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EFFECTIVENESS OF POLYETHYLENE SHEET LINING AND FILTER CAKE APPLICATION IN GOTTA AND POLYPROPYLENE BAG FOR THE PROTECTION OF STORED MAIZE FROM INSECT

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BY

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By

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A Thesis Submitted to the School of Research and Graduate Studies of Bahir Dar Institute of Technology, Bahir-Dar University for the partial fulfillment of the requirements for the degree

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Masters of Science in food technology, faculty of chemical and food engineering

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Co-advisor name: Karta Kaske (Ph.D. candidates)

Bahir-Dar, Ethiopia

January, 2019

DECLARATION

I declare that this study is my original work which has not been presented or done yet in any other academic institute or university

Student

____ ____________________________

Anmut Mulualem Shibeshi Signature Date

Date of submission: ________________

Place: Bahir Dar

This thesis has been submitted for examination with my approval as a university advisor.

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Advisor's Signature: ______________________________

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ABSTRACT

Maize is one of the most important staple cereals in Ethiopia. One of the challenges for maize production in the country is lack of appropriate technologies for post-harvest handling of the crop. Particularly, the storage loss associated to stored product insects is a threat to food security of small holder farmers relying on maize production. Therefore, objective of this study was to evaluate the effectiveness of different storage strategies for the protection of stored maize grain from insect under farmers' conditions. The experiment was conducted in farmers' houses for 6-months and included six storage methods such as 1) Gotta with filter cake (FC+GOTTA),2) Gotta with polyethylene sheet lining(GOTTA+PE),3) Gotta without any treatment (farmers' practice),4) polypropylene bags (PPB) with polyethylene sheet lining(PPB+PE), 5) polypropylene bag without polyethylene sheet lining (farmers' practice) 6) Perdue improved storage bag (PICS) (positive control). Data on thousand kernel weight (TKW), bulk density, moisture, starch, protein, oil, total ash, insect count, % grain damage, % weight loss, and % germination were collected at outset of the experiment, three months after storage and six months after storage. Moisture in FC+GOTTA was decreased from 13.3 % to 11.8 % at the end of storage. Bulk density was decreased from 784.2kgm^{-3} to 744.7 kgm^{-3} in PPB bag and from 789.5kgm^{-3} to 741.8kgm^{-3} in GOTTA during the storage period. Mean germination of maize grain from farmers' storage practices was 71% while over 95% of germination was recorded in FC+GOTTA, PE+GOTTA and PICS. Insect counts recorded in FC+GOTTA, PE+GOTTA and PICS were very low while farmers' storage practices exhibited rapid increases of in insect population. Mean values of counts of live weevils were 78 weevil kg^{-1} in GOTTA and 62 weevil kg^{-1} in PPB bag, 19 weevil kg^{-1} in PPB+PE, 4 weevil kg^{-1}in PICS, 2 weevil kg^{-1} in GOTTA+PE, and 0 weevil kg^{-1} in FC+GOTTA. Moreover, mean values of grain damage were 21% in GOTTA, 13% in PPB bags, 0.7% in PE+PPB, 0.4% in PICS, 0.4% in PE+GOTTA and 0.0% in FC+GOTA. In this study, 2.7% of loss in GOTTA and 1.75% loss in PPB was recorded at the end of 6-months storage. Lower mean values of percentage of grain damage and weight loss were observed in PICS, FC+GOTTA, GOTTA+PE compared to PPB bags and GOTTA. Hence, they are more effective storage strategies that I recommended them for use by small scale-farmers. Hence storing maize using PICS, PE+GOTTA, FC+GOTTA should be promoted for reduce grain damage and loss without use of synthetic chemicals.

Key words: *Loss, Insect, Polyethylene Sheet, Strategy, Gotta, Filter Cake:*

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ABBREVIATION

ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemists
ARARI	Amhara Region Agricultural Research Institute
ATA	Agricultural Transformation Agency
CA	Controlled Atmosphere
CSA	Central Statistical Agency
DB	Dry Basis
DE	Diatomaceous Earth
FC	Filter Cake
HDPE	High Density Polyethylene
ISTA	International Seed Testing Association
IRRI	International Rice Research Institute
MA	Modified Atmosphere
PE	Polyethylene
PHL	Post-Harvest Loss
PICS	Perdue Improved Crop Storage
PPB	Polypropylene Bags
SE	Standard Error
SNNP	Southern Nation and Nationalities
TKW	Thousand Kernel Weight

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1. INTRODUCTION

Maize is one of the most important cereal crops grown in sub-Saharan Africa (SSA) with production constituted mainly by smallholder farmers who rely on agriculture for their livelihood (Chigoverah et al., 2014). Recently, Divekar & Sharma (2016) reported that, 31% maize is produced in United States, 24% in China,8% in Brazil . In Ethiopia, a study by Hiruy & Getu (2018) reported that maize is one of the major staple cereal grain produced annually. In Ethiopia, maize grows at altitudes between 500 to 2400 m above sea level. According to a report by Ethiopian Agricultural Transformation Agency (ATA), 9 million agrarian farmers produce 6 million ton from 2 million hectare of land of which 75% of production is used for household activity in subsistence farming (ATA, 2013-2017).

Seasonality of grain production amid constant demand throughout the year gives storage a critical role to play in ensuring household food security and source of income until the next harvest (Chigoverah et al., 2014). The accessibility, availability and safety of this important food crop are endangered by insect pests, rodents and fungal attacks due to improper storage methods (Anankware et al., 2012). It has been reported that about 140 million hectares of maize grown annually in the tropics are stored at farm level for a long time in granary (gotra) which is exposed for extreme drying and moisture reconstitution with no any application of chemical preservatives (Yakubu and Bern ,2009). In addition to insect pest, maize grain becomes contaminated and infected at any stage of production including cultivation, harvesting, drying, storage, transportation and marketing by a variety of molds, such as *Fusarium, Aspergillus and Penicillium* spp. (Jeremiah, 2016) The infection not only reduces quality of the maize through kernel discoloration and reduction of nutritional value. Therefore, the aim of this study was to assess the effectiveness of polyethylene sheet lining and filter cake application in *Gotta* and polypropylene bag for protection of stored maize from insects.

1.1. Background

Different types of stored product insects deteriorate maize. Among these, the maize weevil (*Sitophilus zeamais)* is the main deteriorative insect on stored maize and other stored cereals. According to Demissie et al.(2008) &Yakubu et al.(2011), about 20% to 30% of stored maize is lost due to maize weevil or *Sitophilus zeamais*. Based on Demissie et al.(2008) findings, 100% damage was observed on maize stored from 6 to 8 month in Bako Research Center in western Ethiopia.

Traditional storage systems in Ethiopia such as gotta, mud block silo, storage crib, underground pit, sack/bags, earthen container, gotera ,e t c are common ineffective storage system (Befikadu, 2014). These traditional storage systems create conducive environments for insect development. Hence, huge amount of maize is lost at farm stores due to insect pest attack and mold contamination. In order to overcome this problem, chemical pesticides are used as solely option in smallholder farmers of some part of Africa to protect stored maize from insect pests (Chigoverah et al., 2014), however, chemical pesticides have been associated with adverse health effect on human being and consumers (Demissie et al.,2008). Synthetic pesticides are environmentally hazardous. Besides, the presence of their toxic residue on food, developments of resistance by targeted species, their limited accessibility and their expensiveness led researchers to look other alternative option of grain preservation technologies to overcome the former chemical's negative impact in smallholder subsistence farmers in Africa (Dejene, 2004).

Researchers have developed an environmentally safe option called hermetic principles of grain storage technology (Murdock et al.,2012). This technology works by modifying the surrounding atmosphere. Since sealed tightly, the metabolic activity of living organism like insects in stored maize is disturbed by reducing oxygen concentration and by increasing carbon dioxide concentration within the store plastic bags, consequently, reduction in feeding activity and increase in concentration of toxic compounds in insect pests' body are leading them final death (Chigoverah et al.,2014). In addition to hermetic bags, inert dust like wood ash, sand, silica aerogels, diatomaceous earth, filter cake powder are reported to be effective option in controlling of mold contamination and development insect pest in stored maize and these inert dusts are very effective in smaller quantities (Girma Demissie et al.,2008). Moreover, inert dusts have advantages in grain preservation technology such as their long-term protection, simple application and accessibility, their low human toxicity, maintain of grain quality (Hiruy & Getu, 2018).In this study, post-harvest loss during storage and drying was try to be investigated to adverse health effect of chemical preservative was also try be reduced.

1.2. Problem Statement

In Ethiopia, traditional storage system has served as the major method to store cereals including maize. However, under farmers' storage systems maize grain is subjected to insect damage and subsequent weight loss. Hence, rural farmers face the challenging on maize grain of storage. Many farmers avoid incurring storage losses by selling grain soon after the harvest at low prices. By selling their grain at low price at harvest, farmers are usually obliged to buy grain later at a higher price, consequently falling into the poverty trap (Chigoverah et al., 2014). This results family level food insecurity.

To overcome such food insecurity, farmers are practicing by using chemicals and insecticides as sole options to protect of their grain from insect and mold damage. However, it is well recognized that, misuse and improper handlings of chemicals are associated with health risks (Mutungi et al.2014). In Ethiopia, smallholder farmers purchase small amounts of unknown pesticides from local shops and self-apply the chemical to their grains to control insect pests. The paper reported that farmers are improperly trained and not knowledgeable on proper and safe use of pesticides(Girma Demissie et al.,2008).

During recent years, effective low-cost chemical free options such as hermetic bags and inert dust are being promoted (Njoroge et al., 2014b). But, the accessibility and feasibility of hermetic bags under the traditional system are limited due to lack of awareness and knowledge on behalf of farmers and lack of advertising on sides of government or producers. Therefore, there is an urgent need to look for techniques, which are locally available (cheaper), and safe alternatives that can be morphed into the existing traditional system. Hence, lining traditional Gotta with polyethylene sheets and treating stored grains with filter cake in Gotta may provide a locally available option that can overcome the problem associated with the traditional system. Such intervention could be environmentally sound and economically feasible, and shall incur less or not the risk.

1.3. Objective

To evaluate effectiveness of polyethylene sheet lining and filter cake application in “GOTTA” and polypropylene bag (PPB) against insect infestation of stored maize.

Specific objective

- ✓ To evaluate the effects of polyethylene sheet lining and filter cake application in GOTTA and polypropylene bags (PPB) on insect infestation and associated loss in stored maize grain
- ✓ To evaluate the effects of polyethylene sheet lining and filter cake application in GOTTA and polypropylene bags (PPB) on physicochemical and germination characteristics of stored maize

Scope and Significance of the study

Maize is the most important cereal crop in Ethiopia. In Ethiopia, the crop is a major source of calories and income for many households. However, maize grains are often infested by insect rodent and molds. Infestation by both insects and rodents create pathways for microbial contamination, spoilage and thus food loss. Today’s consumers demand for chemical-free food due to increased attention to health hazards posed by contaminants calls for noble methods of postharvest commodity storage. In this regard there is need to develop more efficient and effective technologically sound approaches for ensuring food safety and security. For instance, triple layer hermetic bagging (PICS) and inert dusts such as diatomaceous earth and filter cake are used to store and preserve the harvested products. This study was therefore to evaluate effectiveness polyethylene sheet lining and filter cake application in gotta and polypropylene bag for the protection of stored maize from insect.

2. LITERATURE REVIEW

2.1. Maize production in Ethiopia

Over 1.2 billion people in Africa consuming maize crop as food (Nda-Agyima & Addae-Mensah, 2014). It uses as animal feed, processed food, flour, and sweeteners & processed into numerous dishes depending on locality and ethnicity, accounts for 30-50% of the daily caloric intake of foodstuff consumed by smallholder farmers in most developing country (Jeremiah, 2016). Maize is common cereals with consumers' with simple and easy to process, it's easy palatability, high yield and cost-effective than other cereals (Yakubu and Bern,2009)

Maize (Zea Mays L.) is the main staple food and economic cereal crop in sub-Saharan Africa (Mwangangi et al.,2013; Tounou et al.,2013; Hell et al.,2014). About 875,226,630 tons of maize produced in the world is predicted to be covered by United States, China, and Brazil with percentage of 31%, 24%, and 8% respectively (Divekar & Sharma, 2016) . Similarly, the rest maize producing countries were Argentina (2.54%), India and Mexico (2.48% and 2.36% respectively), Ukraine (2.59 %), South Africa (1.38 %), and other (15.77 %) reported by (Rashid et al., 2013).

