of storage structure	Frequency	Percentage
Plastered	19	22.6
Unplastered	54	64.3
partially plastered	10	11.9
unplastered and partially plastered	1	1.2
Total	84	100

Figure 3: Types of storage facilities in the study area

Across the study area, no farmer stored the maize in the form of grain. Farmers stored the maize with the intact husk and in the de-husked form in the *Riqa* and on hanging (Figure 4). The majority of the respondents said that they stored their maize grain with the husk (Table 6).

Table 6: Percentage of farmer’s responses concerning forms of maize in storage

Form of stored maize	Frequency	Percentage
In the husk	76	90.5
De-husked	8	9.5
Total	84	100

Figure 4: Form of stored maize in different storage facilities

Table 7- depicts the storage site in reference to the residence homestead of the households. Accordingly, it was known from the field visit that the crop was stored in various sites.

Table 7: Percentage of farmers' responses concerning maize storage site

Place	Frequency	Percentage
Courtyard	39	46.4
In farming field	35	41.7
Field and Courtyard	10	11.9
Total	84	100

The length of the storage period in the study area showed variations. Some of the farmers stored the crop for several months, whereas others stored for a year or above (Table 8).

Table 8: Percentage of farmers' responses concerning the length of storage period

Storage period in months	Frequency	Percentage
3-6	20	23.8
7-12	62	73.8
Above 12	2	2.4
Total	84	100

The majority of the farming community complained that their maize was infested by insects, however, there were also other pests causing problems to the crop in storage of the farmers (Figure 5).

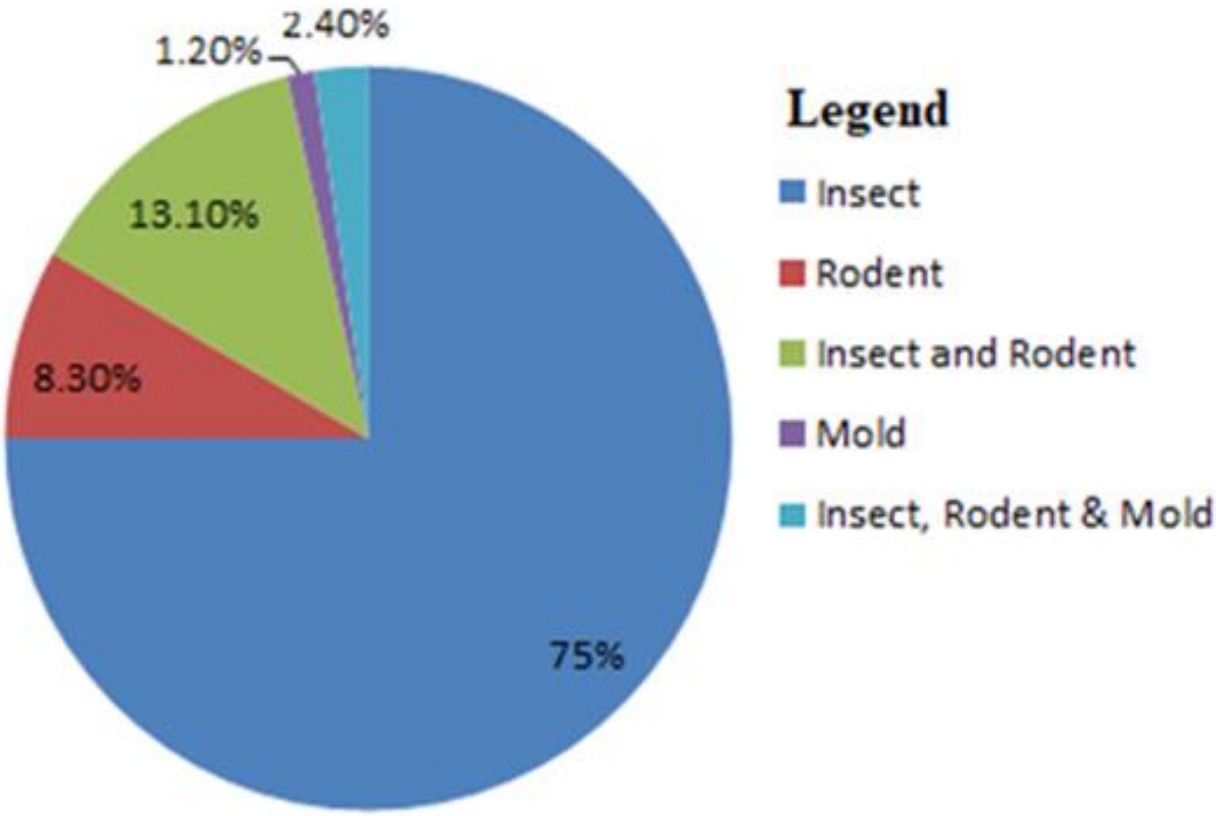


Figure 5: Pest categories as described by the respondent farmers

Most of the respondents replied that the insects and other pests were seen infesting their crop in storage a few months after they stored the crop, whereas a considerable proportion of them complained that pest infestation begun immediately after the crop was stored (Table 9).

Table 9: The earliest period at which the farmers first observed pests infesting maize grain in storage

Time	Frequency	%
At the Beginning of storage	23	27.4
After a few month	55	65.5
Up on empting the store for the next storage season	6	7.1
Total	84	100

The majority of the respondents said that there had been no storage structure treatment methods to protect the grains from pest infestation in their areas. However, some proportions of the maize farming communities practiced few traditional treatment approaches (Figure 6). Some of the respondents underlined that spraying wood ash on the maize cob before storing reduced the pest infestation slightly.

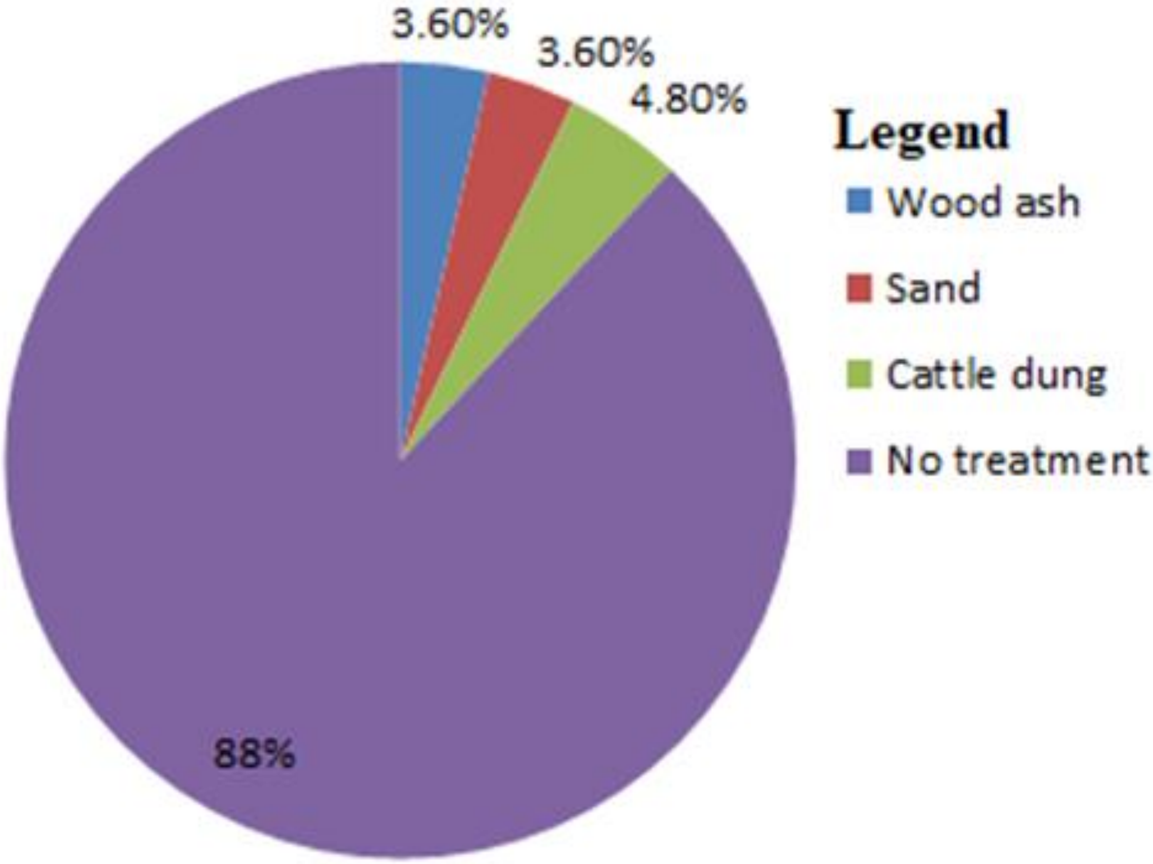


Figure 6: Farmers responses about storage treatment method

Most of the respondents underlined that they used insecticides and rodenticides to protect their stored maize from different pests, whereas a considerable proportion of the farmers took no action against the pests (Figure 7). The majority of the farmers who used the insecticides and those who used the domestic predator said they got a fairly good result. They used the domestic cat as a predator against pest rodents. On the other hand, they said they applied to the crop antimalarial insecticide but they said they were not sure of the impact of the antimalarial insecticide on the pests.

