ASSESSMENT OF ASSOCIATION OF STORAGE PRACTICES, FUNGAL PATHOGEN AND NUTRITIONAL QUALITY OF STORED MAIZE *(Zea, mays* L.*)* AT FARMERS', COLLECTORS' AND WHOLESALERS'STAGESIN JIMMA ZONE, ETHIOPIA

MSc. THESIS

By

LEMLEM GURMU DENBOBA

NOVEMBER, 2015

JIMMA UNIVERSIT

ASSESSMENT OF ASSOCIATION OF STORAGE PRACTICES, FUNGAL PATHOGEN AND NUTRITIONAL QUALITY OF STORED MAIZE *(Zea, mays* L.*)* AT FARMERS', COLLECTORS' AND WHOLESALERS'STAGES IN JIMMA ZONE, ETHIOPIA

A Thesis

Submitted to School of Graduate Studies Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment for the Requirements of the Degree of Master of Science in Postharvest Management (Prishable Crops)

By

Lemlem Gurmu Denboba

Major Advisor: Chemeda Abedeta (PhD scholar), Jimma University

Co-advisor: Fikre Lemessa (PhD), Jimma University

November, 2015

Jimma University

DEDICATION

This thesis is dedicated to my beloved Parents my mother BIZUNESH NEGASH and my father GURMU DENBOBA for nursing me with affection and love and for their devoted partnership in the success of my life.

STATEMENT OF AUTHOR

First, I declare that this thesis is my original work and all sources or materials used for this thesis have been properly acknowledged. This thesis is submitted in partial fulfillment of the requirements for MSc degree in Postharvest Management at Jimma University. I dully declare that this thesis is not submitted to any other institutions anywhere for the award of any academic degree, diploma or certificate.

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Name: Lemlem Gurmu Denboba

Signature:____________________

Place: Jimma University, Jimma

Date of submission: ____________

BIOGRAPHICAL SKETCH

The author, Lemlem Gurmu Denboba, was born on August 29, 1985 at Aleta wondo Southern part of the country. She attended Elementary school in Aleta Wondo Secondary and preparatory school and she successfully passed the Ethiopian School Leaving Certificate Examination (ESLCE) in 2002, and joined Hawassa University College of Agriculture in 2003.Thenafter three years study in the year 2006 she graduated with B.Sc. degree in Plant Science. After her graduation, she had worked for five years in different organization from September 2007 to August 2013. In September 2013, she joined the School of Graduate Studies of Jimma University College in Agriculture and Veterinary Medicine to pursue Master of Science Degree in Postharvest Management (Perishable).

ACKNOWLEDGEMENTS

First and above all, I praise God and his beloved mother Saint Virgin Merry, for providing me this opportunities and granting me the ability to proceed successfully. He has been giving me everything to accomplish this thesis: patience, strength, wisdom and blessing.

My sincere appreciation goes to my advisors Mr. Chemeda Abdeta and Dr. Fikire Lemessa for their professional support, moral and technical advice and I am really grateful for the time you devoted for me despite your busy schedule.

I would like to thanks Jimma University College of Agriculture and VeterinaryMedicine (JUCAVM), Department of Foreign Affairs, Trade and Development (DFATD) and Reduction of Loss and Adding Value (RELOAD) for their financial and material support during my study.

My special thanks and appreciation goes to Ethiopian public health institute (EPHI) laboratory and JUCAVM plant pathology, plant physiology and entomology laboratory for their cooperation during data collection. My special gratitude also goes to Jimma zone Agriculture office for their cooperation and also my especial thanks goes to Dedo,O/Nada, Mana, Kersa and Sokoru district Agriculture office and My very special thanks goes to maize producer farmers and traders for their information and cooperation during data collection.

I am indebted to all post-harvest management department staff especially Dr. Ali Mohamed and RELOAD project coordinator Dr. Debela Hunde. My appreciation and thanks also goes Mr. Abebe W/Senbet, Mrs Mulu, Miss Eleni Alemayehu and Mr. Fikadu Neggese for their support during data collection.

My passionate and profound gratitude goes to my lovely parents my dad Gurmu Denboba and my mom Buzunesh Negash for the love, care and support they gave to me throughout my life. My immense gratitude goes to my friends who supported and encourage me during my study. Finally, I would like to acknowledge authors who cited in this thesis.

ACRONYMOUS

AAS	Atomic Absorption Spectroscopy
AOAC	Association of Analytical Chemists
APHLIS	African Post-Harvest Loss Information System
Aw	Water Activity
CIMMYTE	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
DON	Deoxynivalenol
ATA	Agricultural Transformation Agency
ECX	Ethiopian Commodity Exchange
EPHI	Ethiopian Public Health Institute
FAO	Food and Agricultural Organization
FTC	Farmers Treaning Center
GLM	General Linear Model
HB-660	Bako Hybrid Variety
IFPRI	International Food Policy Research Institute
JUCAVM	Jimma University College of Agriculture And Veterinary Medicine
MAFA	Monitoring African Food and Agriculture
m.a.s.l	Meter Above Sea Level
PA	Peasant Association
PDA	Potato Dextrose Agar
SAS	Statistical Analysis Software
SNNPR	Southern Nation Nationality People Region
SPSS	Statistical Package for Social Scientists
UK	United Kingdom
US$	United States Dollar
USD	United States Dollar
USAID	United States Agency for International Development
WFP	World Food Program
ZoFEDO	Zone Finance and Economic Development Office

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Assessment of Association of Storage Practices, Fungal Pathogen and Nutritional Quality of Stored Maize (Zea, Mays L.) at Farmers', Collectors' and Wholesalers' Stages in Jimma Zone, Ethiopia