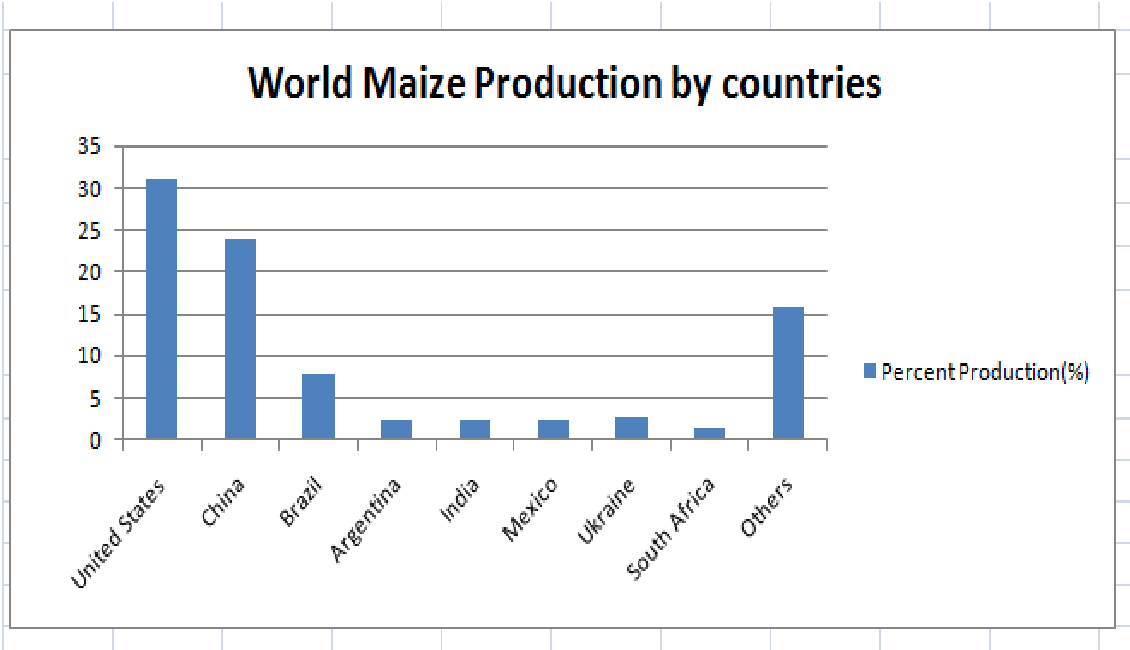

Figure 2.1: The top maize producing country in the world (Rashid et al., 2013**)**

In Ethiopia, maize (Zea Mays L.) is most important, popular staple cereal crops largely grown in many environmental zones, and it grows in large range ecological zones and conditions with an altitude ranging b/n 500 to 2400 meters above sea level. According to Ethiopian agricultural transformation agency report, 6 million tons were produced in 2012 from 2 million hectares of land by 9 million agrarian farmers in Ethiopia (ATA, 2013-2017) and from 9 million farmers,75% of maize grower agrarian farmers grow maize for household consumption. Maize produced in Ethiopia is generally a good source of calorie intake with 20.6% per capital (ATA, 2013-2017). Researchers have reported that increased production and productivity of maize is investigated in the Ethiopian Institute of Agricultural Research (Bako Agricultural Research Center) because of advance in hybrid varieties (Sori & Ayana,2012).

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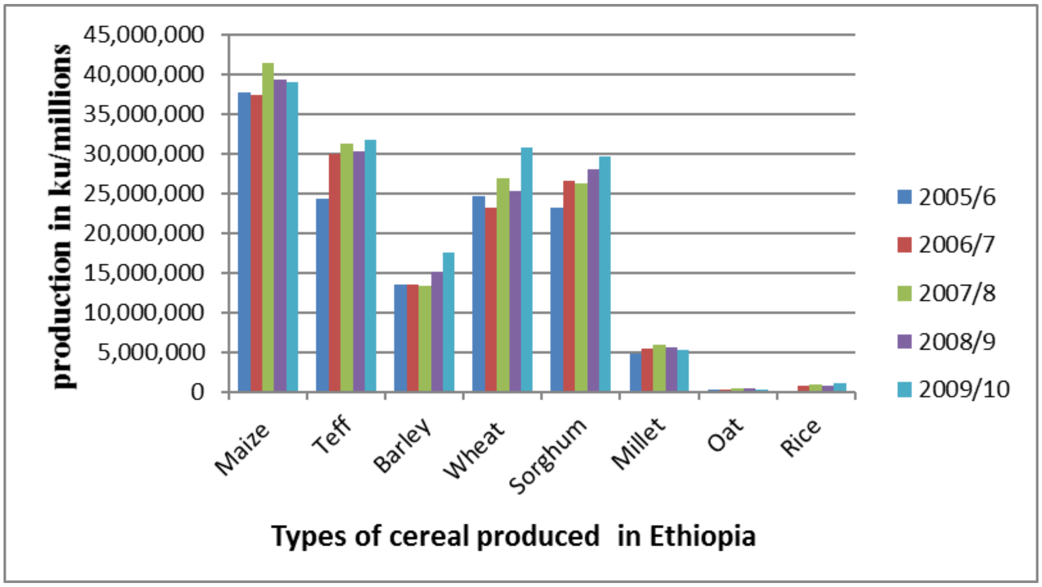


Figure 2.2: Cereal grain production in Ethiopia (CSA, 2005/6-2010)

Based on Ethiopian agricultural and transformation agency report, the major maize growing area are Oromia, Amhara, SNNP, and Tigray. Almost 80% of maize production in Ethiopia is covered by the two main regions of Oromia and Amhara (ATA,2013-2017).

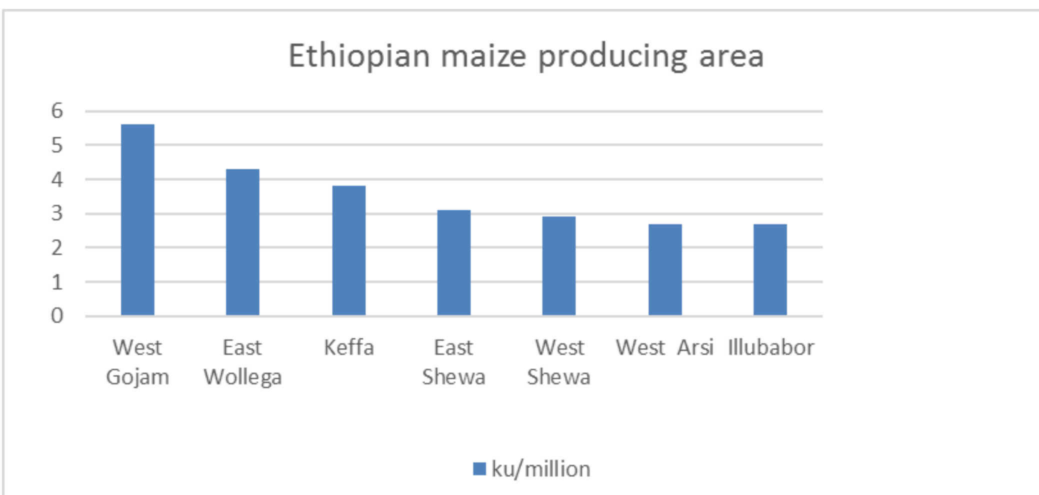


Figure 2.3: Main maize producing zone in Ethiopia (ATA,2013-2017)

2.2. Physicochemical property of Maize grain

Chemical composition of maize crop

Maize has an equivalent nutritional composition of starch, protein, little amount of fat, vitamin, dietary fibers and mineral iron and phosphorus to wheat and rice (Jeremiah, 2016). It has been reported that, maize contains about 76 – 88% carbohydrate, 6- 15% protein, 4.5 - 7% fat and 1.3% minerals and supplying energy density of 365 Kcal/100g (Mbah & Okoronkwo, 2008; Suleiman et al, 2013). Currently, other researchers, Ashwin et al.(2017) reported that, maize has nutrient content of 10% proteins, 4% oil, 70% carbohydrates, 2.3% crude fiber, 10.4% albuminoids and 1.4% ash, however, in terms of protein content, maize contains lower protein content than other cereals like rice and wheat. In the (Figure 2.4) three parts maize plants such as endosperm, pericarp and embryo is demonstrated (Ranum et al, 2014; Jeremiah, 2016).

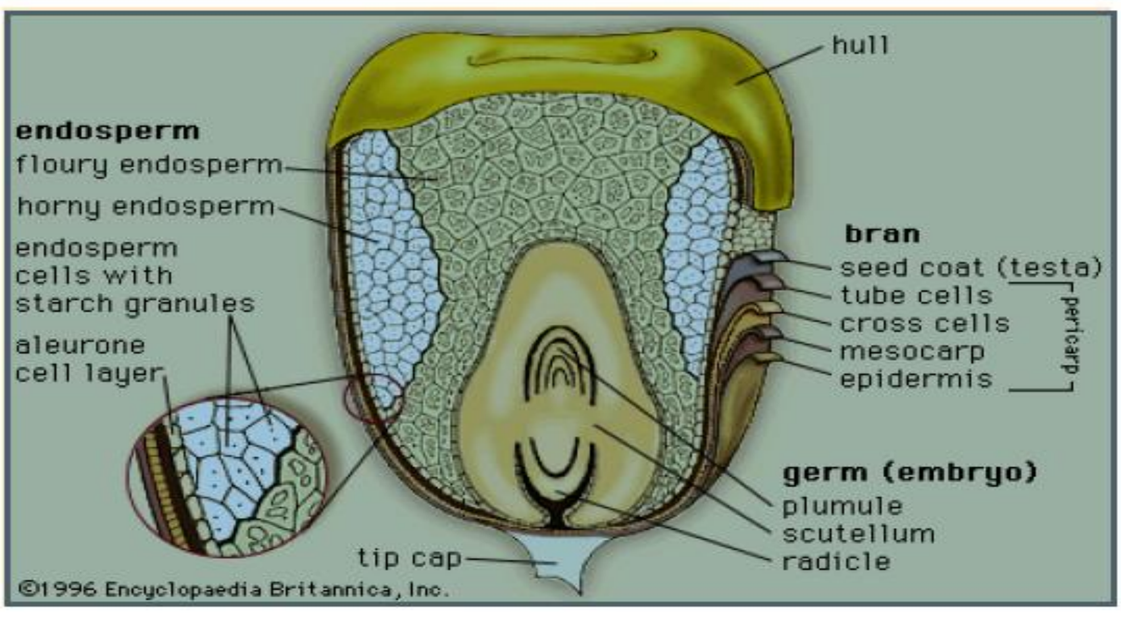


Figure 2.4: Maize kernel of outer layer and internal structure (Jeremiah, 2016)

The bran is the protective outer covering of the grain kernel. Bran is high in dietary fiber. The floury endosperm (at the opposite end from the germ), which is light in color, contains loosely packed starch granules with little protein, whereas the horny endosperm (towards the base), which is more intensely colored in yellow varieties, and has smaller starch granules which are embedded in sheets of proteinaceous material. The germ is the embryo of the cereal grain and its sprout germinates and grows into roots and leaves from the radicle and plumule respectively.

Hydrolytic enzymes released into the starchy endosperm. Grain damaged by micro-flora undergoes chemical changes which effect in increase in free fatty acids (FFA), an increase in reducing sugars, a decrease in non-reducing sugars and an increase in measure of grain deterioration mainly due to mold growth. Biochemical deterioration of grain fats or oils is either oxidative or hydrolytic. Fats in grain are readily broken down by lipases into free fatty acids and glycerol during grain storage especially when moisture content and temperature are high and hence favorable for grain deterioration (Nda-Agyima & Addae-Mensah, 2014).

Table 2.1: Proximate chemical composition of main parts of maize kernels (% DB)

Chemical component	Pericarp	Endosperm	Germ
protein	3.7	8.0	18.4
fat	1.0	0.8	33.2
Crude fiber	86.7	2.7	8.8
ash	0.8	0.3	10.5
Starch	7.3	87.6	8.3
sugar	0.36	0.62	10.8

Source: Ranum et al.(2014)

Physical property of maize grain

Bulk density is one of a physical property of maize used to determine the rate at which cereals flow in grain dryer and the volume of storage intermediates necessary to store the preferred amount of cereal grains and thousand kernel weights are the physical property of maize, which frankly or directly linked to drying rate of the cereal grain. The proportion of the number of grain influences the resistance of a grain bulk to airflow defines to be porosity.

Table 2.2: Physical properties of maize grain

Property	**Maize (S.I units)**
Bulk density	745 kg/m3
1000-kernel weight	325 g

Source: Nda-Agyima & Addae-Mensah (2014)

The amount of water in the kernel can be expressed on a percent wet basis (% w.b) by subtracting the amount of kernel dry matter from the total wet mass and dividing by the total wet mass. since kernel dry matter is denser than water, bulk density should increase with a decrease of kernel moisture (Guo, 2015).

There are three kinds of density that relate to the density of a single particle, which could be used to express the kernel density. The first is the true density, which is the weight per unit volume of the solid particle that excludes any internal and external pores (Guo, 2015). The second is the apparent density, which is the weight per unit volume of the solid particle, which includes internal pores but excludes external pores. It is usually measured using a gas pycnometer. The third is the envelope (aerodynamic) density, which is the weight per unit volume of the solid materials including both internal pores and external pores.

$$\rho true = \frac{m}{vsolid}$$

$$\rho apparent = \frac{m}{vsolid + vinternal\, pores}$$

$$\rho envelop = \frac{m}{vsolid + vinternal\, pores + vexternal\, pores}$$

From these equations we can see that $\rho true \geq \rho apparent \geq \rho envelope$(Guo, 2015) where, ρ = density v=the volume of solid

2.3. The postharvest loss in maize grain in developing country

Post-harvest loss in cereal grain due to insect pest damage in Africa is estimated to be at arranging 20% to 30% reported by (Mwangangi & Mutisya et al., 2013). The main causative agent in this post-harvest loss in stored cereal grain in Africa is insect pests, microorganism (molds, birds, rodents and mites). Among these deteriorative agents, the most and series causative agents are insects (Abraham & Firdissa, 2000).It is estimated that 1% to 5% of stored grain in developed countries and 20% to 50% of stored grain in developing countries are lost due to insect damage (Rashid et al., 2013). More than 500 insect species are reported to be associated with grain, among which 250 are directly linked to maize grain both in field and in storage conditions (Rashid et al., 2013). It has shown that maize grain loss in Africa is predicted to be in a range of 14% to 36% from production and harvesting to end customers (Befikadu et al., 2015). In addition to low production, (Table 2.3) shows developing countries lose a majority of their yield to poor handling, storage and infrastructure, with a total weight loss of 24.5%.

Table 2.3: PHL of maize grain during handling, transportation, storage and marketing

Post-harvest activity	Post-harvest loss (%)
Harvesting/field drying (bird, rodent, insect, missing grain, excessive drying, insufficient drying)	6-16%
Threshing and shelling, winnowing (grain cracking, grain breakage, rodent)	1-4%
Transport to store (spillage, breakage, leakage)	1-2%
Transport to market	1%
Market storage	4%
On farm storage (insect, mite, rodent, mold)	4-10%

Source: Nda-Agyima & Addae-Mensah (2014) .