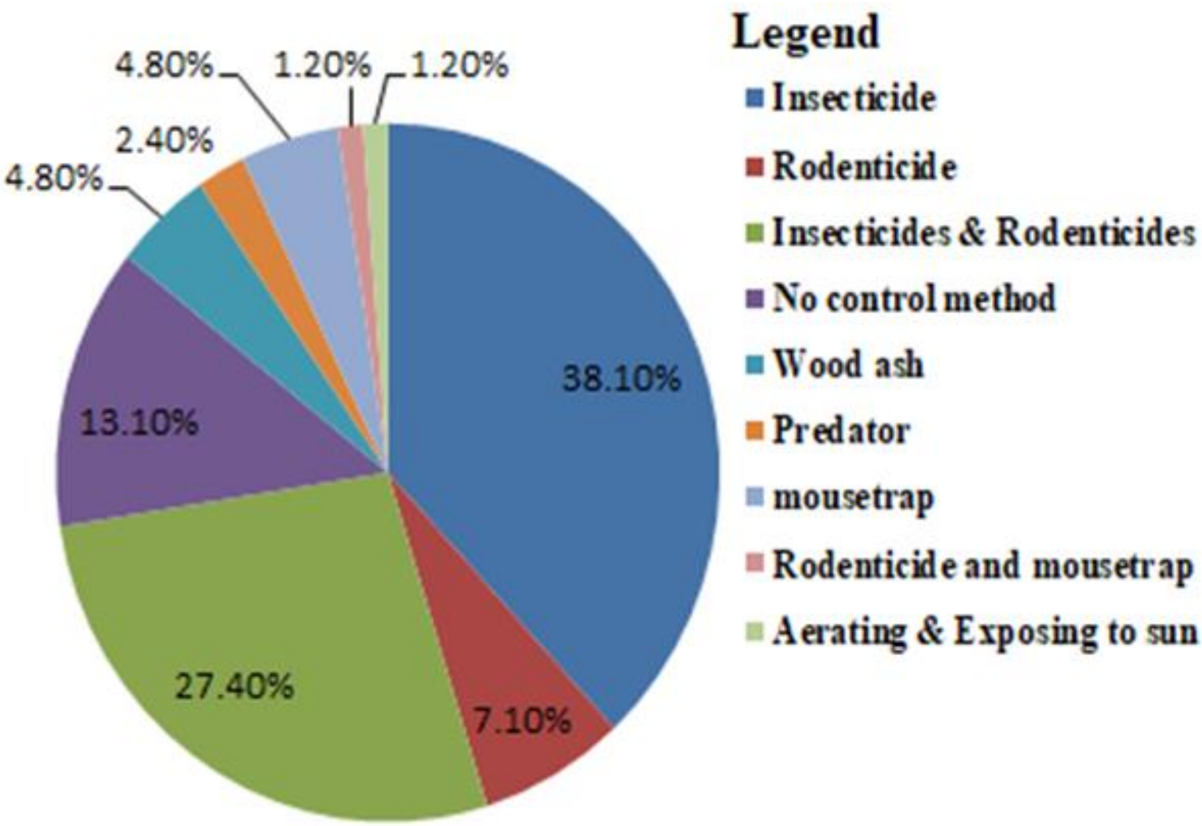


Figure 7: Farmers response about the pest control of the maize in storage

4.2 The storage pests of the maize grain

Insects, mites, rodents, and molds were identified to have become a threat to the maize in the storage structures. Among the pests recorded, Coleoptera and Lepidoptera were the most important insect orders whose some members posed severe threats to the crop (Table 10). In total, eleven arthropod species and molds (*shageta*) were recorded. In this study, the larger grain borer (LGB) *Prostephanus truncatus* (*Coleoptera: Bostrichidae*) was recorded infesting the maize grain in storage for the first time (Figure 8). Farmers have also stated that this beetle was found infesting maize in the field even before harvest.

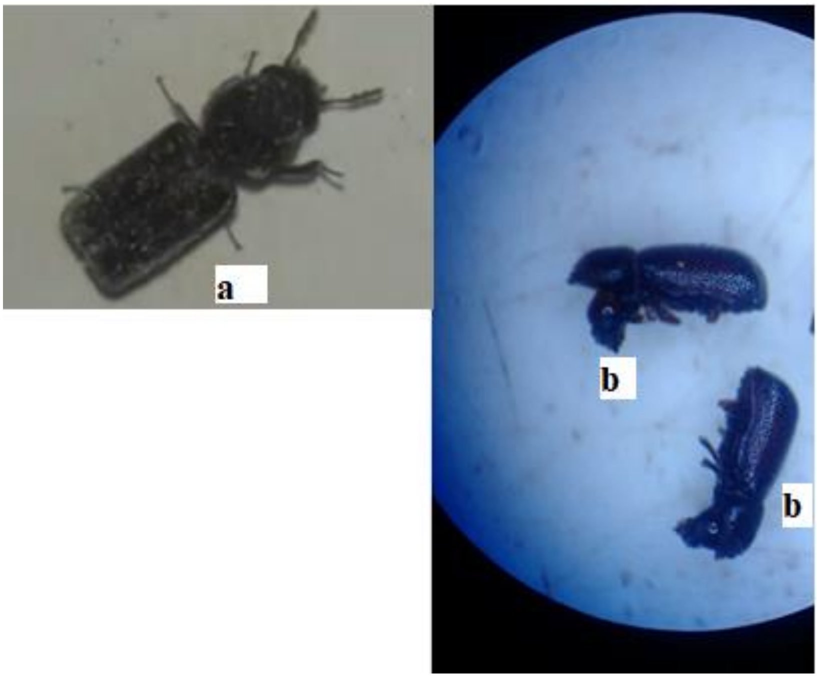


Figure 8. *Prostephanus truncatus* photos (a. taken directly from dorsal position. b. taken from rear position)

The large grain borer was found to have bored through a cob with intact husk, break the maize grain upon consuming it until the whole grain was turned into flour (Figure 9).

Figure 9. The damaged posed by LGB on maize in storage

Table 10: Categories of pests identified from maize in the study area

Order	Family	Common name	Scientific name
Coleoptera	Bostrichidae	Larger grain borer	*Prostephanus truncates*
	Bostrichidae	Lesser grain borer	*Rhyzopertha dominica*
	Curculionidae	Maize weevil	*Sitophilus zeamais*
	Curculionidae	Rice weevil	*Sitophilus oryzae*
	Curculionidae	Granary weevil	*Sitophilus granaries*
	Tenebrionidae	Rust red flour beetle	*Tribolium castaneum*
	Tenebrionidae	Confused flour beetle	*Tribolium confusum*
	Silvanidae	Saw toothed grain beetle	*Oryzaephilus surinamensis*
	Nitidulidae	Corn sap beetle	*Carpophilus dimidiatus*
Lepidoptera	Gelechiidiae	Angoumois grain moth	*Sitotroga cerealella*
Acarina	Acaridae	Grain or flour mite	*Acarus siro*
Mold	Uncategorized	Uncategorized	Uncategorized

The abundance, relative abundance and frequency of occurrence of the arthropod pests were recorded from the stored maize in the study area were presented in the (Table 11)

Table 11: Species composition, abundance and the frequency of occurrence of the pests associated to stored maize grains

Pest species	Total number of adult insects	Species Abundance	Relative abundance (%)	Frequency(%) of occurrence
Prostephanus truncatus	2439	67.75	34.15	75.00
Rhyzopertha dominica	722	20.00	10.10	75.00
Sitophilus zeamais	2608	72.40	36.51	91.60
Sitophilus oryzae	368	10.20	5.15	79.50
Sitophilus granaries	189	5.25	2.65	41.60
Tribolium castaneum	298	8.30	4.17	72.20
Tribolium confusum	213	5.90	2.98	75.00
Oryzaephilus surinamensis	75	2.10	1.05	50.00
Sitotroga cerealella	213	5.90	2.98	66.60
Carpophilus dimidiatus	9	0.25	0.13	8.30
Acarus siro	9	0.25	0.13	5.50

4.3 Level of pest infestation in locally available maize grain storage structures

Almost all of the recorded pests were found to have infested the maize grain in all of the storage facilities with marked differences in the extent of infestation (Figure 10). However, *Carpophilus dimidiatus* and *Acarus siro* were hardly found in some of the facilities.