ABSTRACT

Maize(Zea mays L.*)is a major staple food source for millions of people in Ethiopia. Due to its high productivity and low cost of calorie it is preferred crop for food security of the country. Likewise, in Jimma zone maize ranked first both in production and productivity compared to all cereals and a major staple food crop for large number of households. Even though, the crop plays a key role in household food security the benefit of higher production and productivity has been negated due to high post-harvest loss. Thus, this study was conducted to assess association of storage practices, fungal pathogens and nutritional quality of store maize at farmers', collectors' and wholesalers' storages condition in selected districts of Jimma Zone. The study was conducted in five purposively selected districts (Dedo Kersa, Omo Nada, Mana and Sokoru) which represents the three agro-ecologies of Jimma zonefrom January 2014 to June 2015. Multi-stage sampling procedure was used to select the target groups. Totally 342 respondents were interviewed using semi-structured questioner. For laboratory experiments farmers who produce HB-660 variety and store their maize in "gombissa" were purposively selected. Morphological identification of fungal pathogens wascarried out by direct plating method monthly interval. However, nutritional analysis was done every two month interval starting from harvest to six month storage following AOAC methods. Both qualitative and quantitative data were analyzed using SPSS version 20 and SAS version 9.0. Survey result showed, about 12 post-harvest activities were practiced by farmers and some of the activities also used by traders. Three maize storage structures (gombisa, modified and bag) were identified. However, most of the farmers(>75%) use gombisa which is constructed from bamboo or Soyam wood. Comparing different activities alongpost-harvest period, storage loss identified the critical loss point based on producer's perception. In totals*even fungal genera were isolated. *However, Fusarium, Pencillium and Aspergillus spp.were predominantly identified in all samples with decreasing order.Mould incidence and severity in stored maize showed significant (P <0.05) difference both for storage duration and agro-ecologies for different actors. Nutritional analysis result showed significant (P< 0.05) effect of storage duration and agro-ecologieswere observed on moisture contentof stored maize under all actors storage condition.Crude protein, fat carbohydrate and caloric value were significantly (P<0.05) decreased as the storage duration increased.But, fiber, ash and mineral (Ca, Zn and Fe) content were slightly increased along the storage period whereas, phosphorus content declined along the storage period. The carbohydrate and calorific value were significantly declined from 68.1±0.6% and 349.5±3.4 Kcal to 60.6±0.6% and 305.03.4 Kcal after six monthsof storage. This finding showed that fungal load increased and nutritional quality declined as the storage duration increased. Moreover, the most important mycotoxins producing fungi are dominantly found infecting maize along the value chain. Furthermore, different actors along the value chain are less awared about health hazard of those pathogens. This research highlights, the need for determination of mycotoxin associated with those fungi genera. There is also need for awareness creation all stakeholders on postharvest loss reduction and also health impact of mouldy maize.*

Key words: *storage practices, stored maize, storage fungi, nutrition*

1. INTRODUCTION

1.1. General Background

More than 55% of Africans earn their livelihood from agriculture, which is also the key to economic development of the continent (Nukenine, 2010). Likewise, agriculture is the mainstay of Ethiopia's economy and it provides all the necessary dietary foods, raw materials for food industries and quality products for export market (CSA, 2009). Cereals are the major crops produced in Ethiopia and they constitute the largest share of domestic food production. In 2010/11 main cropping season, cereals were cultivated on 9.9 million hectares producing 17.2 million tons of food grains; this represented 82.3% and 87.7% of the total area and production of food grains in the country, respectively (Ethiopia ATA, 2013). According to CIMMYTE (2011) among cereals, maize ranked second to *teff* in area coverage (21.7% for maize and 27.4% for *teff*) and first in total production (28.5% for maize and 19.9% for *teff*). Maize is a major staple food source for millions of people in Ethiopia and Jimma zone alike. Oromya region is the major maize producer as it accounts 61% of total production of maize in the country (Ethiopia ATA, 2013) and maize first in rank from other cereals in production and productivity around Jimma zone (CSA, 2009).

The per capita consumption of maize in Ethiopia is about 60 kg per person per annum; however, the stage of consumption varies from place to place. In major maize producing areas, maize is a staple food, and in other areas it is used in mixture with other food grains (CIMMYTE, 2011). It is an important food security crop in the country with the cheapest cost for caloric source among all major cereals. Its share with regards to consumption has increased from 14% in (1961-70) to 29% in (2001-07) mainly at the expense of *teff*. Also it has been shown that the unit cost of calories per US dollar for maize is ‘one-and-a-half and two times lower than wheat and *teff*. Maize provides 0.2 kg of protein per US$, compared to 0.1 kg of protein per US$ from *teff* and 0.2 kg of protein from wheat and sorghum (MAFA, 2013). Even though, the sector play key role in the country, PHL of maize in Ethiopia is tremendous as high as 5% to 19% (Dereje, 2000) and it is the major production income challenges in Ethiopia.

Cereal grains such as maize are exposed to qualitative and quantitative losses during post-harvest operations such as harvesting, drying, threshing, transport, storage, shelling/de-husking, cleaning, milling, bagging, distribution and processing (FAO, 1992; Golob *et al*.,2002). However, the losses are more significant during storage in developing countries where the traditional storage structures used are inefficient because they do not keep the product in hermetic and safe conditions that not avoid the entrance of moisture and pests (FAO, 1992) due to this grain preservation is evidently difficult for small and medium farmers in developing countries such as Ethiopia but storage is an important aspect of food security in (IFPRI, 2010; Waktole and Amsalu, 2012).

Grain storage the most important since most cereals, including maize, are produced on a seasonal basis, and in many places there is only one harvest a year. However, seasonal production leads to fluctuating supply at the international, national, regional or at household stages because the fluctuating supply is in sharp contrast to a stable demand throughout the year and region. Therefore, storage helps to even out fluctuations in market supply, both from one season to the next and from one year to the next, by taking produce off the market in surplus seasons, and releasing it back onto the market in off seasons(CIMMYTE, 2013). Despite the realization of the importance of storage, the potential impact of stored products is however undermined by the incidence of increasingly destructive storage pests and disease especially fungus that cause quality deterioration leading to nutritional and financial losses (Belaifa *et al*., 2011).

Due to a lack of awareness and access to appropriate technologies, farmers end up selling their maize soon after harvest, when prices are at their lowest, partly to hold back the loss by post-harvest pests and disease the same farmers are forced to buy the grains back at more than twice the price later during the off season (CIMMYTE, 2013). Therefore, the benefit of bumper harvests has been negated by high post-harvest loss as a result of poor post-harvest management.Post-harvest losses can include not only loss of the crop itself, but also damage to the environment, a lack of return on the resources and labor needed to produce the crop and a decrease in the livelihood of individuals involved in the production process. However, current regional (eastern and southern Africa) maize post-harvest losses (PHL) are estimated4 billion USD annually; this is equivalent to a decade of food aid for the region, or enough annual calories for about 48 million people (CIMMYTE, 2013).

The efficient post harvest management (PHM) of maize depends basically on the ecological conditions of storage; the physical, chemical and biological characteristics of the grain; the storage period and the type and functional characteristics of the storage facility. On-farm storage practices and structures, such as *gotera*, can make maize susceptible to different types of damages, including storage pests and disease (IFPRI, 2010; Dubela *et al.,* 2012 and 2014).

Study conducted in southwestern part of Ethiopia on comparing loading stage and three month stored maize grains revealed that mean grain damage caused by mould and weevil were 37.8 and 20.9% (Hailegiorgis, 2013). Study results showed the extent of maize grain mould distribution and importance in Jimma zone under traditional farmers' storage condition (Hailegiorgis, 2013 and Dubale *et al.,* 2014).However, previous research work focus only at producer stage without considering different actors along maize value chain like collectors and wholesalers store.

Furthermore, so far no information available on mycobiota epidemiology including all actors involved in maize value chain. So current research work consider different main actors involved along maize value chain in selected district of Jimma zone. Moreover, throughout the world much attention is given for bio-deterioration which is caused by fungal pathogen and grain bio-deterioration is a dynamic process, which leads to the loss of physical and nutritional qualities (Reed *et al*., 2007; Belaifa *et al*., 2011) which eventually render grain unsuitable for human consumption. However, most study conducted in major maize producing areas mostly focus on quantitative loss. In Ethiopia study on nutritional quality loss of stored maize under different actors along value chain is limited. In addition, different storage practices used by different actors along value chain during different PHM activities was not thoroughly assessed to identify critical loss point and intervention area in each activities. Therefore, the objectives of current study were :-

General objective:-

The general objective of the study was toassessassociation between storage practices, fungal pathogens and nutritional quality of stored maize *(Zea mays* L.)at farmers', collectors' and wholesalers' conditions in southwestern part of Ethiopia.