Maize is the common grain that popularly known in its high carbohydrate composition in Ethiopia. Due to different pest attack, their yields are very lows. About 80% of food grain produced by smallholder farmers in Ethiopia is estimated to be stored traditionally at the farm level; hence, huge loss and wastage have experienced. Maize weevil/ *sitophilus zeamais* is the principal causative agent of maize stored in Ethiopia (Befikadu et al., 2015). It has been reported that, 2% to 30% of maize damage in Ethiopia is estimated to be lost and wasted by *sitophilus zamais* at in traditional level (Befikadu et al., 2015). Recent study by Shiferaw(2018) reported that, 46.1% of damage was caused by *sitophilus zeamais* insect pests and mainly attack maize, wheat, sorghum those stored traditionally in central part of Ethiopia. However, smallholder farmers in Ethiopia are forced to sell their maize at low price value as the result of quality deterioration of stored maize by insect pests due to uses of robustless storage materials (Sori & Ayana, 2012).

Table 2.4: Estimate loss of farmers' farm storage in Amhara, Oromia and SNNP region of Ethiopia from 3-8- months storage

crop	Amhara region			Oromia region			Southern region		
	insect	mold	total	insect	mold	total	insect	mold	total
maize	6.0	6.6	12.6	7.6	2.5	10.1	6.1	5..1	11.2
sorghum	4..0	0.5	4.5	0.9	1.0	1.9	4.0	4.1	8.1
wheat	0.2	2.5	2.7	0	0	0	0.5	5.7	6.2
barely	<0.1	<0.1	<0.1	0	0	0	0.1	1.4	1.5

Source: (Boxall, 1998)

Grain drying

Sun drying (natural air-drying) is the most common farming and agricultural process in many developing countries. Natural air-drying is a method used to dry maize by passing unheated (natural) air through the grain mass until its moisture content reaches equilibrium moisture content. The merit of open air-drying grain in the sun is which it is an inexpensive and easily manageable method. Improper drying affects quality of dried grains (Yakubu and Bern, 2009). Drying is practiced to maintain the quality of grain during storage to prevent the growth of bacteria, fungi, insects and mites. During high temperature drying, maize grains quality undergo alterations such as stress crack and protein denaturation whereas stress-cracking is the major quality problem caused by high temperature drying and rapid cooling of grain &fractures in the maize endosperm lead to problems in both storage and processing (Akhtaruzzaman et al., 2017).

When air passes in the course of grain it either takes up or liberates moisture. Kernels will absorb moisture from the atmosphere when their equilibrium relative humidity is less than the relative humidity of the atmosphere. Cereal grain will lose moisture to the air in the reverse situation, that is, when the equilibrium relative humidity of the cereal grain is larger than the relative humidity of the atmosphere. When dry air passes over wet or high moisture grain, air takes up or absorbs the moisture from the kernels ever increasing the humidity ratio while decreasing the atmosphere's drying potential. No extra drying happens when the air relative humidity attains the equilibrium relative humidity of cereal grain (Nda-Agyima & Addae-Mensah, 2014). Drying of tough cereal grain in the solar dryer is now commonly practiced in many African countries (De Bruin et al., 2014). Therefore, proper drying of maize at moisture content 13.5% is essential to reduce post-harvest loss happened due to improper drying (Yakubu et al.,2011).

2.4. Maize Storage systems in developing countries

Farmers in developing country use different traditional and improved storage systems. Some of these storage systems are gotera, Gota, underground pits from traditional and PICS bags, super grain bags, silo bags, triple bags are from improved /advanced storage methods. This storage methods used by smallholder farmers in developing country as reported by(Abraham et al., 2004)

2.4.1. Traditional storage systems

There are different traditional grain storage structures practiced in many under-developed countries including Ethiopia. This traditionally grain storage structure is made and constructed from locally accessible constructing materials and depending on the cultural habit in Africa, their configuration varies from place to place. Each constructed traditional storage material has both merit and demerit. Traditional storage methods such as traditional granaries, Gotta, storage crib, ,sack/bags, and underground pit, got era, earthen bin, smoking above fireplace etc are practiced in small-scale farmers in Africa (Befikadu, 2014).Generally, 93.3% of Ethiopian farmers apply traditional storage methods which are able to expose stored cereal grain to living organisms (insect pest, rodents and mites, molds, and birds).

Storage Underground pit

Underground pit traditional storage structure is practiced from the ancient time of human civilization. Since comparatively storage pits are airtight, they maintain and keep maize grain cool; conversely, grain moldiness at the top and sides of pit is occurred (Dejene, 2004; Bhardwaj,2014) before layering the pits container with mud or dirt, polyethylene, hay and stalk are positioned and placed beneath and on cereal grains. This method prevents grain from air (oxygen) contact at the time of storage. Underground pits are used in SNNP region, Hararghe, Tigray, Wollo and Gondar and Somalia provinces of Ethiopia, However, 3%-38% damage of maize grain stored in pits in Hararghe was reported due to fungi and 2% to 25% damage due to insect attack, storage conducted for 12 months reported by(Abraham et al., 2004).

Gotera (above ground bin)

The most commonly used storage container in most parts of the country. It is located outdoor. It is usually a cylindrical structure, flat or conical at the base, placed on raised platform or stones and covered with a conical shaped roof. The size of Gotera could vary depending upon the volume of production. The capacity of Gotera is estimated to be between 1 to 4 tons and it is used for storage of un-threshed maize, which requires further drying (Abraham et al., 2004). Studies conducted in Eastern and Southern parts of Tigray after sorghum was stored 4 -to 6- months showed that losses in gotera was 9.9% (Araham et al., 2004).

Storage Cribs

Storage crib are used for storing grain for several years and its grain holding capacity of storage crib depends on its size or its volume (Jeremiah, 2016). The merit of storage crib is allowing the stored maize airflow pass through maize cobs. Cribs should be either metallic or non-metallic depending on their construction materials. Preparation of wall and floor of the non-metallic crib is made using soil mud and wood. As the result, rodents easily break walls, floors as well as roofs and they enter through holes and cause grain damage. Moisture diffuses through the holes and consecutive damage follows. Since metallic cribs are made from an aluminum sheet, rodents do not break them and rodents do not penetrate through metallic crib to attack the stored grain. From restricted result in Ethiopia recommended that average Losses in crib-stored maize cobs normally approached 15% in those provinces where maize grain was stored on the farm (Abraham & Firdissa, 2000). Losses of up to 30% in the Keffa and Sidamo provinces (Southern Ethiopia) have been recorded by (Abraham & Firdissa, 2000).

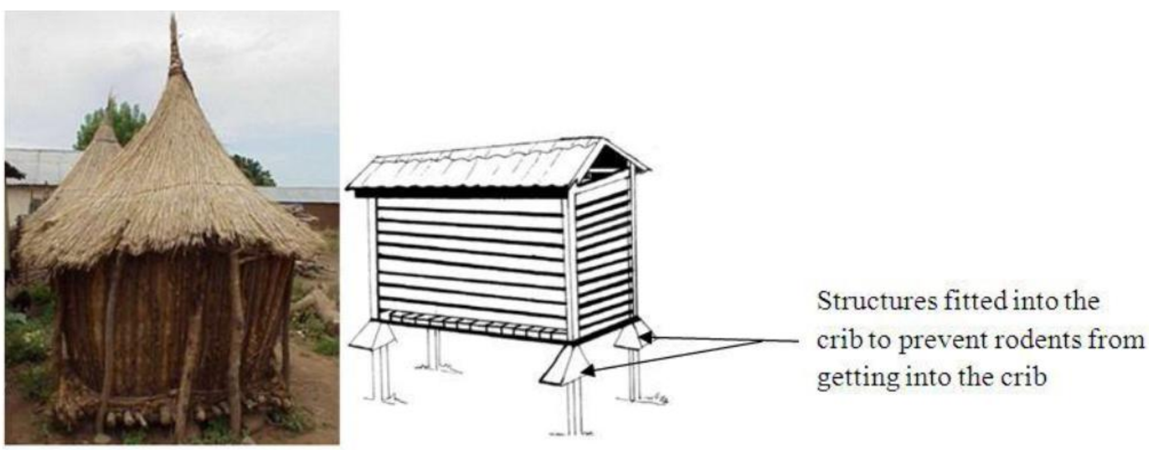


Figure 2.5: Storage cribs for maize (Abraham & Firdissa, 2000)

Smoking and Hanging above the fireplace

Many farmers in developing country hang clusters of cobs in smoke over the fire inside their home and less grain damage is experienced in these types of storage structure(Jeremiah, 2016). Moisture content the grain decreased from 8-10% through continuous drying suspend above the fire at home. So, the smoke prevents the growth of mold and Preserves the grain from insect re-infestation.

However, the acceptability of smoked grain related to food safety issues for instance accumulation of smoke is inedible (Abraham & Firdissa, 2000).

Storage sack or bags

Moisture content is the vital factor in such a storage method. If the incremental moisture content is existed, the numbers of sacks in the grain stock are decreased. It is simple storage material or bags that taking a sample from each sack is easy; however, controlling the grain product from the bag is not easy. This storage method is more costly and expensive, due to higher requirements of labor and more prolonged or time-consuming consequentially lead to easier rodent attack (Pekmez, 2016)**.**Cereal grain stored in sacks was reported to be more vulnerable to infestation than in gotera or underground pit(Abraham et al., 2004). Polypropylene bags are made from woven synthetic fiber and it facilitates deterioration quicker when opened to sun rays (Likhayo et al., 2016)**.**

Traditional Gotta

Traditional gotta was used as storage systems of cereal grain in Ethiopia in the northern part of the country. In west gojam, gotta was used for a longer period for storage. Its holding capacity can range from 50 kg to 7000 kg. Construction materials are cow dung, clay soil and teff straw and made by mother experts. Small Gota is made up of single pieces whereas the big ones are made up of rings (called dengel in some localities) stacked one above the other so that the vessel can be taken in to pieces and reassemble elsewhere. It is estimated to be high cereal grains are lost in gotta.

Earthen bin

Earth bin, which made up of mixed clay with straw is used to increase water-binding capacity and increases the mechanical strength of the bin. Its configuration is circular in shape.

Figure 2. 6: Storage earthen bins (Chattha et al.,2016)

2.4.2. Improved storage systems

Hermetic Storage

Nowadays, smallholder farmers adopt new small-scale technology based on hermetically sealed high-density polyethylene bag, provides inexpensive, economic and effective storage options for smallholder farmers, which should considerably contribute to food security, in particular vulnerable women farmers. This alternative grain storage technology responds to the formulation of the unfavorable modified atmosphere inside the containers or bag's environment. This hermetic flexible plastic storage method in humid tropical climatic continuously supply an excellent remedy offered. There is the extent of tolerance in the presences of live organisms in critical places in storage bags where grain moisture condensation at the grain surface happens. Air tightness in hermetic grain storage system is vital for control of condensation (Navarro & Yehoshua, 2012). Transfer ,adoption and agreement of technologies by farmers are a function primarily carried out by a research institute in cooperation with extension service providers (Likhayo et al., 2016). Controlling of moisture content and permit the reduction of oxygen with an elevation of in CO_2 via respiration of both the product and insects pests are the easy principles of hermetic grain storage technology (Viller et al., 2010). Hermetic storage technology applies a modified atmosphere for protection of grain called sealed storage or airtight storage or sacrificial sealed storage. This method captures merit of adequately sealed structures that facilitate insects and other aerobic organisms in the product or the commodity itself to generate the MA by a decrement of oxygen and increment of carbon dioxide (CO_2) concentrations via respiratory metabolism (Navarro, 2012). Generally, silo bags, super bags and triple bags are very effective hermetic alternatives that recently discovered to replace the chemicals.

According to Cardoso et al. (2012) each silo-bag is 60 meters long and 2.8 meters in diameter with a plastic cover made of three layers (white outside and black inside) of 235 micrometers thickness which has storage capacity of 180 tons of maize. Plastic liners permit the release of CO2 as a by-product produced during grain and live organism respiration.

Super grain bags currently become increasingly well-accepted forms of movable and transportable hermetic grain storage technology or bags. This grain storage system in some research institute like International Rice Research Institute (IRRI) in the Philippines develops thin, transparent; almost provide extremely high barrier property co-extruded multilayer synthetic plastic as liner or polypropylene bags. Super grain bags are capable of holding at a range of from 10 to 1000 kg grain (De Bruin et al., 2014).

Triple-layer hermetic storage bags (PICS)

Researchers, Anankware et al.(2012) reported that triple hermetic bag storage technology is currently a popular storage method which uses thin, transparent, very good barrier co-extruded multilayer plastic liners enclosed by polypropylene sack as an outer layer. A report from Baoua et al.(2012) showed that, the Purdue Improved Crops Storage consists of two-layer envelope made of ultra-thick (80µm) high-density polyethylene (HDPE) liners inserted inside which act as oxygen barrier and has third an outer layer of sack made of woven polypropylene to provide an extreme barrier property of seal and create and provide mechanical strength. It is more attractive and effective preservative grain storage option for smallholder farmers in Africa.

PICS bag liners provide an excellent barrier of gasses b/n product and outside atmosphere, and maintains low modified oxygen level and elevated carbon-dioxide level of the atmosphere created by respiration of grain, and other life forms enclosed during sealing of the bag. As the product in three assemble layered bag is packed and closed, the gases concentration level is reduced significantly as the consequence of respiration of living organisms such, insects, molds, and also seed respiration, conversely, the concentration of carbon dioxide is radically elevated. Such elevation helps to suffocate those respirative and deteriorative live organisms emerged in packs produces. The HDPE plastic liner bag deters the exchange of gases b/n the packed product and the surrounding environment and ensures that the modified atmosphere is continued (Njoroge et al., 2014a).