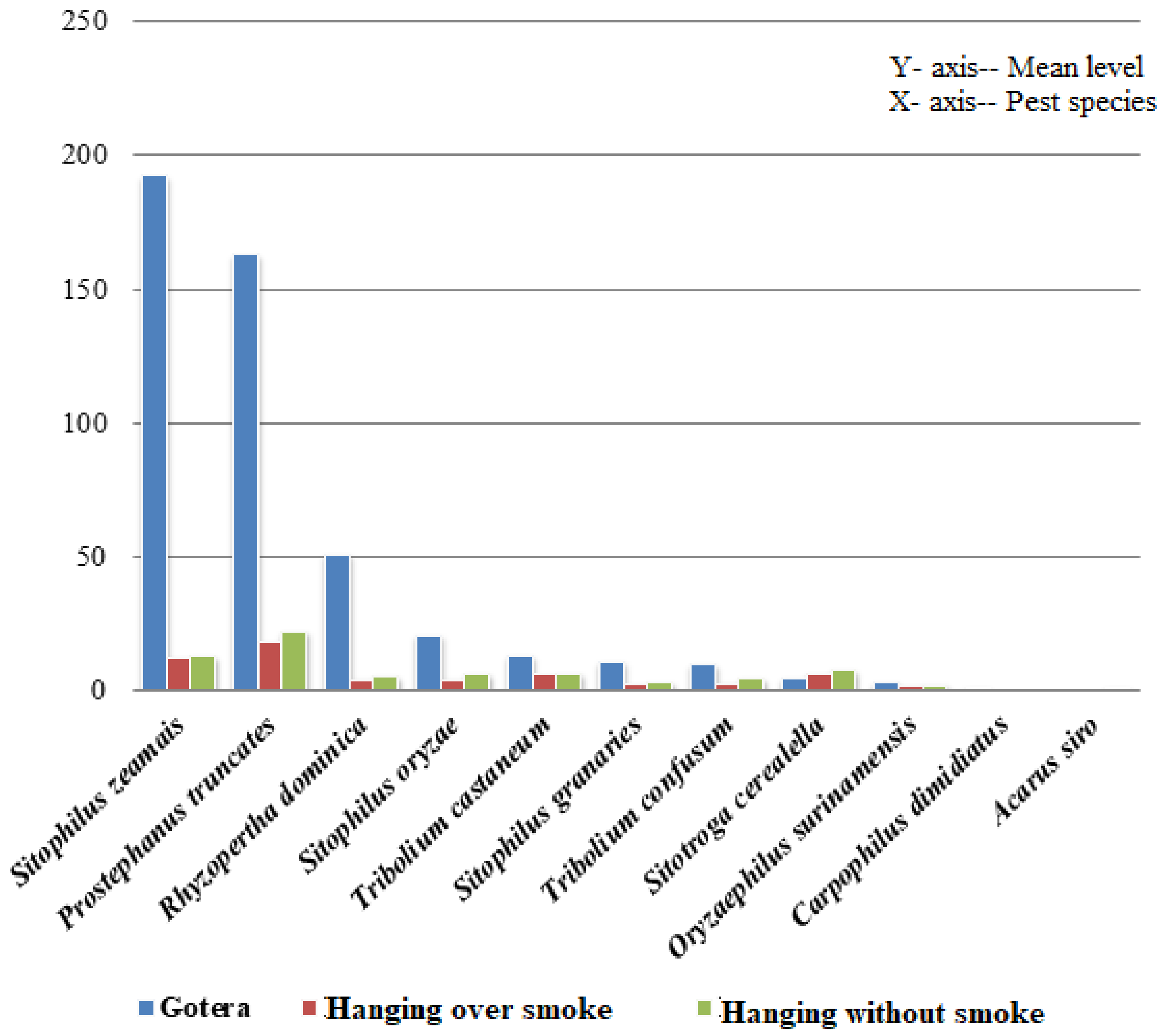


Figure 10: Mean level of insect pest's infestation of stored maize in three different farmer's traditional storage facilities

4.4 Level of maize grain damage and weight loss in the storage structure

The level of maize grain weight loss was significantly higher ($p<0.05$) in Giste, Bayitsemal, and Kaysa compared to that of Bako. In Bako, the weight loss was very minimal. However, there was no significant difference among Giste, Bayitsemal, and Kaysa in this regard ($P>0.05$) (Table 12).

Table 12: Mean percentage of maize grain weight loss in the study Kebeles

Study site	Mean±SE
Giste	13.87 ± 2.98^{a}
Bayitsemal	13.73 ± 2.82^{a}
Kaysa	13.12 ± 3.04^{ab}
Bako	0.14 ± 0.06^{c}
LSD	0.7

Means with the same letter in a column are not significantly different at 5% error level.

There was a difference among the storage facilities in the mean percentage weight loss of maize grain in the study area. The differences were found to be statistically sound ($p<0.05$) (Table 13).

Table 13: Mean percentage of maize grain weight loss in the storage facilities

Storage facilities	Mean±SE
Gotera	19.04 ± 3.25^{a}
Hanging without smoke	6.48 ± 1.13^{b}
Hanging over smoke	5.12 ± 0.91^{c}
LSD	0.61

Means with the same letter in a column are not significantly different at 5% error level.

The maize grain was significantly damaged in Bayitsemal and Giste ($P<0.05$) compared to Kaysa and Bako. However, there was no significant difference in this regard between the first two Kebeles. In Bako, the damage was found to be the least with a significant difference ($P<0.05$) compared to all of the remaining sites (Table 14).

Table 14: Mean percentage of maize grain damage in the study Kebeles

Study site	**Mean±SE**
Bayitsemal	37.03 ± 5.68^{a}
Giste	36.98 ± 6.18^{a}
Kaysa	34.19 ± 6.46^{b}
Bako	2.41 ± 0.64^{c}
LSD	1.82

Means with the same letter in a column are not significantly different at 5% error level.

There was a significant difference ($P<0.05$) in the level of maize grain damage among the three storage facilities. In this regard, in *Gotera* there was severe damage whereas the level of damage was the least in the hangover smoke case (Table 15).

Table 15: Mean percentage of maize grain damage in the storage facilities

Storage facilities	**Mean±SE**
Gotera	46.74 ± 7.34^{a}
Hanging without smoke	20.20 ± 3.04^{b}
Hanging over smoke	16.52 ± 2.99^{c}
LSD	1.58

Means with the same letter in a column are not significantly different at 5% error level.

Within each Kebele, the levels of weight loss and grain damage to the pests were studied. The result showed that a significantly higher percentage of weight loss and grain damage ($P<0.05$) were recorded in *Gotera* compared to the rest storage facilities in all of the study Kebeles (Tables 16 - 17). Percentage weight loss showed a significant difference ($P<0.05$) among the storage facilities in Giste, Kaysa, and Bayitsemal, but in Bako, the difference between hanging over smoke and hanging without smoke showed no significant variation ($p>0.05$) in this regard while both differed from *Gotera* significantly ($p<0.05$).