Specific objectives

1. To assess and document available storage practices in the study areas.
2. To investigate incidence and severity of mould infection at farmers, collectors and wholesalers stages during the storage period.
3. To identify and document disease causing fungal pathogens at farmers', collectors' and wholesalers'stagesduring the storage period.
4. To determine nutritional and anti-nutritional contents of maize at different storage period at farmers', collectors' and wholesalers' storage conditions.

2. LITERATURE REVIEW

2.1. Maize Production in Ethiopia

Teff, wheat and maize are the three most important cereal crops in Ethiopia in terms of the number of smallholder farmers engaged in production, the volume of land coverage and the shear amount of grain produced but maize is the crop with the largest smallholder coverage by 8 million holders (compared to 5.8 million for *teff* and 4.2 million for wheat). Maize is critical to smallholder livelihoods in Ethiopia (IFPIR, 2010). In 2011 production year, maize was cultivated in 2 million hectares of land, with an estimated 5 million tons produced (Ethiopia ATA, 2013). According to APILS (2013) report maize production in Ethiopia was increased by 951,196 tons from production year 2011 to 2012 and in 2012 production year it increase to 6 million tone (FAO STAT,2013).

In Ethiopia, maize is a leading cereal crop with main season production 2.9 million tons in 2005/06 and accounting for 21.2% of major crops production (including oilseeds and pulses). Oromya region is the major maize producer it account 61% of total production of maize in the country followed by SNNPR (20%) (Ethiopia ATA, 2013). Crop utilization survey data shows that, of the total national production of maize, 76.03% was utilized for household consumption (ECX, 2009). Jimma zone represents one of the major maize producing areas of Ethiopia according to MAFA (2013) and in 2007/08 production year 289,474 tonsmaize were producedaround Jimma zone(CSA, 2009).However, in Jimma zone maize was increased year after year as shown in the table 1 bellow (Jimma Zone Agriculture Office, 2013).

Maize is an important food security crop in Ethiopia, with the cheapest cost caloric source among all major cereals(MAFA, 2013) and production was increase year after year(APILS 2013). However, after harvest, maize is extremely vulnerable to post-harvest losses due to mould, pests and theft (Golob *et al.*,2002; Govender *et al*., 2008; Kaaya and Kyamuhangire, 2010)

Table 1: Maize production in Jimma zone

S/no	Districts	Production year (G.C)									
		2008		2009		2010		2011		2012	
		Hec	Qts	Hec	Qts	Hec	Qts	Hec	Qts	Hec	Qts
1	Chora Botor	10493	216571	11095	321691	12784	359227	13249	450466	13268	488928
2	Dedo	10617	217082	10528	289467	8350	211176	8654	259620	10905.5	328048
3	Gera	7620	158719	7310	161644	5769	109902	5979.2	134740	5948.62	147107
4	Gomma	12076	223492	11402	271920	8009	195036	8300	198736	6740	216977
5	Gumay	4360	91126	4264	123090	3659	89106	3792	87216	3687	120696
6	Limu Kosa	13923	295323	14451	325155	13560	391541	14053	480027	14159	524087
7	Limu Saka	12500	249267	12685	392258	12220	320474	12664	379920	11688.5	349891
8	Mana	9047	163675	9021	251513	6568	196860	6806.8	204204	5560	202428
9	N/Benja	4940	90955	2989	88092	5764	147130	5974	180381	6099	196937
10	Omo Nada	13151	336775	14078	626725	14008	432967	14517	551646	9323	432452
11	Kersa	14673	351167	13010	449855	11591	347400	12012	436351	13226	476402
12	Seka Chokorsa	14456	298644	15075	373905	12510	316374	12965	336397	11535	367274
13	Satama	7591	183298	6024	126110	5588	78507	5791	92656	3120	60746
14	S/Sombo	9722	203773	9262	236250	6075	142255	6296	157089	5092.5	171508
15	Sigimo	4703	91769	4821	88200	3937	55312	4080	65280	2500	44990
16	Sokoru	15162	321011	13560	385797	11627	315827	12050	357237	13025	390026
17	Tiro Afata	6324	128070	5660	160978	4150	116615	4301	129030	6626	277820
	Sum	***171357***	***3620716***	***165236***	***4672650***	***146171***	***3825708***	***151484***	***4500996***	***142503.12***	***4796315***

Note: - Hec= Hector, Qts=Quintal

Source: -Jimma Zone Agriculture Office Report (2013) unpublished and combined by the author

2.2. Post- Harvest Activity in Maize Production

Postharvest management aims to preserve and maintain high quality of the harvested produce both in the field immediately after harvest and in storage, as well as in transit; proper methods have to be adopted for postharvest handling of commodities to avoid damage such as appropriate harvesting and handling can do much to reduce fungal contamination of maize (WFP and FAO,2012) and also prevent the need for chemical which increase the cost of the grain and cannot completely restore its original nutritional value (Hodges and Farrell, 2004). Changes in the physical quality of the grain are often a result of mechanical harvesting, shelling and drying; the first two processes sometimes result in external damage, such as the breaking of the pericarp and parts around the germ, facilitating attack by insects and fungi (FAO, 1992). Spillage is another problem during post harvest handling of maize; this leads to loss in terms of quantity and also quality in case contaminated grains or cobs are again mixed with the clean stuff. In this case, contamination will lead to mould development. The situation will be worse if the spill gets into contact with moisture. Losses due to spillage are common during shelling that is done by beating the cobs with sticks (Hodges and Farrell, 2004) thus; Postharvest technologies can contribute to food security in multiple ways. They can reduce post-harvest loss, thereby increasing the amount of food available for consumption by farmers and consumers (FAO and World Bank 2011).

2.2.1. Harvesting

Harvesting is the single deliberate action to separate the cob from its grown medium proper harvesting reduce post-harvest losses; at this stage loss depends on supervision and experience of the workers but harvesting efficiently and at right time is critical to avoid loss during down the chain (FAO and World Bank, 2011; Kiaya, 2014). The optimum time of harvesting maize is when the stalks have dried and moisture of grain as about 20-17% and timely harvesting reduces post harvest loss of produces. (FAO, 1992). Maize harvesting is highly mechanized in developed countries of the world, while it is still done manually in developing countries like Ethiopia (Tadesse, and Basedow, 2004). In developing countries harvesting and transportation is undertaken using manual labor only on a very few large commercial farms and estates is harvesting and drying done mechanically (FAO, 1992).