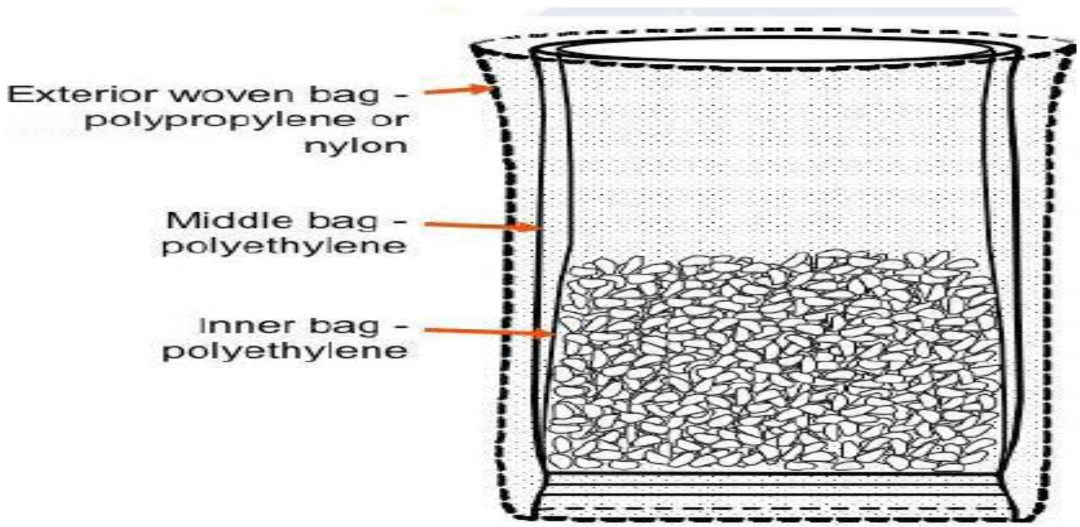


Figure 2.7: Triple layer of PICS bag (Baoua et al., 2012)

2.5. Causes of storage losses in maize grain developing countries

2.5.1. Boitic factors (Insects ,mites,rodents,fungi and molds)

Insects and mites

Infestation by *Sitophilus zamais* begin with the female laying eggs on stored grain, which on hatching the larvae feeds towards within the stored grain till pupal phase is reached (Khakame et al., 2012). Adults appeared and emerged by feeding adults' mode in the direction of testa causing and reasoning rough and strong exit holes following on insect-infested grain. Different types of insects are found in stored crops. Among these insects, few of them cause loss, whereas the rest are yet useful. From harmful insect pests that attack stored cereal grain, weevils such as *Sitophilus oryzae* L. (Rice weevil) are common. Cereals like rice maize, sorghum have been attacked by *Sitophilus zamais* (Maize weevil) (Anankware et al.,2012).

The growth stages of egg, pupae, larvae and adult insects on their morphological skeleton and development of *Sitophilus zamais* entirely found inside tunnel and assembly rooms bored in the grain and therefore not generally observed. Even if 50% eggs may have aid about in the first 4-5 weeks, eggs have laid all over adult's life.150 eggs have been laid by individual female insect. Eggs being laid by each female insect in small holes or cavities have chewed in cereal crop by a female. Therefore, the egg is protected from waxy secretion or from egg-plug produced by the female. Upon emerging, a larva starts and continues to eat within the grain, digging out, tunnel as it grows and develops.

Insects and mites feed on the surface of the grain endosperm by breaking the kernels of it. They feed and cause to remove the nutrient composition of grain and facilitate the emergence of live microorganisms like bacteria, and gradually cause to increase the moisture of grain. These great increase of insect number finally cause qualitative and quantities losses through their feces/residue retained during consumption (Befikadu, 2014).Insects remove food materials by feeding on the surface and boring within kernel results the moisture enhancement in product and support the growth of live organisms(Abraham & Firdissa, 2000)

Rodents

Rodents break the sack of grain container and penetrate into the product through the holes or puncture, they create and they start consuming the grain resulting large damage on cereals and building houses. Rodents infest and pollute large part of cereals by excreting their feces/urine. Study by Befikadu (2014) reported that rodents can daily consume about 10% of their body weight and the biological control method is used to prevent damage associated with rats, which spread diseases (typhus, rabies, trichomoniasis) (Befikadu, 2014). These invasions of rodents on stored cereal crops have effected great quantitative and qualitative loss consequently leads to food insecurity (Befikadu, 2014).

Molds and Fungi

Mold and fungal species can develop on grains, in the field as well as in storage. Contamination of maize grain with mold and fungi is regarded as one of the most serious safety problems in the tropical countries and throughout the world (Rashid et al., 2013). When the moisture is more than its optimum limit and where favorable temperature conditions are available within the bulk grain storage, hence, infestation with fungi and mold take places. When grain moisture levels are low, naturally occurring mold spores stay in a dormant state and remain inactive until the environment is suitable for them to multiply. Micro flora will multiply when equilibrium relative humidity is at least 65% (Nda-Agyima & Addae-Mensah, 2014) and moisture situation above sound levels, grain deterioration from microorganisms development may increase at an exponential rate. Fungi are eukaryotic organisms that flourish on dead organic material and living materials. Spores are fungal reproductive cells and are a single cell about 3 – 30µm in diameter. They settle on a substrate, germinate and project a germ tube. The germ tube develops into a thread-like filament known as hypha, this hypha develops and branches into other hyphae usually seen as a white mass of filaments called mycelium. Hyphae can produce chemicals to repel and deter other fungi growing on food substrates. Ultraviolet rays of sunlight do not affect fungal spores. This is why solar drying does not control levels of aflatoxin. Surroundings favorable for fungal growth are 70% relative humidity and a pH of 5.0 with optimum temperatures between 20^0C and 35^0C (Nda-Agyima & Addae-Mensah, 2014). Toxigenic fungi invading maize are divided into two distinct groups, field fungi and storage fungi (Jeremiah, 2016).

Table 2.5: Conditions for growth of common storage molds on cereal grain at 25^{0}C to 27^{0}C

Mold species	Relative humidity (%)	Moisture content(%w.b)
Aspergillus halophilieus	68	12-14
Aspergillus restrictus	70	13-15
Aspergillus glaucus	73	13-15
Aspergillus candidus	80	14-16
Aspergillusflavusparssiticus	82	15-18
Penicillium spp.	80-90	15-18

Source: Rashid et al.(2013)

Field fungi invade maize and produce toxins before harvest or before the grains are threshed, and can develop under high relative humidity of over 80 %, with moisture content of 22 % to 33 % and wide range of temperature (25-45°C) (Rashid et al., 2013). These usually die out in storage, but some can live below storage conditions cause considerable damage, reducing the yield and quality, especially in warm humid climates. Conversely, storage fungi invade grain principally throughout storage and require equilibrium moisture content with relative humidity of 70 % to 90 % as conducted by (Moturi, 2008).

There are several key fungal species associated with stored grains, including *Fusarium* spp., *Penicillium* spp., *Rhizopus* spp., *Aspergillus* spp and *Tilletia* spp. (Jeremiah, 2016). Contamination of maize grain by storage fungus and mold consequences in kernel discoloration, dry matter loss, loss of viability, Mycotoxins contamination, and subsequent seedling blights, chemical and nutritional changes and overall decreasing of maize grain quality (Chuck-Hernández et al., 2012). It has been reported by Rashid et al.(2013), storage fungi contributes to loss of more than 50 % of maize grain in tropical countries, and ranks second after insects as the major cause of deterioration and loss of maize. It shows that broken maize grain and foreign materials promote growth of storage molds, since fungi more easily go through broken kernels than integral kernels. Mechanical damage during or after harvesting on maize grains can offer entrance points to fungal spores. Similarly, Fandohan et al.(2006) reported that increases in grain damage and cracking generate a chance for fungi to develop and go through maize grain.

Moisture and temperature are the two key environmental factors that influence growth of molds and maize grain is generally harvested with moisture content of around 18 % to 20 % and then is being dried (Jeremiah, 2016). It has been reported that fungal growth in stored grain in the tropical countries is essentially associated with increases in grain moisture contents, and variation in temperatures, resulting in unsafe storage of high-moisture grain and moisture migration and condensation (Rashid et al., 2013) .

Mycotoxins on cereal grain

Molds growing on maize grains present a great threat, especially through production of secondary metabolites (Mycotoxins) (Weinberg et al., 2008). Mycotoxins are a chronic problem for maize grown in warm, humid, tropical, and sub-tropical regions. Molds and fungal infections can result in Mycotoxins contamination in all stage from growing, harvesting, storage to processing. The most important Mycotoxins that frequently occur in cereal grains are aflatoxin, Ochratoxins, fumonisins, trichothecenes, and zearalenone (Pitt, 2000) .The two most common and toxic Mycotoxins compounds encountered on maize in tropical and subtropical regions are aflatoxin and fumonisins. Aflatoxin is predominantly a problem in cereal grains, particularly in maize; it is produced by three main species of fungi, *Aspergillus flavus, Aspergillus parssiticus,* and *Aspergillus nomius* (Martinez et al., 2011).

2.5. 2. Aboitic factors

Grain temperature

The temperature within a store is affected by sun, the cooling effect of radiation from the store, outside air temperatures, heat generated by the respiration of both the grain in the store and any insects present. If stores in most parts of Ethiopia have temperatures between 25 and 35^0C, the effect of both micro-organisms and insects are obviously important (Befikadu, 2014). Differences in cereal grain temperatures generate convection currents that can migrate and concentrate wetness at the top core of storage. The first indication of problem is frequently humid or in bad taste feeling kernels at the grain surface, followed by the creation of a crust. Moisture movement problems can be controlled or minimized by keeping grain mass temperature stabilized within -12 to -9^0C of the average external air temperature (Befikadu, 2014).

Moisture content

Moisture is the prominent factor in grain preservation. If grain moisture content is too high, even the best aeration equipment and monitoring will not keep the grain from spoiling. All microorganisms, including molds, require moisture to survive and multiply. Moisture should, therefore be prevented from entering the store. The moisture content below which microorganisms cannot grow is safe moisture content. (Table 2.7) lists the safe moisture content levels for cereals valid for temperatures up to 27^oC. Condensation of moisture can cause storage problems. If the walls of a store are cooled below their dew point by low night temperature, condensation can occur and increase the moisture in the layers of the stored grain near the edge of the store. It is important to remember that the stored grains are alive and respiring, giving off moisture as well as heat.

Table 2.7: Safe moisture content levels of some cereal grain stored below 27^{0}C

Cereal grain	Safe moisture content % (w. b)
Shelled maize	13.5
millet	16.0
rice	15.0
sorghum	13.5
wheat	13.5

Source: (Befikadu, 2014)

Living organisms, such as molds and insects, and thermal heat created by respiration of the cereal grain itself will enhance and increase water vapor, which in turn will direct to further deterioration of the grain. The higher the moisture content, the more susceptible the maize grain is to mold and insect deterioration. Grain moisture content can be expressed as a percentage of moisture, based on wet (wet basis) or dry matter (dry basis). Wet basis moisture content is generally used.1) Wet basis, the weight of the product is taken as the weight of the dry matter plus water 2) Dry basis, the weight of the product is taken as that of the dry matter only, but dry basis is common in scientific works and wet basis is the most common method of expression. Formula

M.c (wet basis)$= \frac{weight\ of\ water\ in\ sample}{weight\ \ of\ \ water + dry\ matter} \times 100$

M.c (dry basis)$= \frac{weight\ of\ water\ in\ sample}{weight\ of\ dry\ matter} \times 100$

Where M.c is the moisture content of cereal or maize grain

Relative Humidity

Relative humidity can be explained as the amount of water vapor that is enclosed in the air as a proportion of the amount of water vapor required to saturate the air at the same temperature (Lawrence, 2005). It can also be expressed as the ratio of the actual water vapor pressure (e) to the equilibrium vapor pressure over a plane of water (e) (often called the “saturation” vapor pressure.

RH$= \left[\frac{Pw}{Pws}\right] \times 100$

Where p_W= partial pressure of the water vapor, Pws = partial pressure of pure water at saturation, or

$$RH = \frac{E}{Es} \times 100$$

Where E=vapor equilibrium, and Es = saturation vapor pressure

As temperature increases, grain will lose moisture to the surrounding air, thereby increasing the relative humidity. Moreover, it has been reported that in most cereal grains, every 10 °C rise in temperature cause an increase of about 3 % in relative humidity (ACDI/VOCA , 2003) and explained that changing temperature and relative humidity not only encourage molds growth, but also causes considerable nutrient losses of grain. For the case of nutrient loss, reported by Rehman et al.(2002), after 180 days of maize grain storage at 45 °C and 12 % RH, result has showed significant reduces in protein, reducing sugars, up to 20.4 %. Moreover, according to Samuel et al.(2011), even after drying, maize grain harvested in tropical and sub-tropical countries retained a definite amount of moisture.

Gaseous composition

Preservation is often accomplished by adjusting the gaseous environment of the grain. Flooding of the storage environment with CO2, O2 depletion, fermentation, and fumigation with methyl bromide are used to clear masses of grain of insect as reported by (Megerssa, 2010). Mold species involved in the deterioration of stored maize are aerobes but they can grow under limited oxygen levels and significant levels of CO2. Their tolerance for low O2 and high CO2 is influenced by the presence of water. Modified atmosphere influences the suppression of mold growth in stored. Microorganisms need oxygen to survive and reproduce. Aerobic microorganisms require oxygen to develop, while anaerobic microorganisms can develop without the presence of oxygen. The chemical reactions for anaerobic respiration of these organisms are shown below:

$$C_6H_{12}C_6 = 2C_2H_5OH + 2CO_2 + 22(\text{Kcal/mode})$$

At given limited oxygen supply, some microorganisms may continue to develop by partially decomposing carbon dioxide, producing lactic acids, acetic acids and alcohols. This process is commonly known as fermentation. Heat produced in this reaction is much less than in aerobic respiration. Oxygen levels below 0.14% suppress the development of most fungi species and carbon dioxide levels above 50% result in complete inhibition of development of most fungal species as reported by(Nda-Agyima & Addae-Mensah, 2014) .

2.6. Insect management strategies in stored maize

2.6.1. Use of chemicals and pesticides

Uses of chemical insecticides preservative alternatives become increasingly popular in developing countries particularly small-scale subsistence farmers to protect their stored grain from insects and mites, mold and other deteriorative living organisms. Unlimited and unrestricted uses of chemical insecticides for control of stored grain product from insect pests have resulted in associated health risks. Annoyance and disturbance of environment, insect recovery, insect resistance, favor to the buildup of a strain of insect pests, cause lethality for essential microorganism, poisons the applicators of it are some adverse effects of insecticides. These problems are possibly caused by contamination and adulteration of the insecticides by sellers, improper practice such as late uses of treatment, uses of wrong dosage and irregular use by the farmers. Among many insecticides, fumigants are the most broadly practiced in insecticides, but environmentally sound and safe pest control alternative is now increasingly become significant. As the result of their negative impact to the environment like stratospheric ozone layer depletion, the uses of Methyl bromide (MB) should be ceased out from its application. On the other hand, Phosphine increasingly becomes popular, mainly in many developing nations, due to its easy application than MB. But, a few insects built up resistance to Phosphine over the last 10 years (Villers et al., 2010).