Table 16: Mean percentage of maize grain weight loss in the storage facilities in the study Kebeles

		Mean+SE		LSD
Study Kebele	**Gotera**	**Hanging without smoke**	**Hanging over smoke**	
Giste	25.7 ± 0.12^{a}	8.93 ± 0.81^{b}	6.99 ± 0.17^{c}	1.67
Kaysa	25.16 ± 0.25^{a}	8.38 ± 0.08^{b}	5.82 ± 0.28^{c}	0.77
Bayitsemal	24.94 ± 0.99^{a}	8.59 ± 0.32^{b}	7.66 ± 0.40^{b}	2.24
Bako	0.38 ± 0.06^{a}	0.04 ± 0.01^{b}	0.00 ± 0.00^{b}	0.13

Means with the same letter in a row are not significantly different at 5% error level.

Percentage grain damage showed a significant difference ($P<0.05$) between hanging over smoke and hanging without smoke in Giste, Bako, and Kaysa, but in Bayitsemal the difference between hanging over smoke and hanging without smoke showed no significant variation ($p>0.05$) in this regard while both differed from *Gotera* significantly ($p<0.05$).

Table 17: Mean percentage of maize grain damage in the storage facilities in the study Kebeles

		Mean+SE		LSD
Study Kebele	**Gotera**	**Hanging without smoke**	**Hanging over smoke**	
Giste	61.50 ± 0.21^{a}	27.03 ± 1.61^{b}	22.43 ± 0.64^{c}	3.49
Kaysa	59.81 ± 0.51^{a}	24.23 ± 0.29^{b}	18.53 ± 0.86^{c}	2.09
Bayitsemal	59.46 ± 2.30^{a}	26.50 ± 1.35^{b}	25.13 ± 1.61^{b}	6.24
Bako	4.2 ± 0.21^{a}	3.03 ± 0.41^{b}	0.00 ± 0.00^{c}	0.91

Means with the same letter in a row are not significantly different at the 5% level.

5. DISCUSSION

Maize grain storage structures were restricted to cultural materials viz. *Goters* (*Riqa*) and hanging over smoke or without smoke. In all cases, there was no shelling of the grains from the cobs to store and the cobs were in intact husk in some instances. The farmers believed that storing maize with intact husk reduced pest infestation in storage. This finding is in agreement with Midega *et a*l. (2016) who acknowledged that the pest severity was less in the cases of cobs with husks than the de-husked ones. Moreover, keeping the maize unshelled may partially be associated with its suitability for hanging. The maize-producing community in the study area complained that various types of pests destructed their crop, and the infestation began soon after they stored the crop and continued then after till emptying the storage structures. This indicates that the pest might have begun infesting the crop either in the field before harvest or the storage structures might have contained the pests from the previous storage season pertaining to the lack of proper sanitation. It was indicated that proper preservation of the maize grains before storage and sanitation of the storage structures would reduce the severity of the pest attack in storage (Waktole Sori and Amsalu Ayana, 2012; Midega *et al*., 2016).

The major insect pests found severely damaging the pest were members of the order Coleoptera with only one representative each from Lepidoptera, Acarina pest, and a mold. In terms of the relative abundance of the pest species recorded, *Sitophilus zeamais and Prostephanus truncatus* occupied the first and the second positions, respectively. *Prostephanus truncatus*, which is commonly known as the Large Grain Borer (LGB), was recorded by this study for the first time infesting storage products in Ethiopia. The LGB was found piercing the intact husk of the maize cob and making holes through the maize grain by which most parts of the grains were changed completely into maize dust. This finding is in agreement with the studies which depicted that the LGB is a major storage pest that caused the loss of more than half of stored maize in various African countries (Abass *et al*., 2014; Midega *et al*., 2016).

The pests recorded in this study have been frequently reported from stored maize and other field crops from Ethiopia by various area experts except for the LGB (Abraham Tadesse and Basedow 2004; Abraham Tadesse *et al*., 2012; Ararso Gognsha and Berhanu Hiruy, 2020; Tsehaynew Wubetu and Berhanu Hiruy, 2020). On the other hand, the presence of the LGB was confirmed in 2009 from pheromone traps deployed in Ethiopia at localities closer to the Kenyan border, but it was not recorded from any crop so far (Abraham Tadesse *et al*., 2012; Gezahegne Getaneh *et al*., 2016).

It was revealed in this study that the level of efficacy of the traditional storage structures increased from *Gotera* through hanging without smoke to hanging over smoke in that order. The *Gotera* is a container in which the maize cobs were stacked and covered as a result the heat emitted from the pests might raise the internal temperature of the container and might favour the population of the pest to have built up and aggravated the maize grain damage. On the contrary, hanging the maize cob allows enough space for air movement and exposure to sun rays (for those in the field). Moreover, smoking could suffocate the pests thereby limiting the pest build-up so that the pest infestation might be less severe. It noted that farmers use smoking as a control of maize grain infesting pests in Jimma Zone, Ethiopia (Waktole Sori and Amsalu Ayana, 2012). Likewise, suspending, smoking over the fire, and sunning the pea pods were used for the control of cowpea seed beetle in Gambella, Ethiopia (Bayeh Mulatu *et al*., 2008).

From the four study Kebeles and all the three storage structures considered at every Kebele level, an infestation of the maize grain was found to have been the least in Bako compared to Giste, Bayitsemal, and Kaysa whereas the last three were more or less similar in the level of the maize grain damage and percentage weight loss of the grain. This is probably because Bako is at a relatively higher altitude compared to the other study Kebeles. It is common knowledge that crop infestation, mainly by insect pests, decreases with increased altitude which may be a factor in a gradual drop in temperature.

The farmers used various methods of protecting their maize grain against the pests, among which the use of predators against rodent pests, spraying wood ash on the maize cob, and application of the insecticide used against malarial infestation were the main ones. Waktole Sori and Amsalu Ayana (2012) and Bayeh Mulatu *et al*. (2008) reported that wood ash was used by farmers in Ethiopia against maize and pea storage pests, respectively. However, the application of the antimalarial insecticide to have controlled the storage of insect pests is a misuse of the chemical which came into being probably because the severity of the pest infestation has panicked the farmers.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Maize grain is stored in traditional storage structures with the grains unshelled and the husks intact in the study area. The storage management practices are so that the storage pests, mainly the insect pests, are posing a severe threat to maize grain in the study area. However, it can be concluded that hanging the maize cob over smoke has an advantage in controlling the storage pests compared to using G*otera* which is however a common practice in the area.

That the farmers used antimalarial insecticides to control the pests indicates that there has been less or no professional support from agricultural extension agents. Therefore, it can be understood that keeping maize in storage for future use or better market is a challenge not only from the economic point of view but also from the community's health aspect angle.

The level of maize grain damage and percentage maize grain loss differs greatly in various areas along the altitudinal gradient.

In addition to the insect pests which are known to be threats to maize grain storage in Ethiopia in general and in southern Ethiopia in particular, the introduction of *Prostephanus truncatus* into Ethiopia as a new storage pest that it established and began to destruct the maize grain will pose a new and serious challenge to the agricultural sector.

6.2. Recommendation

- Even though the farmers attempted to minimize the impact of the pests on stored maize in various ways, he post-harvest management of the maize crop is not modernised and as a resultt, the farmers couldn’t even distinguish between the roles of the classical agricultural insecticides used against storage pests and that used against malaria vector. Therefore consistent training and professional support shall be provided to the maize farming community.

- Hanging the maize cob over the smoke has shown a better positive response in minimizing the impact that the pests pose on the maize in storage. However, this shall be supported by other strategies. Therefore integrated storage pest management shall be implemented.

- Larger grain borer is a catastrophic pest newly introduced to Ethiopia. However, it is not new to science. Therefore, its control methods shall be shared with the countries which have already experienced pest infestation and be implemented in Ethiopia.

- Countrywide awareness creation and training shall be given to the agricultural sector workers and maize farmers on the biology, phenology, and feeding behaviour of the large grain borer as soon as possible.

- A survey on the geographical distribution of the larger grain borer shall be held as soon as possible in order to design large-scale management practices for the pest before it is too late.

REFERENCES

Abass, A. B., Ndunguru, G., Mamiro, P., Alenkhe, B., Mlingi, N., & Bekunda, M. (2014). Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania. *Journal of Stored Products Research*, *57*, 49–57.