Many farmers in developing country simply leave the plants standing in the field until sufficiently dry for the cobs to be removed and carried home to the store, although the cobs may be bent over when the plants have reached maturity in the field to prevent further water migration into the kernels. Alternatively, maize plants may be cut and the cobs placed on raised platforms, either in the field or at the homestead to assist drying (Hodges and Farrell, 2004). The moisture content at harvest a very important factor for handling and management of the crop in further operations report shows that on time harvesting and storage with recommended moisture content of grain reduce 30-40% of aflatoxin contamination of grain during storage period (Atanda *et al.,* 2013) while, increasing of deterioration were reported due to delayed harvesting (Alakonya *et al*., 2008).

2.2.2. Drying

High grain moisture above 12% favor fungi development in the store (Gregori *et al*., 2013) therefore, in either mechanical or manual harvesting maize grain must be dried to safe moisture stages of about 12% (FAOand World Bank, 2011). Many farmers in tropical countries simply leave the plants standing in the field through bending down the upper part of the plant holding the ear, until sufficiently dry or dry maize after harvest through heaping the cobs inside the room or in the yard (WFP and FAO, 2012) however, drying crop in the field by traditional methods fail to attain safe moisture level for storage; in addition field drying exposes the crop to field pests (FAO, 2003). Keep the grain as clean as possible during drying helps to avoid contamination therefore, drying maize on cement floor or use plastic sheet important to reduce chance of contamination (Golob*et al*.,2002)**.**

On-farm drying of maize in a natural ventilated structure such as, circular granary basket becomes a positive smallholder option in most part of Africa and drying process of maize cob is achieved by means of the air which blows through the structure walls and through the crop inside and removing the moisture (WFP and FAO, 2012). However, there are grains drying technologies such as: - solar and mechanical dryer (Golob, *et al*., 2002)those dryer can be used at small scale or large scale production and may reduce risk of loss related with grain moisture content. Study result shows thatdrying maize using biomass-heated conventional dryer were reduce drying duration to six hours whereas in natural sun drying it was take more than a week and also reduce risk of rain problem during drying (Kaaya and Kyamuhangire, 2010). But if it is carried out too rapidly and with high temperatures; it will induce the formation of stress cracks, puffiness, discoloration and change in protein content, which will resulted effect on product quality (Hawkins*et al*., 2005). Therefore, the temperature of drying should not exceed 54^{o}C because higher temperature may cause change in the protein content (FAO, 2003).

2.2.3. Shelling

Maize shelling in Ethiopia is commonly done by traditional methods of shelling, such as hand shelling and through beating maize cob with the stick (IFPRI, 2010). Beating maize will result in physical damage which makes it more vulnerable to pests and moulds (Hodges and Farrell, 2004). Using a maize shelter is preferred there are different shelling technology used for maize shelling such as handheld and small rotary hand sheller and mechanical shelling technology that improve the efficiency of this process **(**FAO,2003).

2.2.4. Storage

Grain storage is a crucial component of the post-harvest chain(Golob*et al*., 2004). It is practiced by farmers, traders and governments to facilitate marketing and ensure food security. The principal objective in any maize grain storage system is to maintain the stored grains in good condition so as to avoid deterioration both in quantity and quality and perfectly performed by any farmer with little effort and cost (FAO, 2013).

In Ethiopia maize were stored through heaping the cobs inside traditional facilities such as *dibignit* and *gotera* (Tadesse, and Basedow 2004; Abeb and Bekele, 2006; IFPRI, 2010). Bag storage of shelled grains in well designed store rooms is the most suitable and there are improved storage structures that can prolong the storage duration until market prices for grains are favorable but not practiced by most farmers such as metal silos are effective in bringing the losses to zero if properly used; proper usage includes testing grain moisture content it should be less than 13% and depletion of oxygen by burning candle inside the silo (CIMMYT, 2011). But inappropriate storage and handling of produce were leads the development of storage fungi such as insufficient drying and humid condition favor the development of fungi and which result in unacceptable level of mycotoxin contamination in tropics (Suleiman *et al.*, 2013).

2.3. Storage Technology

There are diverse methods of storage of grains and cereals available for small and medium farmers. These include wood cribs, metal drums, plastic containers, household metal silos and plastic or jute bags (Abiodum, 2012). The selection by the user of any of these methods will depend upon factors such as availability, convenience of use, the particular situation, the efficiency of the method and suitable benefit-cost ratio.In developing countries, lack of appropriate grain storage technologies leads up to 20-30% losses, particularly due to postharvest pests; as a result, smallholder farmers end up selling their grain soon after harvest, only to buy it back at an expensive price just a few months after harvest (IFPRI, 2010; CIMMYT,2012) but through application of appropriate storage technologies the loss may reduced; according to CIMMYT (2011) report after 12 months of storage higher loss were recorded in traditional storage(33.2%) as compared to traditional storage using actellic super(12%), super bags (6%) and no loss were observed on maize stored in metal silos.

In Ethiopia 70% of farmers were used synthetic insecticides partly in combination with traditional methods (Tadesse, and Basedow, 2004). The use of synthetic insecticides potent means of protection against storage pests however, synthetic insecticides are falling out of favor for environmental and health reasons, and the future is likely to rest more on other approaches such as good hygiene, hermetic stores, and the application insecticides derived from local plant materials (FAO and World Bank, 2011). Smoking and heat treatment are also used as traditional method of mould and insect control (Groot, 2004).

In many areas local plants roots, leaves, flowers, fruits and/or seeds act as a repellent or as an insecticide; the whole dried leaves of certain plants can be mixed with the stored products in a number of cases. According to Groot (2004) *Persian lilac* leave powder in a concentration of 40-80 g for every 1 kg of product(a concentration of 4-8%) used to control weevil and around 3 g of the driedand powdered leaves of *Hyptis spicigera* or *Cassia nigricans*is sufficient to protect 1 kg of pulses against bean weevil (a concentration therefore of 0.3%) also, 20 g of dried pulverized rhizome of turmeric added to 1 kg of stored product has been found to be highly repellent against grain weevils and the lesser grain borer. The same outher reported that Neem /*Azadartcha indica*/ seed powder or oil was effective for controlling storage insect pests; small amount of Neem oil were killed about 90 % of the Cowpea weevil and he protective effect were last for about 3 months. According to Fikadu *et al.*, (2013) cotton(*Gossypium hirsutum*) and mustard (*Brassica cariata*) seed shows good result for control of maize storage pest; both seed at concentration of 0.3 to 0.5 ml resulted zero weevil progeny emergence, minimum seed damage, zero grain weight loss and 89.2 to 95.5% seed germination rate which were similar to those of malathion (Diethyl succinate). The effectiveness of this method of protection depends on several factors however; the dosage is very important and mostly determined by trial and error (Groot, 2004). Because of their natural source many practitioners believe botanicals to be safer than synthetic alternatives this is not entirely true and some botanicals can be more toxic than many commercial alternatives therefore, it need some precaution (Golob*et al*., 2002).