The majority of small-scale farmers in developing countries have exercised synthetic chemical pesticides for control pest attack on the stored product for many years. According to Likhayo et al.(2016),admixing is the major commercially accessible, marketable and Protectants suggested, and practiced in sub-Saharan Africa. Based on Likhayo et al. (2016) a dilute dust containing 1.6% pirimiphos-methyl + 0.3% permethrin (Actellic Super dust (ASD)) is effective to control insect pests from the stored product even currently , many numbers of comparable and similar admixture are increasingly penetrated into the market (Jeremiah, 2016).

Fumigants

Fumigants are the most effective in controlling of storage pests since they are gases, they can diffuse into pests where they found in the most distant area of hibernation. Because of foods safety problem, the uses of sound and friend fumigant pesticides are now limited to Phosphine and CO_2 (Jeremiah, 2016). Phosphine disinfection, decontamination, and the chemicals are now applicable in the form of solid states of tablets and pellets. These solid-state chemicals loose and liberate Phosphine gas when chemicals interact and contact with moist air. All growth phases of eggs, larvae, pupae and adults are killed and destroyed when insects are subjected to correct dose of fumigation in well-closed surroundings. These chemicals do not damage the stored cereal crop and other leave deposit (Jeremiah, 2016).

Well-trained persons should perform the application of Phosphine fumigation. Since it is very toxic to human beings, Care has to be taken while using Phosphine gas. Fumigation must be applied in a field, which securely and tightly sealed. When the grain's exposing period to Phosphine is completed, the grain has to be ventilated and the remaining of residual Phosphine gas in the bin has to be checked before opening. Insect pests require air for their breathing, but, the oxygen content in the storage bin is substituted by co_2 gases which asphyxiate, desiccate and produce poisonous chemicals in pests' fluid during carbon dioxide fumigation (Bohinc & Trdan, 2017)**.**

Concerning to health risk: misuse and improper application of pesticides has contributed an adverse health effect on human, not environmentally friend (Hiruy & Getu, 2018). Study by Mutungi et al.(2014) reported that on synthetic chemical fumigants and residual insecticides approaches principally fumigation with Phosphine gas, for instance, require safety measures and skill in and is restricted to licensed pesticide applicators (Sande et al., 2011).According to Gilden et al.(2016) synthetic pesticides that harm human life are insecticides, fungicides , rodenticides, pediculicides, and biocides. These chemicals through respiration, ingestion, dermal contact, enhance the threat of allergen and favors developments of cancer. In addition to the above health effect, asthma, allergies, hypersensitivity and pesticide exposure is also linked to cancer, hormone disruption, and problems with reproduction and fetal development are human diseases occurred (Abdel-Mallek et al., 2011).

2.6.2. Alternative methods

2.6.2.1. Cultural and biological methods

Cultural methods

Traditional methods frequently provide inexpensive and viable ways of post-harvest handling of the crops. It is significantly vital to control the rate of insect migration and movement into stored grain from contamination and infestation sites in storage bin bottoms. Within biological restrictions, the higher the temperature, moisture content, exposure to air and the time products are in a vulnerable condition, the greater of the consequential insect pest population. Some cultural practices are field isolation, crop hygiene, time of harvesting, proper drying (Abraham & Firdissa, 2000).

Biological Control

In biological control and regulation system, pest populations are maintained and kept by natural enemies usually in combination with other control methods. The natural enemies may be predators, parasitoids or pathogens (Flinn et al.,2006). Predators such as spiders, ladybirds, lacewings or predatory mites, usually feed on a range of different insects. Parasitoids lay eggs on one host insect, and the larvae live and feed on the host, which dies (true parasites do not kill their hosts). The adult parasitoids are characteristically honey feeders. Pathogens can be bacteria, fungi, viruses, nematodes or protozoa. Generally biological control is by mating disruption, the uses of crop resistant variety and sterile males (Befikadu, 2014).

2.6.2.2. Use of Inert Dust, Botanicals

Inert dusts

The use of chemically inert materials, such as diatoms or plant products in big quantities to fill up or pack the interstitial space in cereal grain mass and offer a hurdle to insect movement(Nukenine et al.,2010). Similarly, Abraham & Firdissa(2000) reported that, tobacco dusts are more effective in all activities in terms of grain spoilage and damage in controlling of adult insect as compared with wood ash, sand, sawdust, neem seed powder and pirimiphos-methyl in the laboratory report result at Hawassa (Southern Ethiopia). According to Khakame et al.(2012), diatomaceous earth dust (DE) mainly adsorb the epicuticular lipid layers bringing death primarily as a consequence of too much water loss via cuticle of the insect's body. Effectiveness of wood ash as a grain Protectants assessed the effects of admixing locally accessible and available powders at the rate of 1%, 5%, 15% and 30% (w/w) through maize and found that wood ash restricts infestation as conducted by (Jean et al.,2015).

Botanicals

Botanical pesticides are an option to chemical synthetic pesticides i.e. insecticidal plants or plant compound and the use of natural compounds, such as essential oils, foodstuffs of the neem tree, Azadirachta indica A. that result from Secondary metabolism in plants has been broadly stated and reported by (Nukenine et al.,2010). A potential source of botanical pesticide is essential oil and their constituent. In agricultural pest control, botanical insecticides are best appropriate for use in organic food production in developed countries, but able to take part in a much greater function in the production and crop preservation of food in under-developed countries (Teshome & Tefera, 2011). The insecticidal action of extracts derived from different plants and parts of the plant in opposite to stored produce insect pest has been reported (Megerssa, 2010).

2.6.2.3. Modified /Controlled Atmosphere, Aeration and Radiation

Modified atmosphere

Fumigants are successfully substituted by new air or gases application technology for the stored crop in bags or bulk in humid and warm climatic condition. Modified atmosphere (MA) and controlled atmosphere (CA) treatment have been confirmed not only to manage and control insect pests but also to protect the quality of the crop with no residue after treatment (Pekmez, 2016). Modified atmospheres (MA) or controlled atmospheres (CA) recommend an option to the use of predictable residue producing and generating chemical fumigants for protecting insect pests attacking stored grain, processed produce, and a number of packaged food products. MA is planned to provide as a broad term, including entire cases in which the atmospheric air composition or their partial pressures in the manipulation-enclosed space has modified to produce in its surroundings favorable for the control and manage of insects. In an MA treatment, the atmospheric composition within the treated enclosed space may well modify at the time of treatment. In a CA treatment and manipulation, atmospheric composition within the treated enclosed space is maintained at a stage or a level and duration toxic to insects (Navarro, 2012).

Aeration

Application of mechanical aeration by the mean fan is used to alleviate and reduce the commodity temperature at a tolerable and acceptable level. Aeration is the forced movement of the ambient air suitable quality or well-conditioned air or gases via a grain mass for the modification of cereal grain storage (Navarro, 2012). This preservation system creates unsuitable conditions for the growth of harmful and damaging organisms in the stored grain and simultaneously it produces suitable condition for continued preservation of stored grain quality. The main function of aeration is to improve and modify abiotic factors such as temperature, humidity, surrounding air composition and hence to condition the stored grain to modify and improve existing condition in the grain mass in the concept of the ecological storage system. It has been reported that on aeration carried out mainly in temperate climate as the consequence of principal requirement and desire and accessibility of low temperature and humidity in temperate climatic region(Navarro, 2012).

2.6.2.4. Uses of Pheromones

These types of preservation technology use Semio-chemicals decide insect life conditions such as feeding, mating and egg laying. These chemicals are therefore potential agents for selective control of insect pests. Biological controls with pheromones or kairomones can be used for detection, recognition monitoring and supervision of insect populations. Mating interference and disruption by use of pheromones is a potential and, for several reasons, a successful approach for control (confusion strategy). Another approach to utilize of semiochemicals are feeding deterrent and prevention. Attracting, trapping and killing of the insect pests are the most frequent approach or strategy of control by using semiochemicals. Insects' olfactory organ is very susceptible and restricted quantity of semiochemicals being required and needed for control and management (Megerssa, 2010).

The most frequent trap design and plan for flying insect pests utilize plastic or wax-coated paper enclosed with insect-trapping glue on one or more surfaces. Sticky traps prepared from the paper have been used almost solely for monitoring storage moth (which insects having to two broad wings covered in microscopic scales) (Navarro,2012).

2.7. Polyethylene lining

Ethylene molecules are essentially composed of two ethylene units (CH_2) linked together by a double bond between the carbon atoms (CH_2=CH_2n) under the influence of polymerization catalyst. The double bond can be broken and the result can be hard and rigid or soft and pliable. Extra single bond used to link to a carbon atom in another ethylene molecule. The long chain-like molecules in which hydrogen atoms connected to a carbon backbone can produce in linear or branched forms. Polyethylene sheet in this study is a bag made of ethylene monomer units join together and has 78 µm thick (Likhayo et al., 2016). Such plastic generally has flexibility, good moisture control, oil and chemical resistance, and good impact strength, with good gas and water barrier Properties (Yakubu and Bern, 2009). Polyethylene sheet is also an inexpensive plastic, usually the most economical choice. The resalable and reusable polyethylene bags are custom-made to meet customer needs (Yakubu and Bern, 2009).

2.8. Use of filter cake as an insecticide

Filter cake (a factory by-product) is successfully effective against the maize weevil at a rate of 1% or higher (Girma Demissie et al.,2008). Filter cake is a by-product of aluminum sulfate factory (Awash Melkassa Aluminum Sulphate and Sulphuric Acid Share Company, Melkassa Awash, Ethiopia (AMASSASC)) (Girma Demissie et al.,2008). According to Nukenine et al.(2010) concerning the mode of action, the filter cake absorbs the lipids of the insect's epi-cuticle and death results from loss of water and desiccation. Therefore, filter cake was used in this study to protect stored maize grain from insect pests for 6-months.

Generally, different traditional grain storage approaches and strategies are practiced in developing countries. Huge grain loss has been experienced in smallholder farmers who were practiced traditional storage strategies resulting huge economic loss and crisis. On the other hand, grain stored in advanced storage system is highly reduced. Recently, improved storage options have been highly exercised and practiced in Africa, and great loss of grain has been reduced and minimized. It is better for small-scale farmers to practice advanced storage systems to protect their grain from any deteriorative agents rather than traditional storage practices. Hence, this study focused on the effectiveness of polyethylene sheet lining and filter cake application in traditional Gota and PPB bag against commercialized bags to protect stored grain from insect for 6-months.

3. MATERIALS AND METHODS

3.1. Material

Maize grain of variety of Lemu with moisture content of 22%-25% (w.b) was purchased from farmers in Mecha district, Kudimi *Kebele*. The moisture content was reduced to 13.5% (w.b) by using a solar bubble dryer (Grain-Pro^{TM} in collaboration of International Rice Research Institute (IRRI) at University of Hohenheim, Germany) at dryer temperature (60^{o}C). After drying to the desired moisture level, the maize grain was allowed to cool to equilibrate temperature before storage. Brocken kernel, dockage materials were removed by winnowing and hand picking. A total of 900 kg of the dried maize was used for this storage experiment.

3.2. Study site

The storage experiment was conducted under farmers' conditions in Kudmi *kebele* of Mecha district, West Gojjam. Mecha district is located around 515km north of Addis Ababa and 38km from Bahir-Dar at an altitude ranging from 1800 m to 2500m above sea level. The area receives mean annual rainfall of 1500 mm, 90 % of which falls between May and September and the 10% of it falls from March to April. Mean annual temperature is between 24 and 27 °C.

Mecha district was selected based on its maize production status (main maize producing area). Focus group discussions showed that weevils are serious post-harvest storage insects. The site is known for its year-round production using Koga dam.

3.3. Experiment set up

3.3.1. Storage methods

Six storage methods such as

1) PPB (polypropylene bag) (T1) used as a negative control;

2) PICS (Perdue Improved Crop Storage bags) (T2) used as a positive control;

3) GOTTA without any treatment (T3) used as a negative control;

4) GOTTA + PE (Gotta + Polyethylene lining) (T4) PE in double layers;

5) GOTTA+ FC (Gotta+ Filter Cake) (T5); and

6) PPB+PE (polypropylene + polyethylene lining) (T6) PE in a single layer were used in the experiment. Each treatment received 50 kg of solar bubble dried maize. The grain was filled manually, and each bag was closed by firmly twisting and fastening with sisal rope.

Polypropylene bags of 100 kg size were purchased from the local markets in Merawi town, West Gojjam. Polyethylene sheet of 0.078 mm was purchased from plastic sheet dealers in Bahir Dar city. Perdue Improved Crop Storage (PICS) bags were obtained from the Shayashone PLC, Addis Ababa, Ethiopia. Traditional Gotta (*gushgusha*) of about 50 kg size were obtained from farmers in Kudmi *kebele*, Mecha district. The filter cake powder passing through 0.4mm mesh was obtained from Awash Melkassa Aluminum Sulfate and Sulfuric Acid Factory, Adama, Ethiopia.

Figure 3.1: Six storage method in three farmers' house at Mecha district in Kudmi kebele

***Gotta preparation*:**

Nine traditional Gotta structures were purchased from willing farmers in Mecha district particularly in Kudimi kebele. The structures were constructed by experienced Gotta makers in the locality from tumbled mud (from special soil and straw). However, the structures had slight differences in size, between the capacities of 50kg to 55kg.