Abd El-Aziz, S. E. (2011). Control strategies of stored product pests. *Journal of Entomology*, *8*(2), 101–122. https://doi.org/10.3923/je.2011.101.122

Abedin, M. Z., Rahman, M. Z., Mia, M. I. A., & Rahman, K. M. M. (2012). In-store losses of rice and ways of reducing such losses at farmers level: An assessment in selected regions of Bangladesh. *Journal of the Bangladesh Agricultural University*, *10*(1), 133–144.

Abraham Mulu & Belayneh Zelalem (2016). Comparative Evaluation of Underground Pit Storage Systems for Grain Quality Attributes in Jigjiga and Awubarre Districts of Fafen Zone, Ethiopia. *Advances in Crop Science and Technology*, *4*(4). https://doi.org/10.4172/2329-8863.1000235

Abraham Tadesse (1996). Insects and other arthropods recorded from stored maize in western Ethiopia. *African Crop Science Journal*, *4*(3), 339–343.

Abraham Tadesse, Amare Ayalew, Emana Getu, and Tadele Tefera (2006). Review of research on post-harvest pests. *Increasing Crop Production through Improved Plant Protection*, *2*, 475–563.

Abraham Tadesse & Basedow, T. (2004). A survey of insect pest problems and stored product protection in stored maize in Ethiopia in the year 2000/Eine landesweite Untersuchung über die Schädlingsprobleme und den Vorratsschutz bei gelagertem Mais in Äthiopien im Jahre 2000. *Zeitschrift Für Pflanzenkrankheiten Und Pflanzenschutz/Journal of Plant Diseases and Protection*, 257–265.

Abraham Tadesse, Hiwot lemma and Mulugeta Negeri (2012). A review on the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera:Bostrichidae) an invasive pest of maize and cassava in Africa. Bayeh Mulatu (ed.). 2012. Invasive pest threatening Ethiopian agriculture, 19-42 Plant protection society of Ethiopia. Proceeding of the 17th annual conference, Nov, 26-27, 2010, Addis Ababa.

Adejumo, B. A., & Raji, A. O. (2007). *Technical appraisal of grain storage systems in the Nigerian Sudan Savanna*.

Adugna Haile (2006). On-farm storage studies on sorghum and chickpea in Eritrea. *African Journal of Biotechnology*, *5*(17), 1537–1544.

Agada, O., & Ijih, B. E. (2019). Analysis of Post Harvest Management Practices among Farmers in Oju, Benue State, Nigeria. *Journal of Agriculture and Environmental Sciences, 8*(1), 2–7.

Alam, M. J., Ahmed, K. S., & Mollah, M. R. A. (2014). Survey of insect pests of maize crop and their identification in Shibganj upazilla under Bogra district. *Bangladesh Journal of Seed Science and Technology*, *18*(1), 73–77.

Alam, M. J., Ahmed, K. S., Sultana, A., Firoj, S. M., & Hasan, I. M. (2018). Ensure food security of Bangladesh: Analysis of post-harvest losses of maize and its pest management in stored condition. *Journal of Agricultural Engineering and Food Technology*, *5*(1), 26–32.

Ali Mohammed and Abraham Tadesse (2018). *Review of Major Grains Postharvest Losses in Ethiopia and Customization of a Loss Assessment Methodology. USAID/Ethiopia Agriculture Knowledge, Learning, Documentation and Policy Project, Addis Ababa. November*, Pp57.

Ararso Gognsha & Berhanu Hiruy (2020). Species Composition and Status of Stored Sorghum Pests in Traditional Farmer's Storages of Kena District of Koso Zone, Southern Ethiopia. *Journal of Experimental Agriculture International, February,* 12–22. https://doi.org/10.9734/jeai/2020/v42i130447.

Araya G/ Silassie (2007). *Evaluation of powder and essential oils of some botanical plants for their efficacy against Zabrotes subfasciatus (Boheman)(Coleoptera: Bruchidae) on haricot bean (Phaseolus vulgaris L.) under laboratory condition in Ethiopia*. MSc. Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Baloch, U. K. (1999). Wheat: Post-harvest operations. *Food Agric Organ United Nations, 10*, 279–293.

Bankole, S. A., & Mabekoje, O. O. (2004). Occurrence of aflatoxins and fumonisins in preharvest maize from south-western Nigeria. *Food Additives and Contaminants*, *21*(3), 251–255.

Bayeh Mulatu , Mekasha Chichaybelu , Tafa Jobe , Tesfaye Belay (2008). Review of Research Outcomes on Insect Pests of Economic Importance to Major Small Cereals. Abraham Tadesse (ed.). 2008. Increasing Crop Production through Improved Plant Protection – Volume I. Plant Protection Society of Ethiopia (PPSE), 325-374

Bekele Shiferaw, Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world. Past successes and future challenges to the role played by maize in global food security. *Food Security*, *3*, 307–327.

Bellon, M. R., Hodson, D., Bergvinson, D., Beck, D., Martinez-Romero, E., & Montoya, Y. (2005). Targeting agricultural research to benefit poor farmers: Relating poverty mapping to maize environments in Mexico. *Food Policy*, *30*(5–6), 476–492.

Biruk Gezahegn, Wodajo Gebire, and Kedir Bamud (2018). Identification of major crop production constraints in debub ari district, south omo zone, southern Ethiopia. *Horticult Int J*, *2*(6), 383–388.

Boxall, R. (1998). *Grains post-harvest loss assessment in Ethiopia : Final report*. 33. http://gala.gre.uk/10758.

Boxall, R. A. (1974). Underground storage of grain in Harar Province, Ethiopia. *Tropical Stored Products Information*.

Boxall, R. A. (2002). Damage and loss caused by the larger grain borer Prostephanus truncatus. *Integrated Pest Management Reviews*, *7*(2), 105–121.

Boxall, R. A., Brice, J. R., Taylor, S. J., & Bancroft, R. D. (2002). Technology and management of storage. *Crop Post-Harvest: Science and Technology: Principles and Practice*, *1*, 141–232.

Bradford, K. J., Dahal, P., Van Asbrouck, J., Kunusoth, K., Bello, P., Thompson, J., & Wu, F. (2020). The dry chain: Reducing postharvest losses and improving food safety in humid climates. In *Food Industry Wastes* (pp. 375–389). Elsevier.

Brown, P. R., McWilliam, A., & Khamphoukeo, K. (2013). Post-harvest damage to stored grain by rodents in village environments in Laos. *International Biodeterioration & Biodegradation*, *82*, 104–109.

Bucklin, R., Thompson, S., Montross, M., & Abdel-Hadi, A. (2019). Grain storage systems design. In *Handbook of farm, dairy and food machinery engineering* (pp. 175–223). Elsevier.

Bueno, V. H. P., & Souza, M. B. (1991). Ocorrência e diversidade de insectos predadores e parasitóides na cultura de couve brassica oleracea var. *Acephala Em Lavras MG, Brazil*.

Cairns, J. E., Chamberlin, J., Rutsaert, P., Voss, R. C., Ndhlela, T., & Magorokosho, C. (2021). Challenges for sustainable maize production of smallholder farmers in sub-Saharan Africa. *Journal of Cereal Science*, *101*, 103274.

Central Statistical Agency (CSA). (2021). Farm Management Practices (Agricaltural Sample Survey) 2020/21 (2013 E.C.). *Central Statistical Agency*, *III*(12), 19–49. https://www.statsethiopia.gov.et/wp-content/uploads/2021/06/2020_21-2013-E.C-AgSS-Main-Season-Agricultural-Farm-Management-Report.pdf

Central Statistical Agency (CSA). (2018). Central statistical agency agricultural sample survey report on area and production of major crops. *The Federal Democratic Republic of Ethiopia*, *I*(October), 125.

Channal, G., Nagnur, S., & Nanjayyanamath, C. (2004). Indigenous grain storage structures. *Leisa India*, *6*(3), 10.

Costa, S. J. (2014). Reducing food losses in sub-saharan Africa. *An 'Action Research'Evaluation Trial from Uganda and Burkina Faso*.

Daniel Obeng-Ofori. (2008). The use of botanicals by resource poor farmers in Africa and Asia for the protection of stored agricultural products. *Stewart Postharvest Review*, *3*(6), 1–8. https://doi.org/10.2212/spr.2007.6.10

De Groote, H. (2002). Maize yield losses from stemborers in Kenya. *International Journal of Tropical Insect Science*, *22*(2), 89–96.