Grain moisture is one of important factor for grain deterioration in the store however, water absorbing materials are useful method to dry grain in the store such as; mixing grain with wood ash or straw ash and dried clay (Groot, 2004) and also there are drying technologies that may used before and after storage (Golob*et al*.,2002).

Hermetic storage is a recent development in the use of MAs in a low pressure environment; resulted in very promising treatments with market acceptability. Hermetic storage for dry commodities is now used in 32 countries for storage of a number of important commodities and hermetic containers were ranges from small portable containers of 60 kg to 1 tone called super grain bag to a series of large flexible storage structures, called Cocoons, Tran Safe liners and Bunkers, ranging from 5 to 30,000 tones (Villers *et al.*,2008). Super bags are hermetic sacks made of a multi-layer polythene material that incorporates a gas barrier that restricts oxygen and water vapors movement and vary in sizes that can hold 50kg to 3 tons of grain/seed (WFP and FAO, 2012). The household metallic silos one of the post-harvest technologies in the fighting hunger and food security problem because it allows grains to be kept for long periods and prevents attack from pests such as rodents, insects and birds but the grain should be dried properly moisture content (Kiaya, 2014). Locally available materials such as:- oil drum with a perfect fitting lid, Plastic bags and very dry underground pits are traditionally used as an air-tight storage container by smallholder farmers (Groot, 2004).

2.3.1. Traditional storage structure

Traditional methods of storage still predominate in the developing countries such as Ethiopia (Tadesse, and Basedow 2004; Abebe andBekele, 2006). The selection of storage methods depends on the commodity, the climate, the social and economic characteristics of the particular situation for instance:-in humid countries, where grain cannot be dried adequately prior to storage and needs to be kept well ventilated store during the storage period, traditional granaries (cribs) are usually used for such purpose (WFP and FAO, 2012). However, underground pit storage is practiced in the Sahelian countries and southern Africa, and is used in dry regions where the water table (low) does not endanger the contents (Nukenine, 2010). Underground pits keep grain without damage for many years due to cool and relatively airtight however; grain on top and around the sides exposed to high moisture and often mouldy (FAO, 2004; USAID, 2011). Crib/ *gotera* and pits also used in different parts of Ethiopia (Tadesse and Basedow, 2004).

In most parts of Africa conical platform used to facilitate drying during storage and grain stored on platforms in heaps, in woven baskets or in bags (USAID, 2011). Conical platforms are pointed at the bottom facilitate drying because of their funnel shape (Golob, 2002; FAO, 2004).

Crib or storage baskets are a distinct improvement on platforms, a crib has ventilated sides made of bamboo, stalks and tree twig; mud-plastered walls can provide protection from rain and prevent uptake of moisture by dried grain (Golob, 2002; Hodges and Farrell, 2004). However, un-plastered baskets/cribs are used for both drying and storage of grain in most parts of humid countries to facilitate drying during storage (USAID, 2011). This type of storage is common in some parts of Ethiopia (FAO, 2003; Tadesse and Basedow, 2004; Abebe and Bekele, 2006). Such types of storage structures also common in Jimma zone (Dubale *et al.*, 2014).

2.3.2. Improved storage structures

Traditional systems have evolved over long periods of time to satisfy storage requirements within the limits of the local culture; they have been developed to suit the needs of a simple, subsistence farming system. However, as production systems become modernized these storage methods may not be able to cope with increases in production and provide only limited protection against insect, mould and rodent damage, particularly in areas where the climate is warm and humid (FAO, 2013). While improved storage is a prerequisite for sustaining increment in production without increased post harvest losses, the improvements must be carefully inline with economic, social, and cultural realities (FAO and World Bank, 2011). In East and Central Africa, very little success has been achieved in improving the main farm storage structure however; new practices adopted by producers living in peri-urban areas, they use smaller, more convenient stores such as old oil drums and high-density polyethylene containers or tanks, which are manufactured for water storage (Hodges and Farrell, 2004;Yakubu, 2009). However, in different part of developing countries various modifications were done on available local storage structure in order to reduce loss during storage and to keep grain quality during storage.

The "Pusa" binwas developed by the Indian Agricultural Research Institute (IARI), these silos are made of earth or sun-dried bricks and have a capacity of 1 to 3 tons. It has been demonstrated in some African countries and it gives good results when loaded with well dried grain (FAO, 1992; Golob, 2002). The "Burkino" silois a modification of traditional dome shaped bin and constructed with stabilized earth bricks. "Burkino" silo further modified to "USAID" siloin Nigeria. It can holding one tone of maize grain and the walls are made of stabilized earth bricks and are plastered inside and out with cement reinforced with chicken wire mesh (FAO, 1992).Another modification of "Burkino" silo is Ferro cement Bin ("Ferrumbu"); itconsists mainly of chicken wire plastered inside and developed in Cameroon. It tested in a number of African countries and adapted in many parts due to its several advantage in keeping grain quality through protecting the grain from external environment, rodent, birdand insect (FAO and World Bank, 2011).

Household metal silosare made of smooth or corrugated galvanized metal (FAO, 2003)and often regarded as too costly for small scale storage but effectively reduce loss of product during storage (Kiaya, 2014) and study result showed the net effect of metal silo adoption was a 99 percent reduction in maize storage losses due to insect pests (Gitonga *et al.*, 2012). Better to provide cover, to avoid excessive variations in temperature and moisture translocation (Golob, 2002).However, concrete/cement silosare 'cement rich', and potentially expensive storage structure but lower in cost than metal silos and have good resistance to corrosion and better able to resist abrasive than most metals and more robust and thus better able to withstand internal pressure loads and impact loads (FAO, 1992).

The most common method for grain storage in many countries is bag storage in a variety of buildings such as:- concrete, local brick, corrugated iron, and mud (Hayma, 2003). Bag storage have advantage over bulk storage such as:- flexibility of storage, slow handling, reduce spillage, low capital cost and easy inspection (FAO, 1992). According to Tadesse, and Basedow (2004) in most parts of Ethiopia farmers were store shelled maize using bag similarly it also used around Jimma zone (Dubale *et al* 2014). However, jute bags do not give any protection against insects and rodents; in order to reduce such problems triple layer bag was developed. it used in some parts of Africa as hermetic storage (Yakubu, 2009; WFP and FAO, 2012). Grain storage loss due to moisture, insects, mould and rodents can cost farmers 25%-30% of their yield per season however; effective use of the hermetic bags could reduce wheat storage loss from 25-30% to 5-10% (FAO, 2013).

2.3.3. Modern warehouses

Warehouses are intended for the storage and physical protection for grain. It may also include materials and equipment required for the packaging and handling of bagged grain and storage pest control; although, in an ideal situation such items should be stored separately (Saleem *et al*., 2012). The approximate location of a proposed warehouse for grain storage will have been decided first in order to store the product safe and site selection mostly done based on topography of the area and load bearing capacity of soil, resistant to compaction and well drainage characteristics moreover; for easy access and movement of stocks, the warehouse should be sited as near as possible to a main road (FAO, 1992). In tropical countries it is very important that the long axes of warehouses are oriented East-West as nearly as possible (USAID, 2011); this way, the side walls are least exposed to the sun and temperature variations inside are minimized. Before calculating the dimensions of a warehouse it is important to identify the function either it intended to be a transit store or used to reserve stocks (Golob*et al*., 2002).