***Filter cake treatment*:**

The filter cake powder was sifted using 0.4 mm mesh sieve to increase its effectiveness. Then, solar bubble dried maize grain was mixed with filter cake powder at the recommended ratio of 10 g per 1kg of maize (Girma Demissie et al., 2008). Hence, 500 g of filter cake powder was mixed with 50 kg of maize grain. Then, manual mixing of maize and filter cake powder was carried out for each Gotta.

Polyethylene sheet lining preparation (PE sheet):

Polyethylene sheet with 0.078mm thickness was purchased from the Bahir-Dar local market. Thickness was measured by electronic caliper (BEAPO HARDWARE INDUSTRIAL CO., LCD, Hunan, China). Then, based on the holding capacity of gotta, six PE bags (135cm height, 10cm radius) were prepared by sealing its one end by heating with candle light. Each prepared polyethylene bags had a capacity of holding 50 kg of maize grain. Before the bags were filled with grain, tears or leakages were tested by allowing air into the PE bags and then pressing back. Then, doubled layered polyethylene plastic bags were inserted in to Gotta structures and filled with maize grain. At last, plastic bags were sealed using sisal with rope and gotta were covered with a structure made from mud. Hence, gotta was assumed as a mechanical barrier from rodents and mites while the inner inserted double polyethylene bags served as oxygen barrier.

Sampling

Duplicate samples were taken from each treatment. Maize samples were taken three times through the course of the experiment: at the outset of the experiment, after three months of storage, and after six months of storage. For plastic storage materials, to obtain samples for measurement of parameters, bags were opened and 2k g of stored maize grain in each 18 storage methods stored in three farmers' house was taken using (ISTA, 2014). Samples were taken manually from the top, middle and bottom of the bag so that a representative column comprising grains from all layers of the bag was taken randomly. After taking the sample, bags were compressed to remove excess air and sisal twine with rope was done and sealed. Each 2kg sample taken from each storage method was ready for further analysis.

3.4. Data collection

Collected samples were subject to measurement of moisture content, bulk density, thousand kernel weights in the laboratory. At the same time, insect count, grain damage percentage, weight loss, and percent data were collected from each sample. Proximate composition (protein, starch, oil, and total ash) were recorded for each experimental unit.

Count data were subject to log transformation.

$$\text{Log transforms of insect count} = \log_{10}(x+1)$$

Where, x=the numbers of live insect count.

When the percentage data were out of the standard range between 30 and 70, arcsine transformation was employed:

$$\text{Percentage data} = \sin^{-1}\left(\frac{x}{100}\right)$$

Where x= the percentage data

3.4.1. Insect count in stored maize grain

At every interval of sampling, samples were brought to Bahir-Dar University Food Chemistry analysis laboratory. Sub-samples (1kg) were first kept in a refrigerator maintained at 2^0C for 3 h to immobilize crawling insects. The damaged grains were further split open to remove insects remained inside the grain. Each sample was sifted with 3.35mm and 2mm mesh sieve and pan arranged from top to bottom respectively to separate grain, dust and insects. Then, insects were counted as live and dead. Dead and boring insect pests were removed at all time of counting. All live insects were placed in a translucent plastic jar for additional weevil identification step using stereomicroscope; live insect was identified as maize weevil/*Sitophilu*s spp. Then, live insect counts were reported as the number of live adult maize weevils or *Sitophilus zeamais* per 1k g of grain (Njoroge et al., 2014a).

3.4.2. Grain damage and weight loss

A 125g of sieved stored maize grains were sorted counted and weighed consecutively into insect damaged and undamaged grains. Therefore, percent damage and weight loss were calculated by (Njoroge et al., 2014b).

$$\text{Percent damage (\%)} = \frac{Nd}{Nd+Nu} \times 100$$

Percentage weight loss was calculated by the count and weigh method using the

$$\text{Weight loss (\%)} = \frac{((U \times Nd)-(D \times Nu))}{U(Nd+Nu)} \times 100$$

Where, the weight of undamaged grains (U), the weight of insect-damaged grains (D), number of undamaged grains (Nu), and the number of insect-damaged grains (Nd)

Figure 3.2: Counting the numbers of damaged and undamaged maize grain

3.4.3. Bulk density and thousand kernel weight measurement.

Bulk density was determined by filling the container with a known volume of maize grain sample and weighing the contents. The ratio of the mass and volume was expressed as bulk density. Since the bulk density includes the inter-granular spaces, it is necessary to avoid any compaction of the samples in the container (Sangamithra et al., 2016). Test Bulk density was expressed as mass per unit volume (kg/ m3)(ISTA, 2014). Bulk density was calculated using the following equation:

$$\text{Bulk density} = \frac{samples\ of\ mass}{volume}$$

Where, Sample mass is the mass of grain filling a known volume (Guo, 2015).

Thousand-kernel weight

The thousand-seed weight was determined by weighing 250 kernels and multiplied by 4. The thousand-seed weight was reported in gram (ISTA, 2014).

Figure 3.3: Insect count, bulk density & thousand kernel weight testing

3.4.4. Germination testing

Maize samples were subject to germination before and after storage. Sub-samples (125 g) from sieved maize were thoroughly mixed and 40 grains were randomly selected. These were steeped in 250 ml of tap water for about 15 min to imbibe. The grains were then sandwiched between two sheets of moistened Whatman filter paper as a base for sprouting, placed in a Ziploc bag and incubated at room temperature (25^0C) for three days. Percent germination was calculated as the number of seeds showing the emergence of plumule and radicle multiplied by 2.5 (Njoroge et al., 2014a).

3.4.5. Proximate analysis of stored maize

Ash content determination

Solar bubble dried maize of the lemu varieties at different moisture content (13.5% and 12%) were used in this study. Samples were initially grounded by a mortar and pestle then, passed through 0.6 mm sieve. The powdered samples of particular moisture content were packed in high-density polyethylene (HDPE) package at room temperature until further analysis. Ash content of maize sample was analyzed by AOAC official method (2000). 5g powdered sample was taken in pre-weighed crucible. Then, it was placed in a muffle furnace at 550°C to 600°C for 5-6 h. After ashing, the crucible was cooled and kept for some time in desiccators and then weighed. Ash content was calculated by the following Equation (Akhtaruzzaman *et al*., 2017)

$$\text{Ash}(\%) = \frac{[(\text{crucible weight} + \text{ash weight}) - (\text{empty crucible weight})]}{[\text{crucible weight} + \text{sample weight}] - (\text{empty crucible weight})} \times 100$$

Or when it was symbolically rewritten as

$$\text{Ash}\ (\%) = \frac{\text{A1} - \text{A2}}{\text{A}} \times 100$$

Where, $A1$ = weight of ash with the crucible, g; $A2$ = weight of empty crucible, g, and A = weight of the sample.

Fat, Protein, and Starch, and Moisture Determination

An InfrateC™ 1241 (Foss Tecator AB, Höganäs, Sweden) grain analyzer from Amhara Regional Agricultural Research Institute (ARARI) was used to determine the chemical composition of maize grain kernels before and afte**r** storage tests. The moisture, starch, protein, oil were measured using this grain analyzer. Moisture content was reported as a dry basis. When the equipment power supply was on, light from the lamb was emitted and 400g of maize grain was added in the hopper and passed through the emitted light from the lamp. Hence the light was absorbed the nutrient composition of maize grain sample. The amount of light absorbed in grain was reported as nutrition constituents of the sample (as protein, oil, starch and moisture content).

3.5. Experimental design

The experiment was conducted in a nested design in three farmers' houses. Each experimental unit at every farmer's house had two sub-samples at each period of storage. The six storage treatments were nested into each farmer, and two sub-samples were nested into each treatment.

Data were collected at every three-month interval (immediately after drying before storage, after three-month storage and at the end of storage). The baseline sample was taken at outset of storage. Farmers' storage method like polypropylene bag and gotta were considered as a negative control and PICS bag was considered as positive control.

3.6. Statistical Data Analysis

The collected data was entered in to excel and arranged for analysis. This data entry was analyzed using R software. To stabilize variance, insect count was logarithmic (Log(x+1) transformed. Since the numbers of live insect counted in each three-sampling period (before starting, after 3-months and at the end of the storage) was far apart. In order to bring this variation into small gap, logarithmic transformation was used whereas percent germination data was arcsine ($\sin^{-1}\left(\frac{x}{100}\right)$) transformed. Analysis of variance (ANOVA) was run by using linear and nonlinear mixed effect model from R version 3.5.0, software package (R version, 2018). One-way ANOVA was used for one-factor storage method. Mean comparison was conducted using Tukey's student test (HSD) at 5% level of significance.

4. RESULTS & DISCUSSION

4.1. Effect of storage strategies on live insect count

The effect of storage strategies on live weevil counts were significant (P<0.0001). No live insects were detected at the outset of the experiment in all storage strategies (Table 4.1) and in the storage strategies such as GOTTA+PE and FC+GOTTA after three months of storage. However, after three and six -months of storage, mainly the *Sitophilus* spp. was detected. The treatments GOTTA+PE and FC+GOTTA exhibited live insects after six months of storage While other strategies had mean values of live insect counts ranging from 0.6 insect kg^{-1} to 2.2 insect kg^{-1} at three months of storage. At six months of storage, live adult weevils were detected in all storage strategies, but there was a significant different among the treatments. Traditional storage practices such as PPB and GOTTA exhibit the largest mean values of insect counts (62.14 insect kg^{-1} and 78.4 insect kg^{-1}, respectively). The populations of weevils in PPB and GOTTA did not differ significantly (Table 4.1). Using PICS bag, GOTTA+PE and GOTTA+FC has significantly reduced the mean values of live insect count. The lowest mean value of live insect count was recorded in the treatment GOTTA+FC, indicating that this strategy was the most effective against maize weevil population growth. Moreover, the mean values of insect count in the storage strategies such as PICS bag and GOTTA+PE was not significant at the end of storage period. This shows that lining the traditional GOTTA structure with polyethylene sheet caused a comparable suppression on weevil population growth. In PPB+PE, there was a slight increase in insect population as storage period increased up to six months (19 insect kg^{-1}). This shows that using PPB+PE strategy is not a promising alternative. Future works may compare the double-layered lining of the polypropylene bag with the present finding.

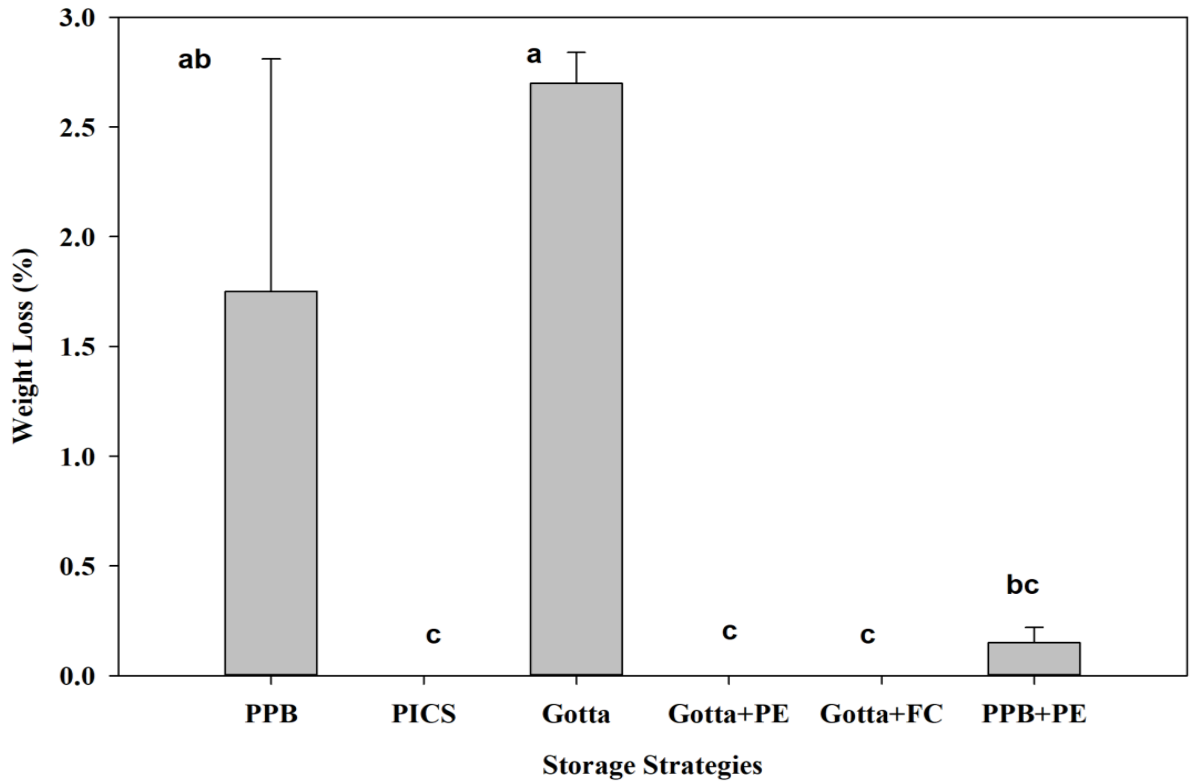
The finding from the present study regarding filter cake is in agreement with previous reports about this dust. Girma Demissie et al.(2008) indicated that filter cake caused high mortality of *Sitophilus zeamais*. In the present study, only 0.3 live insects per kg persisted in filter cake treated maize grain stored in traditional GOTTA after six months.