Dhineshkumar, V., Sudha, K., & Siddarth, M. (2017). Control and management of stored grain insect in farmer stores and public ware houses. *Pestology*, *41*(8), 32–53.

Diallo, A. O., Kikafunda, J., Wolde, L., Odongo, O., Mduruma, Z. O., Chivatsi, W. S., Friesen, D. K., Mugo, S. N., & Banziger, M. (2002). *Drought and low nitrogen tolerant hybrids for the moist mid-altitude ecology of Eastern Africa. Integrated Approaches to Higher Maize Productivity in the New Millennium.*

Dick, K. (1988). *A review of insect infestation of maize in farm storage in Africa with special reference to the ecology and control of Prostephanus truncatus (NRI Bulletin No. 18)*.

Dowell, F. E., & Dowell, C. N. (2017). Reducing grain storage losses in developing countries. *Quality Assurance and Safety of Crops & Foods*, *9*(1), 93–100.

Edoh Ognakossan, K., Mutungi, C. M., Otieno, T. O., Affognon, H. D., Sila, D. N., & Owino, W. O. (2018). Quantitative and quality losses caused by rodents in on-farm stored maize: a case study in the low land tropical zone of Kenya. *Food Security*, *10*, 1525–1537.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., & Prasanna, B. M. (2022). Global maize production, consumption and trade: trends and R&D implications. *Food Security*, *14*(5), 1295–1319.

Fantu Bachewe, Bart, M., Alemayehu Seyoum, Pauw, K., Cameron, A., & Tirsit Genye (2018). Farmers' Grain storage and Losses in Ethiopia: Measures and associates. *Ethiopian Development Research Institute (EDRI):Strategy Support Program*, *115*(March), pp.15.

Fantu Bachewe, Minten, B., Alemayehu Seyoum, Pauw, K., Cameron, A., & Tirsit Genye (2020). Farmers' Grain Storage and Losses in Ethiopia. *Journal of Agricultural and Food Industrial Organization*, *18*(1), 1–19. https://doi.org/10.1515/jafio-2019-0059

Firdissa Eticha & Abraham Tadesse (1999). *Effects of some botanicals and other materials against the maize weevil (Sitophilus zeamais Motsch.) on stored maize*.

Food and agriculture organization united nation (FAO) (2019). The state of food and agriculture. Moving forward on food loss and waste reduction.

FAO (2021). *STATISTICS STATISTICAL YEARBOOK*.

Gezahagne Getaneh, Gashawubeza Ayalew, Eshetu Derso, Bayeh Mulatu, Endale Hailu, & Tariku Hunduma (2016). Plant protection research in Ethiopia: major achievements, challenges and future directions. *Agricultural Research for Ethiopian Renaissance. Challenges, Opportunities and Directions*, *December*, 199–212.

Girma Demissie, Tadele Tefera, and Abraham Tadesse (2008). Importance of husk covering on field infestation of maize by Sitophilus zeamais Motsch (Coleoptera: Curculionidea) at Bako, Western Ethiopia. *African Journal of Biotechnology*, *7*(20), 3774–3779.

Girma Beriso (2018). Assessment of Maize (Zea mays) seed Storage Techniques in West Guji Zone Southern Oromia ,. *Academic Research Journal of Agricultural Science and Research*, *6*(7), 423–428. https://doi.org/10.14662/ARJASR2018.063.

Grover, D. K., & Singh, J. M. (2013). Post-harvest Losses in Wheat Crop in Punjab: Past and Present §. *Agricultural Economics Research Review*, *26*(2), 293–297.

Guush Berhane, Zelekawork Paulos, Kibrom Tafere, and Seneshaw Tamru (2011). *Foodgrain Consumption and Calorie Intake Patterns in Ethiopia*.

Hagstrum, D. W., & Subramanyam, B. (2009). Stored-Product Insect Resource; AACC International: St. *Paul, MN, USA*, 1–505.

Haines, C. P. (1991). *Insects and arachnids of tropical stored products: their biology and identification (a training manual)*. Nri.

Harris, K. L., & Lindblad, C. J. (1976). *POSTHARVEST GRAIN LOSS ASSESSMENT METHODS. A Manual of Methods for the Evaluation of Postharvest Losses*. 1–185.

Hell, K., Cardwell, K. F., Setamou, M., & Poehling, H.-M. (2000). The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *Journal of Stored Products Research*, *36*(4), 365–382.

Hengsdijk, H., & de Boer, W. J. (2017). Post-harvest management and post-harvest losses of cereals in Ethiopia. *Food Security*, *9*(5), 945–958. https://doi.org/10.1007/s12571-017-0714-y

Holst, N., Meikle, W. G., & Markham, R. H. (2000). Grain injury models for Prostephanus truncatus (Coleoptera: Bostrichidae) and Sitophilus zeamais (Coleoptera: Curculionidae) in rural maize stores in West Africa. *Journal of Economic Entomology*, *93*(4), 1338–1346.

Hubert, J., Stejskal, V., Munzbergova, Z., Kubatova, A., Váňová, M., & Žd'Árková, E. (2004). Mites and fungi in heavily infested stores in the Czech Republic. *Journal of Economic Entomology*, *97*(6), 2144–2153.

Hughes, A. M. (1976). *The mites of stored food and houses.* (Issue 2nd edition). Her Majesty's Stationery Office.

Ivbiljaro, M. F. (1981). The resistance of new varieties of maize to post-harvest infestation by Sitophilus zeamais Motsch and Sitophilus oryzae (L.). *The Journal of Agricultural Science*, *96*(2), 479–481.

Karabhari Rekha Bhaskar, & Kunde Padmakar C. (2014). INDIGENOUS FOOD GRAIN STORAGE \nPRACTICES FOLLOWED BY TRIBAL FARMERS \nOF NANDURBAR DISTRICT. *Golden Research Thoughts*, *4*(4), 1–4. http://aygrt.isrj.org/UploadedData/4615.pdf

Khosravi, A. R., Mansouri, M., Bahonar, A. R., & Shokri, H. (2007). Mycoflora of maize harvested from Iran and imported maize. *Pakistan Journal of Biological Sciences: PJBS*, *10*(24), 4432–4437.

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, *6*(1), 8.

Kumar, R., Mishra, A. K., Dubey, N. K., & Tripathi, Y. B. (2007). Evaluation of Chenopodium ambrosioides oil as a potential source of antifungal, antiaflatoxigenic and antioxidant activity. *International Journal of Food Microbiology*, *115*(2), 159–164. https://doi.org/10.1016/j.ijfoodmicro.2006.10.017

Longe, O. (2010). Investigations into fumigant toxicity of mixed formulations of commercially produced Eucalyptus oil and Eugenia aromatica dust to Sitophilus zeamais (Motschulsky). *International Journal of Biological Science*, *2*(5), 83–87.

Makundi, R. H. (2009). *The mysteries of the rats*.

Manandhar, A., Milindi, P., & Shah, A. (2018). An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. *Agriculture*, *8*(4), 57.

Mashilla Dejene (2004). Grain Storage Methods and Their Effects on Sorghum Grain Quality in Hararghe , Ethiopia. *Doctoral Thesis Swedish University of Agricultural Sciences*.

Mendesil, E., Abdeta, C., Tesfaye, A., Shumeta, Z., & Jifar, H. (2007). Farmers' perceptions and management practices of insect pests on stored sorghum in southwestern Ethiopia. *Crop Protection*, *26*(12), 1817–1825. https://doi.org/10.1016/j.cropro.2007.03.018

Midega, C. A. O., Murage, A. W., Pittchar, J. O., & Khan, Z. R. (2016). Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. *Crop Protection*, *90*, 142–149. https://doi.org/10.1016/j.cropro.2016.08.033

Mihale, M. J., Deng, A. L., Selemani, H. O., Kamatenesi, M. M., Kidukuli, A. W., & Ogendo, J. O. (2009). 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*, *3*(9).

Minister of Agriculture (2000). *Agroecological Zonations of Ethiopia.* Addis Ababa Ethiopia.

Mollah, M. R. A., Ali, M. A., Prodhan, M. Z. H., Rahman, M. M., & Alam, M. J. (2016). Effect of containers on storability of true seeds of onion. *European Journal of Biomedical and Pharmaceutical Sciences*, *3*(1), 1–4.