Even if there is variation in composition and construction all warehouses consist of a well constructed floor, walls, roof, and one or more entrances and may include others, such as ventilators, windows, artificial lighting, etc. for good management of grain and protection from insect pest and disease and paramount importance should be attached to ensuring that the quality of the commodity to be stored will not be affected by physical factors such as moisture and heat (USAID, 2011). Ventilation through opening is necessary for allowing the renewal of air and reducing the temperature in the warehouse. Openings should be located under the eaves to avoid entry of water, rodents, etc. and fitted with anti-bird grill on outside (FAO, 1992). Grain in the warehouse can be fumigated with gas lethal for insect pest to control damage of grain (USAID, 2011).

According to FAO(2003) and USAID (2011) report around Eastern Africa warehouse with ranges of 2,000 to over 15,000 tons were mostly used for communal storage and the grain stored in bag in large stalk. However, warehouse was usually owned by governmental or non-governmental organization (Nukenine, 2010).

2.4. Factors that Affect Post-Harvest Quality of Maize

Storage facilities not only offer the opportunity to provide a supply of food between staple crop harvests but farmers are able to improve farm incomes by storing crops and selling at premium prices(CIMMYTE, 2013). However, the quality of grain may affected by several factors during storage period and the most important factors are temperature, moisture, fungi, insects, mites, rodents, birds, geographical location and storage facility (Govender *et al*., 2008). Those factors generally divided in to biotic and abiotic factors (Pitt and Hocking 2009).

Quality and nutritional changes that occur during storage of cereal grain are the net result of interactions within a complex ecological system(Hayma, 2003; Govender *et al*., 2008). Controlling of safe storage conditions enables preservation of quality characteristics of freshly harvested grain over storage period; quality integrates such as physico-chemical conditions, nutritional value, sanitary condition and safety for human or animal consumption are a set of properties that ultimately affect the final market value of grain (Batey,2010).

2.4.1. Abiotic factors

Those factors are related with external environment or the intrinsic characteristics of the grain; according to most study findings factors such as:- temperature, relative humidity, moisture content of the grain, storage duration and storage technologies are the most important factors which affect the quality of stored grain (Groot, 2004; Narayanasamy, 2006; Giorni *et al.*, 2007a; Kaaya and Kyamuhangire, 2010; Oladle and Osipitan, 2011; Fekadu *et al*, 2013;Dubale *et al*., 2014).

2.4.1.1. Temperature and relative humidity

High temperature was developed in the store as a result of respiration of grain, insects and moulds(Jayas and Ghosh, 2006).Temperature of the store and relative humidity are associated each other; rising temperature by 10 ^{o}C will cause increasing of relative humidity by 3% however declining of temperature by 10^{o}C cause declining of relative humidity by 3% (USID, 2011). Storage temperature higher than normal temperature (28+2^{o}C) create favorable condition for thermophilic fungi whereas; lower temperature (10^{o}c) inhibit the development of storage fungi (Oladle and Osipitan, 2011). Similarly,most of the insects that affect stored grains at temperatures between 25 and 30 °C and a relative humidity in between 70 and 80%(Hayma, 2003).

Fungi develope best in a warm and humid atmosphere (Hayma, 2003) in particular, humidity is crucial for the development of fungi even at a low temperature however; a dry atmosphere will not kill the spores of fungi which infect the produce as they are highly resistant to dry conditions (Groot, 2004).According to Dubale*et al*. (2014) finding the relative humidity and temperature of traditional storage structure /*gombisa* around Jimma zonewere optimal for the growth of some storage fungi.

Nutritional quality of cereal gains was adversely affected as a result of storage at elevated temperatures (Rehman, 2006). Report shows that dried maize stored at 38^{o}C protein content was decreased from 8.39 to 8.26% after six weeks storage (Oladle and Osipitan, 2011).

2.4.1.2. Moisture content of grain

Moisture content of maize, an important part of its chemical composition but has much influence on composition, quality changes during storage, processing and economies when it is higher or lower than the recommended; in the tropics the recommended moisture levels is 12.5% for bagged maize and 13.5% for bulk maize (Hayma, 2003).

The relative humidity of the air affect the moisture content of grain at harvest; if grains harvested during warm and humid weather the moisture content will be high (Groot, 2004) and high grain moisture content due to continued rainfall towards the end of the harvest period creates an optimal condition for increased fungi infection and mycotoxin contamination during storage (Mukanga *et al.,* 2010). Study finding showed that grain moisture content higher than recommended which means higher than 12% (FAO, World Bank, 2011) crate favorable condition for fungi growth (Niaz *et al.,* 2011; Dubale *et al.,*2012 and 2014). Furthermore, fungi can grow with the range of water availability between 1.00 (pure water) to 0.6 aw (Narayanasamy, 2006).

2.4.1.3. Storage duration

Prolonged storage affects both microbial and nutritional quality of grain as a result of different factors such as natural respiration of grain, development of storage fungi and insect pests(Hayma, 2003). According to Fikadu *et al.*(2013) around 20.92% of stored maize were lost due to insect pests in six month storage in Jimma zone and similar result were reported in Kennya (Kimenju and Groote, 2010). Similarly, Storage duration has significant effect on the development and incidence fungal pathogen on stored maize (Atukwase *et al.*, 2012). Study result reported that heavy (98-100%) fungal infection after six month storage of maize (Niaz *et al.*, 2011). Moreover, Biochemical changes in maize grains were occurred as a result of storage duration such as:-decrease in pH, an increase in titratable acidity and reduction of protein content (Rehman, 2006; Barreto *et al.*, 2013).

2.4.1.4. Storage practice

Traditional storage such as storage pit creates a suitable environment for the development of storage fungi through diffusion moisture can enter to pit from the surrounding soil and creates a favorable condition for the development of mould however; use of improved grain storage methods such as providing polythene lining for stores can minimize grain deterioration due to growth of moulds (Mashilla *et al.*, 2004). On-farm storage practices and structures, such as gombisa can make maize susceptible to different types of damages such as storage pests and disease (FAO and World Bank, 2011; Waktole and Amsalu 2012; Dubale *et al.*, 2014). High moisture of maize during storage cause high fungi infection (Niaz *et al.*, 2011) and post-harvest drying maize in bare ground using sun drying expose the product for fungal infection (Golob *et al.*,2002; Kaaya and Kyamuhangire, 2010). Therefore, storage practices should be improved or supported by other post-harvest technologies such as drying maize to appropriate moisture content using dryer, sanitation, and other(Golob *et al.*,2002; Kaaya and Kyamuhangire, 2010).