4.2. Effect of storage strategies on Grain damage and weight loss of maze grain

Table 4.1: Mean (±SE) of grain damage, and live insect count after 0-month, 3-months, and 6-months of storage

Month(period)	Storage strategy	Grain Damage (%)	live insect
Month-0	PPB	0.0±0.4a	0.0±0.3 a
	PICS	0.0±0.4a	0.0±0.3 a
	GOTTA	0.0±0.4a	0.0±0.3 a
	GOTTA+PE	0.0±0.4a	0.0±0.3 a
	FC+GOTTA	0.0±0.4a	0.0±0.3 a
	PPB+PE	0.0±0.4a	0.0±0.3 a
Month-3	PPB	0.1±0.4a	0.6±0.3abc
	PICS	0.1±0.4a	0.6 ±0.3abc
	GOTTA	0.2±0.4a	0.6 ±0.3ab
	GOTTA+PE	0.1±0.4a	0.0±0.3a
	FC+GOTTA	0.1±0.4a	0.0±0.3a
	PPB+PE	0.23±0.4a	2.2±0.3bcd
Month-6	PPB	13.0±0.4b	62.1 ±0.3 f
	PICS	0.4 ±0.4a	4.0±0.3 d
	GOTTA	21.4±0.4c	78.4 ±0.3f
	GOTTA+PE	0.4±0.4a	2.2 ±0.3cd
	FC+GOTTA	0.0±0.4a `	0.3±0.3ab
	PPB+PE	0.7±0.4a	19 ±0.3 e
F (15,70)		17.3622	34.686
p-value		<0.0001	<0.0001

Means within the same column followed by the same letter were not significantly different (p>0.05%) using Tukey's studentized range test (HSD). Means are based on three farmers and two sub-samples. Where, **FC**= filter cake, **PE** = polyethylene sheet, **PICS** =Perdue improved crop storage, **PE+GOTTA** =polyethylene sheet lined Gota, **FC+GOTTA** = filter cake treated maize in Gota, **PPB** = polypropylene bag, **PE+PPB** =polyethylene lined polypropylene bag).



F (2,6)	5.6
P-value	>1.742367

Figure 4.1: The weight loss of stored maize based on 6-month mean

Means within the same column followed by the same letter were not significantly different (p>0.05%) using Tukey's studentized range test (HSD). Means are based on three farmers and two sub-samples. Where, **FC**= filter cake, **PE** = polyethylene sheet, **PICS** =Perdue improved crop storage, **PE+GOTTA** =polyethylene sheet lined Gota, **FC+GOTTA** = filter cake treated maize in Gota, **PPB** = polypropylene bag, **PE+PPB** =polyethylene lined polypropylene bag).

Grain damage and grain weight loss in the six storage strategies were shown in (Table 4.1). At the beginning of the experiment, the maize had no grain damage. Further damages were minimal (<1%) observed in PICS, PE+GOTTA, FC+GOTTA, and PPB+PE through out of the storage period (Table 4.1). In contrast, grain damage in PPB bags and GOTTA increased from 0.0% at the beginning to 13.0% for PPB and 21.4% for GOTTA after six months. In PPB+PE, the mean values of percentage of insect damaged grain showed slight increase from 0.0% at the beginning to 0.7% after six months of storage. Percent grain damage in GOTTA was significantly higher than that PPB at the end of storage period. There was no significant difference between the percent grain damage on maize stored among all six storage strategies at 3-month storage. Moreover, there was no significant difference between storage strategies of GOTTA+PE, FC+GOTTA, PICS, PPB+PE on stored maize at the end of storage period even though grain damage in PPB+PE was relatively higher at the end period of storage.

No further losses were observed in the PICS bag, PPB+GOTTA, FC+GOTTA through the entire storage. However, weight loss in PPB and GOTTA was increased as 1.75% and 2.7% respectively at the end of storage. The effect storage Strategy on weight loss was not significant ($P > 0.05$). At the end of storage, significant weight loss was observed in traditional storage practices such as PPB and GOTTA. Similar to insect damage, there was no significant difference between the weight loss in PICS, PPB+PE, FC+GOTTA and PPB+PE strategies through the entire storage period (Figure 4.1). But, PPB was significantly differed from FC+GOTTA, GOTTA+PE, and PPB+PE and GOTTA was significantly differed from FC+GOTTA, GOTTA+PE, and PPB+PE strategies at the end of storage (Figure 4.1). In PPB+PE, there was slight increase in weight loss 0.15% at the end of storage. This indicates that using PPB+PE strategy is not effective option. Generally, PICS, GOTTA+PE, FC+GOTA storage strategies were the promising option in loss reduction during grain storage.

Plastic bags in PE+GOTTA, PE+PPB and PICS were oxygen barrier as reported by (De Bruin et al., 2014) since insect pests are biological living organisms, they require air or oxygen for their respiration. As the gas concentration within the bag decreases, the carbon dioxide concentration increases. This phenomenon leads them to lethality as reported by (Villers et al., 2010). But, in storage method FC+GOTTA, there was no more damage existed within the 6-months storage as the result of the action mechanisms of the filter cake power towards insects. According to Nukenine et al.(2010), filter cake powder absorbs and adhere the lipid portion Insect pests by causing to dry and dehydrate consequently lead to death. This storage strategy is the most effective storage strategy. The high levels of grain damage and weight loss in traditional storage practices such as GOTTA and PPB may be attributed to high rate of grain respiration and insect pest proliferation as the consequence of presence of conducive environment particularly high oxygen concentrations inside the bags.

Grain damage and losses were principally a consequence of *Sitophilus zeamais* infestation. for, instance, Tefera et al.(2011) has conducted that weight losses of 6.9% conducted after 3-months storage for *Sitophilus zeamais.* Moreover, Sori & Ayana (2012) reported that grain damage and weight losses 54% and 41% correspondingly on maize stored for 6-months in farmers store in Jimma zone, Ethiopia. even though not experimentally tested individual farmers reportedly suffering heavy losses of up to 34% dry weight and in severe cases, 70% to 80% of stored maize grains were damaged has reported by (Tefera et al., 2011). In a separate study, Nukenine et al.(2002) has conducted that *Sitophilus zeamais* caused up to 80% losses in cultural storage methods in Cameroon after 6 - 8 months of storage. Recently, Baoua et al.(2014) in storage testing with stored maize grain using PPB bags in Benin, Burkina Faso and Ghana beneath natural infestation conditions has reported grain damage of 6.7 - 53.9% corresponding to weight loss of 1.1% - 21.5% in maize grain stored in PPB bags where populations of *Sitophilus zeamais* were the principal species after 6.5 months. The present study regarding to PPB argued with the earlier work that 13% of grain damage and 1.75% of weight losses were recorded at the end of 6-months (Table 4.1). Similarly, 21% of grain damage and 2.7% of weight loss in GOTTA was recorded at end of 6-months in this study (Figure 4.1). During the storage experiment, Baoua et al.(2012) employed local storage spaces present by the applicant; the quality of grain stored in PICS bags was protected. The present study regarding to PICS agreed with the earlier work that quality of grain was preserved in this study (Table 4.1).

4.3. Effect of storage strategies on Bulk density &thousand kernel weight of maize

At the outset of the experiment, the bulk density of all storage strategies had exhibited nearly the same result except GOTTA+FC. From (Table 4.2), the bulk density of FC+GOTTA was (739.7 ±3.3kgm^{-3}) at the outset of experiment. The bulk density for GOTTA (789.5±3.3kg/m^{-3}), for GOTTA+PE (784.7±3.3kgm^{-3}), for PICS (784.2±3.3kgm^{-3}), for PPB (789.5±3.3kgm^{-3}) at the outset of experiment. The decrease of bulk density in FC+GOTTA from outset trial to end was shown as (739.7±3.3kgm^{-3}) at outset, (738.3±3.3kgm^{-3}) after 3-months and (720.2±3.3kgm^{-3}) at the end storage. This indicates that filter cake absorbs the moisture so that reduction in density on this strategy was exhibited. Hence, FC+GOTTA was best alternative strategy in reducing moisture of grain so that any deterioration related to moisture was preserved. On the other hand, bulk density in PPB and GOTTA also decreased at the end of storage (Table 4.2). It was decreased in GOTTA (784.2±3.3 kgm^{-3} to 744.7 ±3.3 kgm^{-3}) from initial to end of storage. It also was decreased in PPB (789.5±3.3kgm^{-3} to 741.8±3.3kgm^{-3}) from outset to end of storage. Bulk density in PICS, PE+GOTTA, and PE+PPB strategies didn't indicate significant difference within six-months. The effect of storage strategies on bulk density was highly significant ($p < .0001$). FC+GOTA storage strategy differed significantly from all fives storage strategies at the outset of storage in terms of bulk density. Similarly, there was significant difference between, PICS and PPB, PICS and FC+PE, FC+GOTA and PPB+PE storage strategies from 3-6-month storage. Insignificant different was observed between PPB and GOTTA at the end of storage (Table 4.2).

Bulk density of maize storage in GOTTA and PPB (Table 4.2) has been decreased after three-month storage. The decrease of bulk density of the two strategies was caused due to the increase of insect population in the two storage strategies as the result of maize damage and weight loss. Moisture content is the major factor in determining of bulk density of maize grain variety as reported by (Guo, 2015).

Table 4.2: Mean (±SE) of bulk density and thousand kernel weight maize after 0-month, 3-month and 6- months' storage

Month (Periods)	Storage Strategy	Bulk density	Thousand kernel weight
Month-0	PPB	789.5±3.3cd	347.7±3.8 c
	PICS	784.2±3.3cd	347.5±3.8c
	GOTTA	784.2 ±3.3cd	344.4± 3.8bc
	GOTTA+PE	784.7 ±3.3cd	339.2 ±3.8abc
	FC+GOTTA	739.7 ±3.3 b	342.5 ±3.8bc
	PPB+PE	793.1 ±3.3 d	346.0±3.8bc
Month-3	PPB	792.8 ±3.3 d	339.2 ±3.8abc
	PICS	787.9 ±3.3cd	340.7 ±3.8bc
	GOTTA	794.1 ±3.3d	340.2±3.8bc
	GOTTA+PE	785.3 ±3.3cd	344.2 ±3.8bc
	FC+GOTTA	738.3 ±3.3 b	334.1±3.8abc
	PPB+PE	783.7 ±3.3cd	336.6±3.8abc
Month-6	PPB	741.8 ±3.3b	329.2±3.8ab
	PICS	773.8±3.3c	331.9±3.8abc
	GOTTA	744.7±3.3b	321.7±3.8a
	GOTTA+PE	783.7±3.3cd	343.7±3.8bc
	FC+GOTTA	720.2±3.3 a	343.8±3.8bc
	PPB+PE	773.6 ±3 c	337.4±3.8abc
F(15,70)		45.0	2.67
p-value		<0.0001	<0.0030

Means within the same column followed by the same letter were not significantly different (p>0.05%) using Tukey's studentized range test (HSD)**.** Means are based on three farmers and two sub-samples. Where, **FC**= filter cake, **PE** = polyethylene sheet, **PICS** =Perdue improved crop storage, **PE+GOTTA** =polyethylene sheet lined Gota, **FC+GOTTA** = filter cake treated maize in Gota, **PPB** = polypropylene bag, **PE+PPB** =polyethylene lined polypropylene bag*)*

Thousand-kernel weight

From (Table 4.2) the effect of storage strategies and storage period on thousand kernel weight of maize grain was highly significantly ($p < .0001$). Thousand kernel weights at the end of storage were decreased in GOTTA and PPB strategies. From (Table 4.2) TKW in GOTTA (321.7±3.8g) at the end of storage was lower than (344.4±3.8g) at the outset of storage). TKW in PPB (329.2±3.8g) at end of storage was lower than (347.7±3.8g) at outset of storage.

Recent study concerning to TKW is in agreement with earlier work about this TKW. Recently, Nda-Agyima & Addae-Mensah(2014) reported that similar TKW reduction in PPB was recorded. In this study, 321g of thousand-kernel weight in PPB was recorded at the end of storage from 347.5 g of TKW at the outset of storage. In GOTTA and, 329g of TKW was recorded at the end of storage from347.5 g of TKW at the outset of storage.

4.4. Effect of storage strategies on Germination of maize grain

Table 4.3: Means (±SE) of percent germination of maize after 0-month, 3-months, and 6-months storage

Month (Period)	Storage Strategy	% germination
Month-0	PPB	100.0±0.0e
	PICS	99.7±0.0e
	GOTTA	96.4±0.0cd
	GOTTA+PE	99.7±0.0e
	FC+GOTTA	99.7±0.0e
	PPB+PE	99.7±0.0e
Month-3	PPB	99.7±0.0±0.0e
	PICS	93.2±0.0bc
	GOTTA	93.2±0.0c
	GOTTA+PE	99.7±0.0e
	FC+GOTTA	99.7±0.0de
	PPB+PE	93.2±0.0c
Month-6	PPB	71.7±0.0a
	PICS	99.7±0.0e
	GOTTA	71.7±0.0a
	GOTTA+PE	99.7±0.0e
	FC+GOTTA	98.5±0.0e
	PPB+PE	84.1±0.0b
F(15,70)		16.836
p-value		<0.0001

Means within the same column followed by the same letter were not significantly different (p>0.05%) using Tukey's studentized range test (HSD). Means are based on three farmers and two sub-samples. Where: **FC**= filter cake, **PE** = polyethylene sheet, **PICS** =Perdue improved crop storage, **PE+GOTTA** =polyethylene sheet lined Gota, **FC+GOTTA** = filter cake treated maize in Gota, **PPB** = polypropylene bag, **PE+PPB** =polyethylene lined polypropylene bag).

At the outset of the experiment, maize grain in all six storage strategies was almost germinated. The effect of storage strategy on percentage germination was highly significant ($p < .0001$). From (Table 4.3) large numbers of non-germinated grains were observed in GOTTA and PPB at the end of storage. As the result, the percentage germination was decreased more in the two traditional storage strategies. For instance, in GOTTA, % germination decreases from 96.4±0.0% at the outset to 71.7±0.0 % at end of storage and in PPB; it was decreased from 100.0±00% at the outset of storage to 71.7±0.0% at the end of storage. Significant loss of grain viability was observed on both PPB and GOTTA storage strategies from 3-6 months. Storage strategies such as PICS, PE+GOTTA, FC+GOTTA have mean % germination from 99.7±0.0%, 99.7±0.0%, and 98.5±0.0%, at the end of storage. This shows significant grain viability on these storage structures. This also indicates that lining traditional GOTTA structure with polyethylene sheet kept better grain viability. From (Table 4.3) percent germination in PE+PPB strategy was decreased from 3-6-months. For instance, percent germination was decreased from 99.7±0.0% at the outset to 84.1±0.0% at end of storage. This shows that using PPB+PE is not promising alternative storage strategy in maintaining grain viability. Further work may evaluate the present study with the doubled layered lining of polypropylene bag concerning on maintaining grain viability or quality.