Mwangi, J. K., Mutungi, C. M., Midingoyi, S.-K. G., Faraj, A. K., & Affognon, H. D. (2017). An assessment of the magnitudes and factors associated with postharvest losses in off-farm grain stores in Kenya. *Journal of Stored Products Research*, *73*, 7–20.

Nand, V. (2015). Effect of spacing and fertility levels on protein content and yield of hybrid and composite maize (Zea mays L.) grown in rabi season. *J. Agric. Vet. Sci*, *8*(9), 26–31.

Negussie Efa, Gorman, M., & Phelan, J. (2005). Implications of an Extension Package Approach for Farmers' Indigenous Knowledge: The Maize Extension Package in South-western Ethiopia. *Journal of International Agricultural and Extension Education*, *12*(3). https://doi.org/10.5191/jiaee.2005.12306.

Nyambo, B. T. (2008). *Post - harvest maize and sorghum grain losses in traditional and improved stores in South Nyanza District , Kenya*. *0874*. https://doi.org/10.1080/09670879309371787.

Obeng-Ofori, D., & Amiteye, S. (2005). Efficacy of mixing vegetable oils with pirimiphos-methyl against the maize weevil, Sitophilus zeamais Motschulsky in stored maize. *Journal of Stored Products Research*, *41*(1), 57–66.

Olayemi, F. F., Adegbola, J. A., Bamishaiye, E. I., & Awagu, E. F. (2012). Assessment of postharvest losses of some selected crops in eight local government areas of rivers state, Nigeria. *Asian Journal of Rural Development*, *2*(1), 13–23.

Olsson, S., & van Hage-Hamsten, M. (2000). Allergens from house dust and storage mites: similarities and differences, with emphasis on the storage mite Lepidoglyphus destructor. *Clinical and Experimental Allergy: Journal of the British Society for Allergy and Clinical Immunology*, *30*(7), 912–919.

Palyvos, N. (2017). *Seasonal abundance and vertical distribution of mites in flat storage containing wheat Seasonal Abundance and Vertical Distribution of Mites in Flat Storage Containing Wheat*. *February 2006*. https://doi.org/10.1007/BF02981336.

Pingali, P., & Pandey, S. (2001). *Meeting world maize needs: technological opportunities and priorities for the public sector*.

Probst, C., Bandyopadhyay, R., & Cotty, P. J. (2014). Diversity of aflatoxin-producing fungi and their impact on food safety in sub-Saharan Africa. *International Journal of Food Microbiology*, *174*, 113–122.

Quellhorst, H., Athanassiou, C. G., Zhu, K. Y., & Morrison III, W. R. (2021). The biology, ecology and management of the larger grain borer, Prostephanus truncatus (Horn)(Coleoptera: Bostrichidae). *Journal of Stored Products Research*, *94*, 101860.

Rahman, M. M., Islam, W., & Ahmed, K. N. (2009). Functional response of the predator Xylocoris flavipes to three stored product insect pests. *International Journal of Agriculture and Biology*, *11*(3), 316–320

Ramírez-Martínez, M., de Alba-Avila, A., & Ramírez-Zurbía, R. (1994). Discovery of the larger grain borer in a tropical deciduous forest in Mexico. *Journal of Applied Entomology*, *118*(1-5), 354–360.

Rees, D. (2007). *Insects of stored grain: a pocket reference*. CSIRO publishing.

Sánchez-Borges, M., Fernandez-Caldas, E., Thomas, W. R., Chapman, M. D., Lee, B. W., Caraballo, L., Acevedo, N., Chew, F. T., Ansotegui, I. J., & Behrooz, L. (2017). International consensus (ICON) on: clinical consequences of mite hypersensitivity, a global problem. *World Allergy Organization Journal*, *10*, 1–26.

Sauer, D. B. (1988). Effects of fungal deterioration on grain: nutritional value, toxicity, germination. *International Journal of Food Microbiology*, *7*(3), 267–275.

Schulten, G. G. M. (1982). Hunger Technology and Society: Post-Harvest Losses in Tropical Africa and their Prevention. *Food and Nutrition Bulletin*, *4*(2), 1–7.

Shah, D. (2013). Assessment of pre and post harvest losses in tur and soyabean crops in Maharashtra. *Agro-Economic Research Centre Gokhale Institute of Politics and Economics*.

Stejskal, V., & Hubert, J. (2008). Risk of occupational allergy to stored grain arthropods and false pest-risk perception in Czech grain stores. *Ann Agric Environ Med*, *15*(1), 29–35.

Suleiman, R., Rosentrater, K. A., & Bern, C. (2013). Effects of deterioration parameters on storage of maize: A review. *Journal of Natural Sciences Research*, *3*(9), 147–165.

Swanepoel, L. H., Swanepoel, C. M., Brown, P. R., Eiseb, S. J., Goodman, S. M., Keith, M., Kirsten, F., Leirs, H., Mahlaba, T. A. M., & Makundi, R. H. (2017). A systematic review of rodent pest research in Afro-Malagasy small-holder farming systems: Are we asking the right questions? *PloS One*, *12*(3), e0174554.

Tadele Tefera, T., Kanampiu, F., De Groote, H., Hellin, J., Mugo, S., Kimenju, S., Yoseph Beyene, Boddupalli, P. M., Bekele Shiferaw & Banziger, M. (2011). The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop Protection*, *30*(3), 240–245.

Tadele Tefera, Mugo, S., & Likhayo, P. (2011). *Effects 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 truncatus*.

Thamaga-Chitja, J. M., Hendriks, S. L., Ortmann, G. F., & Green, M. (2004). Impact of maize storage on rural household food security in Northern Kwazulu-Natal. *Journal of Consumer Sciences*, *32*.

Tigar, B. J., Key, G. E., Flores-s, M. E., & Vazquez-a, M. (1994). Field and post-maturation infestation of maize by stored product pests in Mexico. *Journal of Stored Products Research*, *30*(1), 1–8.

Tsedeke Abate, Bekele Shiferaw, Abebe Menkir, Dagne Wegary, Yilma Kebede, Kindie Tesfaye Menale Kassie,Gezahegn Bogale, Berhanu Tadesse and Tolera Keno (2015). Factors that transformed maize productivity in Ethiopia. *Food Security*, *7*(5), 965–981. https://doi.org/10.1007/s12571-015-0488-z

Tsedeke Abate, Van Huis, A., & Ampofo, J. K. O. (2000). Pest management strategies in traditional agriculture: An African perspective. *Annual Review of Entomology*, *45*(February), 631–659. https://doi.org/10.1146/annurev.ento.45.1.631

Tsehaynew Wubetu & Berhanu Hiruy (2020). The Status of Insect Pests Prevailing in Stored Wheat Grain under Traditional Storages of Cheha District of Gurage Zone of South Central Ethiopia. *Journal of Applied Life Sciences International*, *23*(1), 1–7. https://doi.org/10.9734/jalsi/2020/v23i130137

Upadhyay, R. K., & Ahmad, S. (2011). Management strategies for control of stored grain insect pests in farmer stores and public ware houses. *World Journal of Agricultural Sciences*, *7*(5), 527–549.

VICTOR, R., & OJARUEGA, E. (1993). Humidity responses of the maize weevil Sitophilus zeamais Motsch (Coleoptera; Curculionidae) under laboratory conditions. *African Journal of Ecology*, *31*(4), 337–342.

Waktole Sori (2014). Effect of selected botanicals and local seed storage practices on maize insect pests and health of maize seeds in Jimma Zone. *Singapore Journal of Scientific Research*, *4*(2), 19–28.

Waktole Sori & Amsalu Ayana (2012). Storage pests of maize and their status in Jimma Zone, Ethiopia. *African Journal of Agricultural Research*, *7*(28), 4056–4060.

Wambugu, P. W., Mathenge, P. W., Auma, E. O., & Van Rheenen, H. A. (2009). Efficacy of traditional maize (Zea mays L.) seed storage methods in western Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, *9*(4).

ŽĎárková, E., & Reška, M. (1976). Weight losses of groundnuts (Arachis hypogaea L.) from infestation by the mites Acarus siro L. and Tyrophagus putrescentiae (Schrank). *Journal of Stored Products Research*, *12*(2), 101–104.