2.4.2. Biotic factors

Living organisms like insects, rodents, birds (on-farm storage) and micro-organisms are serious constraints to the traditional storage systems of Africa as well as Ethiopia (Tadesse and Basedow, 2004). Storage insect pests are the most important cause of stored maize loss both in terms of quantity and quality loss (Groot, 2004; Kimenju and Groote, 2010; Wakitole and Amsalu, 2012; Dubale*et al*., 2012) and also Fungi are the second most important storage pest which cause spoilage of stored maize around Jimma zone (Dubale*et al.,* 2014) and contamination of maize grain with fungi is regarded as one of the most serious safety problems throughout the world which is related with mycotoxin production (Kaaya and Kyamuhangire, 2010).

2.4.2.1. Storage insect pests

Estimated amount of 1% to 5% of stored grain in developed countries and 20% to 50% of stored grain in developing countries were lost due to insect damage (Rashad *et al.,* 2013). Weevils (Sitophilus zeamais) are among the most destructive pests of stored grain and classified as a major storage pest (Yakubu, 2009) due to it causes high damage of stored produce and its ability to destroy a whole grain (Kanyamasoro *et al.,* 2012). Type of storage structure is one factor for insect damage during storage period such as; traditional storage structures expose the grain to insect attack also create favorable conditions for their proliferation. Study result reported by Tadesse and Basedow (2004) showed that storage pests are very important in Ethiopia and it damage 29% of stored maize. Higher insect damage were reported on maize stored under traditional farmers storage structures around Jimma Zone similarly; 54 to 75% damage and 41 to 80% weight loss between three to six months were reported by Waktole and Amsalu (2012) in Jimma zone uder traditional farmers storage. Another study conduted in Jimma zone also reported that 19.42 and 19.92% damage in gombisa and sack respectively, (Dubale *et al.,* 2012). Study conducted in Keneya were reported that significant damage of maize stored by hugging above the fireplace (Wambugu *et al.,* 2006). Insect pests in addition to direct damage on stored grain generate metabolic heat and this heat condensation on surfaces due to temperature difference and develop hot spots which can quickly result in heating and complete spoilage and create favorable environment for the development of storage fungi (Hayma, 2003;Yakubu, 2009).

2.4.2.2. Fungus

A moisture level of the maize kernels is vital for the development and dominance of fungi(Mukanga *et al.,* 2010; Niaz *et al.,* 2011; Dubale *et al.,*2014). Maize stored at a higher moisture level supports the growth of field fungi in storage but as the storage time increases, moisture levels decrease this shift in moisture level causes the field fungi to be replaced by storage fungi because of this reason the field fungi are not aggressive invaders of maize kernels under storage conditions but storing maize below the optimal recommended conditions can expose the product for field and storage fungi infestation (Dawlal *et al.,* 2012).

Field fungi: Which invade the grains before harvest and require wateractivity (a*w*) for growth greater than 0.93 (equivalentto a moisture content of 22–25% wet weight formost cereals). They cause blemishes, blights and discolorations (Golob *et al*., 2002). Can be detected by routine inspection and does not continue to increase in storage if grain is stored at the proper moisture content and temperature and most field fungi are more prevalent when rainfall during harvest however; invasion by field fungi may be more severe if the crop has been damaged by insects, birds or hail (Narayanasamy, 2006; Fandohan *et al.,* 2003; Dawlal *et al.,* 2012). With corn, ears well covered by husks and maturing in a downwards position usually have less rot than ears with open husks or ears maturing in an upright position (Girma *et al.,* 2008). Field fungi require high moisture content to grow, averaging 22 - 25% on wet weight basis or 30 - 33% on dry weight basis and they generally infect maize while it is still in the field (Dawlal *et al.,* 2012). Field fungi common on corn include species of *Alternaria,Cladosporium, Diplodia* and *Fusarium* (Barney *et al.,*1995; Kaaya and Kyamuhangire, 2006).

Storage fungi: Agricultural produce may be exposed to infection by microbial pathogens both prior to harvest in the field and after harvest during transit, handling, and storage (Narayanasamy, 2006). Growth of storage fungi and insect damage may well start before the before harvest in the field (Hodges and Farrell, 2004); mostly storage fungi which invade grains during storage and they are usually not present in serious extent before harvest however; small quantities of spores of storage fungi may be present on grain going into storage or may be present on spilled grain during harvest, handling and storage equipment or structures; under improper storage conditions this small amount of inoculums can increase rapidly leading to significant problems (Hodges and Farrell, 2004).

The development of storage fungi in stored grain is influenced by the moisture content of the stored grain, the temperature of the stored grain, the condition of the grain storage, the length of grain storage (Niaz *et al.,* 2011; Atukwase *et al.,* 2012) and the amount of mite and insect activity in the grain (Magan *et al.,*2003). The most common storage fungi are *Aspergillus spp.* and *Penicillium spp.*(Kaaya and Kyamuhangire, 2006). These fungi are widely distributed all over the world. *Fusarium, Asparagillus* and *Pencillium* species of fungi were identified from stored maize (Gregori *et al.,* 2013).

Storage fungi can grow at lower moisture content even when no free water is present and due to their ability to produce vast amounts of spores; it is much easier to infect crops during storage (Dawlal *et al*., 2012). Various types of adverse effects are induced by storage fungi on durables, such as reduction in germination, discoloration, musty or sour odors, caking, nutritional alterations, reduction in processing quality and lower its food and feed value. Furthermore, contamination with mycotoxin produced by fungal pathogens is possibly the most serious adverse effect, resulting in dangerous health hazards to humans and animals (Hayma, 2003; Kaaya and Kyamuhangire, 2006; Felicia, *et al.,* 2011; Farhan *et al.,* 2013; Paraginski *et al.*,2013).

2.4.3. Important post harvest fungi that affect maize grain

In both tropics and temperate climate important fungi colonizer of maize are *Aspergillus* spp., *Fusarium spp*. and *Alternaria spp.* are the most common (Lee and Magan,2000). The predominant grain storage fungal genera are *Aspergillus*, *Fusarium*, *Penicillium* and *Cladosporium.*However, *Fusarium, Pencillium* and *Aspergillus* species are common regardless of agro-ecological zone (Kaaya and Kyamuhangire, 2006; Oladele and Osipitan, 2011). Also in Ethiopia various storage fungi including *Fusarium, Penicillium, Aspergillus*, and *Nigropora spp.*reported from maize samples collected from Bako, Hawassa, Areka, Billito, Shallo and Arsi Negele (CIMMYT, 2011).

Fusarium spp. is one of the most important genera of plant pathogenic fungi, with a record of devastating infections in many kinds of economically important plants. The genus *Fusarium* belongs to the *Ascomycota* phylum, *Ascomycetes* class, *Hypocreales* order, while the teleomorphs of *Fusarium* species are mostly classified in the genus *Gibberella,* and for a smaller number of species, *Hemanectria* and *Albonectria* genera (Moretti, 2009). The main approach for the *Fusarium* classification is still by morphology which is banana shaped asexual spores with septate (Moretti, 2009).