It has been stated that the rate of percent grain germination was not affected by filter cake products and did not have negative effects as conducted by (Girma Demissie et al., 2008). It has been agreed with the present study that maize grain treated with filter cake suffered no deterioration in grain quality 12-month storage (Girma Demissie et al., 2008),however, at present, lack of its availability is preventing their extensive use in un-developed countries. For a separate recent study, Prasantha et al.(2014) reported that percent germination was decreased from 93 to 87% in the hermetic samples, whereas it was decreased from 93 to 46% in control samples studied on mung bean seeds after 6-month storage. In this study, from (Table 4.3) percent germination in GOTTA and PPB was decreased from 96.4% and 99.7% to71.4% respectively from outset to end of six months. Percent germination in PICS, PE+GOTTA ,and FC+GOTTA storage strategies was remained unchanged from outset to end of storage (Table 4.3).With regard to hermetic storage strategies and filter cake treatment , it has been agreed with previous study that PICS,PE+GOTTA and FC+GOTTA are very effective strategies in maintaining grain viability, preserving the quality of grain (Ndegwa et al.,2015).

4.5. The effect of storage stragegies on the physicochemical properties of stored maize

Effect moisture content on stored maize grain

The effects of storage strategies on moisture content was highly significant ($p<0.001$). From (Table 4.4) moisture in PPB, GOTTA and GOTTA+FC strategies was decreased. Storage strategies such as PICS, GOTTA+PE and PPB+PE were relatively shown an increase in moisture content from 3-6-months storage (Table 4.4). The moisture content in GOTTA was decreased from 13.2±0.2% to 12.4±0.2% at outset to end of storage and moisture content in PPB was also decreased from 13.2±0.2% to 12.3±0.2% at outset to end of storage. The moisture content in FC+GOTTA was also decreased from 13.3±0.2% to11.8±0.2% from start to end of storage. For instance, from (Table 4.4) moisture content in PICS was (12.8±0.2% at the beginning, 12.9±0.2% after 3-months and 13.5±0.2% at the end of storage). In GOTTA+PE, moisture content was increased as (13.2±0.2% at outset of experiment, 13.2±0.2% after 3-month storage and then it was decreased to13.0±0.2% at end of storage). Moisture content in PPB+PE also was increased as (13.3±0.2% initial, 13.6±0.2% after 3-month storage, and 13.6±0.2% at the end of storage). Generally, GOTTA+PE, PPB+PE and PICS storage strategies normally retained its moisture content throughout the storage period whereas moisture content of in PPB, GOTTA and GOTTA+FC continued to decline reaching levels that were significantly lower than in PICS, PPB+PE and GOTA+PE through the entire storage. Significant difference in moisture content was observed in PPB and FC+GOTTA from 0-3-month storage. Moisture content in PICS, GOTTA+PE, PPB+PE did not differ significantly through the entire period (Table 4.4).

From this study, the moisture content of maize grain stored in plastic bags of (GOTA+PE, PICS and PP+PE) was slightly increased (Table 4.4).Plastic bags (double bagging) cause grain deterioration due to the influx of oxygen and external moisture by bag reopening during sampling and condensation nature of the plastics (Yakubu and bern,2009). In addition, the study area was used as irrigation during storage period and the environment was humidified, due to this occasion, the plastic bags' moisture may increase. Moisture content of maize grain stored in FC+GOTA was decreased through the entire storage (Table 4.4). Since, Nukenine et al.(2010) reported that filter cake's mode of action causes loss of water from grain. It has stated that similar related studies with the present study on proximate composition of maize were conducted by (Khakame et al., 2012). Similarly, the present study regarding to moisture content reduction in traditional structures was conducted by(Baoua et al., 2014).In this study, experiments were set up immediately after rainy season, subsequently, ambient relative humidity continued to drop, consequently, maize stored in PPB bags and GOTTA might lose moisture due to evaporation.

Table 4.4: Mean (±SE) the moisture content of maize grain after 0-month, 3-months, and 6-months

Month (Period)	Storage Strategy	Moisture Content
Month-0	PPB	13.2±0.2 cde
	PICS	12.8±0.2 bcde
	GOTTA	13.2±0.2 cde
	GOTTA+PE	13.2 ±0.2 de
	FC+GOTTA	13.3 ±0.2 de
	PPB+PE	13.3±0.2 e
Month-3	PPB	12.1±0.2 ab
	PICS	12.9±0.2 bcde
	GOTA	12.1±0.2 ab
	GOTTA+PE	13.3±0.2 e
	FC+GOTTA	11.9 ±0.2 a
	PPB+PE	13.6 ±0.2 e
Month-6	PPB	12.3±0.2 a bc
	PICS	13.5±0.2 e
	GOTTA	12.4±0.2 abcd
	GOTTA+PE	13.0±0.2 bcde
	FC+GOTTA	11.8 ±0.2 a
	PPB+PE	13.6±0.2 e
F(15,70)		11.31
p-value		<0.0001

Means within the same column followed by the same letter were not significantly different (p>0.05%) using Tukey's studentized range test (HSD). Means are based on three farmers and two sub-samples. Where, **FC**= filter cake, **PE** =polyethylene sheet, **PICS** =Perdue improved crop storage, **PE+GOTTA** =polyethylene sheet lined Gota, **FC+GOTTA** = filter cake treated maize in Gota, **PPB** = polypropylene bag, **PE+PPB** =polyethylene lined polypropylene bag).

Table 4.5: Means (±SE) of protein, oil, starch, and ash content of maize after 0-mnth, 3-months and 6-months storage

Month (Period)	Storage Strategy	Protein	Starch	Oil Content	Ash content
Month-0	PPB	8.6±0.1	70.1±0.2	5.7±0.1	1.3±0.02 cd
	PICS	8.4±0.1	70.1±0.2	5.6 ±0.1	1.3±0.02 bcd
	GOTTA	8.4±0.1	70.1±0.2	5.6 ±0.1	1.4±0.02 d
	GOTTA+PE	8.5±0.1	70.2 ± 0.2	5.5 ±0.1	1.4 ±0.02 d
	FC+GOTTA	8.5±0.1	70.3± 0.2	5.6±0.1	1.4 ±0.02 d
	PPB+PE	8.5±0.1	70.2± 0.2	5.7 ±0.1	1.4 ±0.02 cd
Month-3	PPB	8.1±0.1	69.9± 0.2	5.6 ±0.1	1.3 ±0.02 ab
	PICS	8.4±0.1	70.5± 0.2	5.6 ±0.1	1.3 ±0.02 bc
	GOTTA	8.5±0.1	69.7 ±0.2	5.6 ±0.1	1.3 ±0.02 bc
	GOTTA+PE	8.6±0.1	70.2 ±0.2	5.6 ±0.1	1.4 ±0.02 cd
	FC+GOTTA	8.4±0.1	69.9 ±0.2	5.6 ±0.1	1.4±0.02 cd
	PPB+PE	8.5±0.1	70.3± 0.2	5.6 ±0.1	1.4 ±0.02 cd
Month-6	PPB	8.6±0.1	70.1± 0.2	5.6 ±0.1	1.2 ±0.02 a
	PICS	8.6 ±0.1	70.1± 0.2	5.6 ±0.1	1.3±0.02 bc
	GOTTA	8.7±0.1	69.7± 0.2	5.8 ±0.1	1.2±0.02 a
	GOTTA+PE	8.4±0.1	70.1± 0.2	5.8 ±0.1	1.3±0.02 bc
	FC+GOTTA	8.6±0.1	69.7± 0.2	5.6±0.1	1.3±0.02 bc
	PPB+PE	8.5±0.1	70.3± 0.2	5.6 ±0.1	1.3 ±0.02 bc
F(15,70)		1.27	1.0	1.27	7.039
p-value		>0.2426	>0.5083	>0.2459	<0.0001

Means within the same column followed by the same letter were not significantly different (p>0.05%) using Tukey's studentized range test (HSD). Means are based on three farmers and two sub-samples. Where, **FC**= filter cake, **PE** = polyethylene sheet, **PICS** =Perdue improved crop storage, **PE+GOTTA** =polyethylene sheet lined Gotta, **FC+GOTTA** = filter cake treated maize in Gotta, **PPB** = polypropylene bag, **PE+PPB** =polyethylene lined polypropylene bag*)*.

The effects storage strategies on protein, starch and oil were not significant ($p>0.05$). The percentage of carbohydrate was in the range from 69.7% -70.5% while the percentage of oil was in the range of 5.5% - 5.8% and percentage protein was in the range of 8.1% - 8.7% from (Table 4.5). From (Table 4.5) in all storage strategies protein, starch and oil, neither increased nor decreased was observed within 6-months.

The percentage of the total ash content of was in range of 1.2%- 1.4% from the end of storage to beginning of storage. From (Table 4.5) ash content in GOTTA was decreased from 1.4±0.02% at start of storage to 1.2±0.02% at the end of storage. The percentage of storage strategy on total ash content was significant ($p<0.0001$). In PPB, ash content was decreased from 1.3±0.02% at the start of the storage to 1.2±0.02% at the end of storage. Generally, insignificant total ash content was observed in four storage strategies (PP+PE, GOTA+PE, FC+GOTA and PICS) from beginning to end of storage.

In this study, nutritional content did not change significantly in hermetic storage strategies as well as non-hermetic storage strategies. Similar results with the present study regarding to nutritional content correlated with studies carried out by Weinberg et al. (2008). Proximate composition results in (Table 4.5) generally remained unchanged in hermetic storage due to bags ability to conserve grain quality by protecting it from causal agents. This finding is consistent with previous research studies (Reed et al.2007) and some other finding results have also agreed that the proximate composition of maize grain was reported as similar results as this finding. For instance, Ashwin et al.(2017) has reported that ,Maize contains about 10% proteins, 4% oil, 70% carbohydrates, 2.3% crude fiber, 10.4% albuminoides and 1.4% ash. Similarly, in this study result (Table 4.5) agreed that the proximate composition of carbohydrate, protein, oil and total ash content were in range of 69.7 -70.5%,8.1% - 8.7%, 5.5 %- 5.8% and% 1.2-1.4% respectively.

5. CONCLUSION & RECOMMENDATION

In this study, effectiveness of six different storage strategies were compared using solar bubble dried maize grain in Mecha district Kudimi *kebele*. The storage strategies included PPB, PICS, GOTTA, GOTTA+PE, GOTTA+FC and PPB+PE. The storage experiment involved in three maize farmers' and the experiment longed for six months. Sampling was done at three-month interval. Proximate composition such as protein, oil, starch, total ash and moisture content and insect count, % germination, % damage and % weight loss, bulk density and thousand kernel weights were analyzed. Variance of data (ANOVA) was analyzed using Linear and non-linear mixed effect model in nested design and mean comparison was done using tukey's student test (HSD).

It was observed that using double layered lining of polyethylene sheet in the Gotta is effective storage method. Hence, it can be recommended that the double layered polyethylene sheet lining strategy (PE+GOTTA) has the potential in protecting stored maize from insect attack. This (PE+GOTTA) successfully hindered the multiplication of insect pests in stored maize grain. It is also effectively controlled the development insect population in all growth stage and hence it is good alternative techniques for storing maize grain where limitation and accessibility even more than this. Moreover, using the filter cake powder at rate of 1% (w/w) in Gotta structure (FC+GOTTA) was the most effective storage type with significantly reduced insect count, grain damage and weight loss after six months of storage.

Maize stored in traditional storage structures such as PPB and GOTTA was highly infested by insects and was unfit to human consumption at the end of the storage period. Infestations as high as 78 insect kg^{-1} in GOTTA and 62 insect kg^{-1} in PPB were recorded at the end of storage period. Similarly, in this finding, 13% of grain damage in PPB bag and 21% of grain damage in GOTTA were recorded at the end of storage and about 2.7% of weight loss in GOTTA and 1.75% of weight loss in PPB bag were recorded within 6- months. Insignificant weight loss, grain damage, insect counts were recorded in all other storage strategies through the entire storage.

The viability of seed germination in GOTTA and PPB bag decreased as storage period increased. Percent germination in GOTTA was decreased from 96.4% to 71.7%. In PPB, it was decreased from 100% to 71.7%. In other storage strategies, loss of germination capacity of maize grain was not as high as that of the traditional storage methods. Use of PICS bag, double layered PE lining of GOTTA and application of filter cake powder in Gotta resulted in comparably high germination. Therefore, depending on their availability, farmers can use any of these three strategies for storage of maize seed.

Concerning proximate composition, insignificant difference in protein, oil and starch were observed, however, reduction in ash content was recorded in GOTTA and PPB. The bulk density of filter cake treated grain (FC+GOTTA) was much less than the rest five storage methods at the start to end of storage. This was due to the reduced flow of the powder treated grain. But, bulk density of the maize stored in Gotta and pp bag was also reduced at the end of storage. Moisture content, in FC+GOTTA, GOTTA and PPB bag was reduced.

Generally, PE+GOTTA, PICS bag and GOTTA+FC were the most effective alternatives storage methods to store maize grain safely for longer period than traditional storage system like GOTTA and PPB bag which would be applicable for Ethiopian smallholder farmers. Therefore, extension systems working on the post-harvest loss reduction of maize can popularize these strategies.

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APPENDEXES

The analysis of variance (ANOVA) of data using mixed effect model

Parameters Measured	Period	strategy*period	strategy*period*sample
Live Insect	373.6687**	34.8634**	0.7114 Ns
Grain Damage	43.78427**	17.3622***	0.03714 Ns
Bulk Density	104.4**	45.0**	0.6 Ns
Thousand kernel weight	11.76**	2.67**	0.44 Ns
Germination	243.787**	16.836**	0.455Ns
Moisture	15.09**	11.31***	0.1 Ns
Protein	1.67Ns	1.27Ns	0.75 Ns
Starch	0.8Ns	1.0Ns	0.6Ns
Oil	2.12Ns	1.27Ns	0.90Ns
Ash	70.794**	7..039**	0.524 Ns

Note** indicates highly significant

Ns- Indicates non-significance