APPENDICES

Appendix 1. Analysis of variance (ANOVA) for mean percentage weight loss of maize in Bako Kebele in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	0.25578024	0.12789012	31.50	0.0007
Within Groups	6	0.02435699	0.00405950		
Total	8	0.28013724			

Appendix 2. Analysis of variance (ANOVA) for mean percentage grain damage of maize in Bako Kebele in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	28.21468889	14.10734444	67.35	<0.0001
Within Groups	6	1.25686667	0.20947778		
Total	8	29.47155556			

Appendix 3. Analysis of variance (ANOVA) for mean percentage weight loss of maize in Bayitsemal Kebele in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	566.9072222	283.4536111	225.61	<0.0001
Within Groups	6	7.5383333	1.2563889		
Total	8	574.4455556			

Appendix 4. Analysis of variance (ANOVA) for mean percentage grain damage of maize in Bayitsemal Kebele in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	2267.922756	1133.961378	116.23	<0.0001
Within Groups	6	58.538933	9.756489		
Total	8	2326.461689			

Appendix 5. Analysis of variance (ANOVA) for mean percentage weight loss of maize in Giste Kebele in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	635.0606000	317.5303000	455.57	<.0001
Within Groups	6	4.1820000	0.6970000		
Total	8	639.2426000			

Appendix 6. Analysis of variance (ANOVA) for mean percentage grain damage of maize in Giste Kebele in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	2735.315556	1367.657778	446.14	<.0001
Within Groups	6	18.393333	3.065556		
Total	8	2753.708889			

Appendix 7. Analysis of variance (ANOVA) for mean percentage weight loss of maize in Kaysa Kebele, in *Gotera*, Hanging without smoke and Hanging over smoke

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	662.3984222	331.1992111	2253.91	<.0001
Within Groups	6	0.8816667	0.1469444		
Total	8	663.2800889			

Appendix 8. Analysis of variance (ANOVA) for mean percentage grain damage of maize in Kaysa Kebele, in Gotera, Hanging without smoke and Hanging over smoke.

Source of variation	Df	Sum of square	Mean square	F value	P
Between Groups	2	3002.977222	1501.488611	1361.89	<.0001
Within Groups	6	6.615000	1.102500		
Total	8	3009.592222			

Appendix 9.Type of maize storage methods (put √ for most commonly used and × for less used)

Ser no.	Activities	Most commonly used	Less used
1	*Gotera*		
2	Hanging without smoke		
3	Hanging over smoke		
4	Other		

Appendix 10.Types of Gotera (put √ for most commonly used and × for less used)

S. no.	Activities	Most commonly used	Less used
1	Plastered		
2	Unplastered		
3	Partially plastered		
4	Other		

Appendix 11.Form of stored maize (put √ for most commonly used and × for less used)

S. no.	Activities	Most commonly used	Less used
1	As shelled grain		
2	In the Intact husk		
3	De husked		
4	Other		

Appendix 12. Questionnaire's on assessment of Maize Grain Storage Practices and related aspects

I. Personal information

1. Age ______ Sex _______ Educational status______________________________

2. How long have you lived in this area? ______________ year

II. General information

A. Storage practices

3. When is the harvested maize stored?

A. Immediately after the harvest B. Keeping temporarily till dry_____

4. If you keep temporarily till dry? Why do you do so______?

5. Where do you keep your maize temporarily till dry?

A. On the field B. In the house C. Mention if there is any other________

6. For how long do you store your crop? _____

7. What storage method do you use? List

____

8. Where is your storage structure located?

A. Field B. In the house C. Courtyard D. any other (indicate, please)______

9. What construction material did you use to make your store?

A. Wood B. Clay C. Metal D. any other (indicate, please)

10. For how many seasons have you used the store? _____

11. Do you store other products in the store, together with maize?

A. Yes B. No, list ______

Storage problems

11. Do you encounter storage pest?

A. Yes B. No

12. Which storage pest is the most important?

A. Insects B. Rodents C. Birds D. Mould E. Others (indicate, please) ______

13. When do you encounter storage pest infestation?

A. From the beginning of the storage B. Few months after the storage

C. Up on empting the store for the next storage season

14. What method did you use to solve the pest problem? List, please

____

____

15. Did you use maize grain treatment chemical for the storage

A. Yes B. No

16. If yes which type of chemical did you used? List (please)

____

____

17. Any other idea.

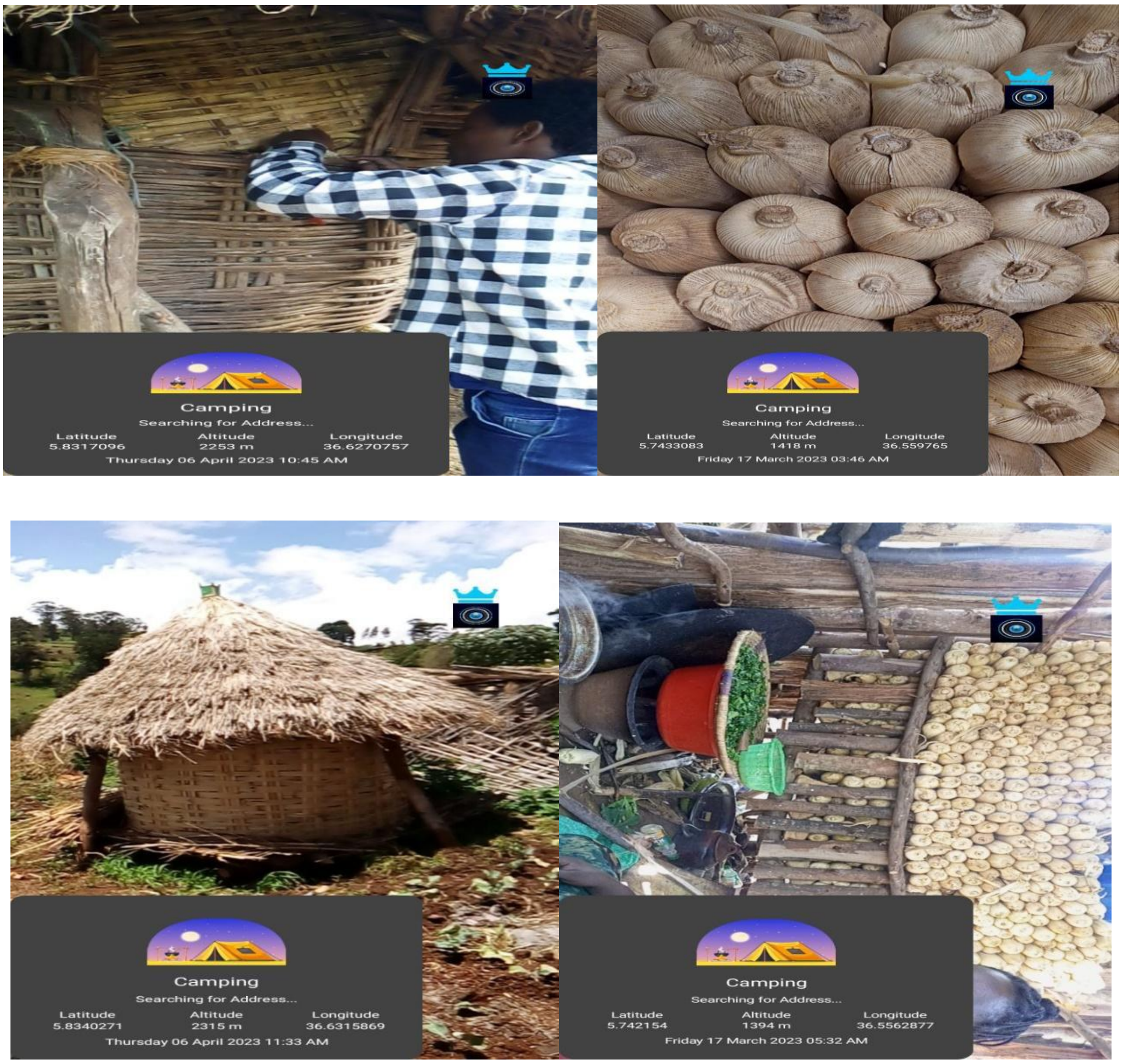
____

____

____

Appendix 13. Pictures taken during interview

Appendix 14. Pictures taken during sample collection



Appendix 15. Pictures taken during laboratory work