Unlike most *Aspergillus spp.* and *Penicillium spp.*,*Fusarium spp.* grows in crops before harvest, and grows only at high water availability levels and generally considered as field fungi rather than storage fungi (Barney *et al.,* 1995). Mycotoxins are therefore usually produced before or immediately after harvest however, high fumonisin contamination (90 and 100%) of stored maize were reported by Garrido *et al.* (2012). *Mycotoxin* such as: -fumonisins, Deoxynivalenol (DON), trichothecene and zearalenone produced by *Fusarium spp.* which have been strongly associated with chronic and fatal toxicoses of humans and animals (Moretti, 2009; Pitt, 2013; Vahčić *et al.,* 2013).

Aspergillus spp. belongs to genus of Hyphomycetes and reproduce only by sexual spores and the stature that bear sexual spore is most important taxonomy; spore-bearing cells distinguishes *Aspergillus* from *Penicillium,* asphialide production in *Penicillium* and a related genus is always successive, not simultaneous (Hocking, 2006). The genus was first described almost 300 years ago and an important genus in foods, both from the point of view of spoilage and mycotoxins production (Pitt and Hocking, 1997). There are over 200 species of *Aspergillus* occupy divers ecology worldwide (Pitt, 2013). However, within section the two important predominantly aflatoxin producing species are *A. flavus* and *A. parasitucus* (Pitt and hocking, 2009); which produce tan, sooty-black, greenish, or greenish yellow mould grows on and between the kernels finally resulted ear and kernel rots and also produce aflatoxins (Hocking, 2006; Hedayati *et al.,* 2007). *A. flavus* is most frequently found between 26^{o}C and 36^{o}C (Caister academic press, 2010). *Aspergillus* spp. is less important before harvest but infections often follow drought stress and damage done by insect pests or birds and damage is most common at or near the tip of the ear (Muthomi *et al.,* 2009). However, it cause a serious losses in stored maize (Tesfaye and Dawit, 2000; Tagne *et al.*, 2003; Kulkarni and Chavan 2010; Tizaki and Mostafa, 2011; Dubale *et al.*, 2014; Bosah and Omorusi, 2014).

Aspergillus mycotoxins of greatest significance in foods and feeds are aflatoxins mostly produced by *A. flavus* and *A. parasiticus*. aflatoxin contamination occurred particularly when maize come into contact with infested soil during harvesting, threshing, and drying also contamination can occur when grains are in the storage due to pest infestation and poor storage conditions (Naresh *et al.*, 2003; Felicia *et al.*, 2011; Karami *et al.*, 2011; Kimatu *et al.*, 2012; Saleem, *et al.*, 2012). However, grain moisture content and temperature determine the extent of contamination (Cotty and Garcia, 2007). Over the last decade, the share of maize production by developing countries declined due to related with afilatoxin; from 2001–2003 maize produced in Kenya were decline slowly (Felicia *et al.*, 2011). Other mycotoxins produced by *Aspergillus* are ochratoxin A, sterigmatocystin, cyclopiazonic acid and Citrinin, patulin and penicillic acid may also be produced by certain *Aspergillus* species (Hocking, 2006; Atehnkeng *et al.*, 2008; Muthomi *et al.*, 2009; Garrido *et al.*, 2012; Kos *et al.*, 2013).

*Penicillium*spp. is a large genus with about 200 species recognized and at least 50 species of common occurrences (Pitt, 1999). The discovery of penicillin in 1929 gave recognition of mycotoxins and nearly 100 *Penicilliumspp.* have been reported as toxin producers(Peterson *et al.*, 1999; Pitt, 2013). The toxins produced by *Penicillium spp.* can affect the liver and kidney function in humans or animals (Peterson *et al.*, 1999). Mycotoxins such as:-Ochratoxin and Citrinin commonly produced by *Pencillium* (Peterson *et al.*, 1999). Toxins were reported in freshly harvested maize samples as well as in stored maize (Mansfield *et al.*, 2008). *Penicillium spp.*invade particularly on ears injured mechanically or by corn earworms and European corn borers and blue-eye mould occurs in stored corn with high moisture content and blue eye damage is characterized by a blue-green discoloration in the germ area; the discoloration results when *Penicillium* fungi invade the germ area through the tip of the kernel and the damage usually occurs at the tip of the ear (University of Illinois Extension, 1991;Wagacha and Muthomi, 2008).*Pencillium* were reported from stored maize (Amadi and Adeniyi, 2009;Njobeh *et al.*, 2009).

Cladosporium spp.is one of the most common fungi genera which isolated from maize. It belongs to phylum ascomycota and family davidiellaceae which affect quality of stored maize (Suproniene *et al.*,2008; Niaz and Dawar, 2009). Some other important species of fungi regarding to stored maize quality deterioration which reported by most findings are *Geothrichum* spp.,*Phoma* spp.,*Rhizopus* spp. and *Alternaria spp.*(Ghiasian *et al.*, 2004; (Kaaya and Kyamuhangire, 2006; Njobeh *et al.*, 2009; Niaz and Dawar, 2009; Mostafa and kazem, 2011; Srenivasa *et al.*, 2011; Bosah and Omorusi, 2014).

2.4.4. Factor influence the development of fungi

There are several factors which influence the development of fungi however; according to Narayanasamy (2006) broadly categorized in to four and listed below:-

2.4.4.1. Intrinsic characteristics of storage fungi

The survival and development of storage fungi are dependent on the genetic constitution of the fungi, atmospheric condition of the store and moisture content of the seed furthermore; insect pest damage are the most important for the development of storage fungi.

Moisture Content: High moisture content generally favors the development of storage fungi however; some fungi tolerate low water activity and water activity with the range of 1.00 (pure water) to 0.6 aw allow fungal growth (Narayanasamy, 2006).

Establishment, development, and growth of storage fungi during storage primarily depends on the moisture content of seeds; water activity below 0.65 helps to prevent fungal growth during storage and this can be achieved through keeping moisture content of grain below 12% (Narayanasamy, 2006). The limiting moisture contents of seeds may differ based on host plant species and fungal species and grain moisture content determines the type of fungi that invade the produce therefore; low initial kernel moisture content inhibited the growth of some fungi while enhance the incidence of others for instance:-*Penicillium spp.* were isolated frequently on kernels with an initial moisture content of 9.7% than those at 12.3% (Barney *et al.*, 1995) however; mould contamination was 5 times larger in the 16% MC maize than 13% MC (Sone, 2001; Niaz *et al.*, 2011).

Temperature : The development of storage fungi within seeds is affected by atmospheric, seed and inter-granular air temperature; grain temperature is altered not only in response to changes in the ambient air temperature, but also in response to the metabolic activity of fungus and insects, resulting in a process known as spontaneous heating (Golob *et al.*, 2002; Hayma, 2003; Yakubu, 2009). The minimum, optimum, and maximum temperatures required for the growth of most storage fungi vary depending on the temperature requirement of fungi species generally categorized as 0 to 5°C, 30 to 33°C, and 50 to 55°C (Narayanasamy, 2006) but maize at a storage temperature of 30^{o}C is particularly vulnerable to contamination (Galati *et al.,* 2011). High temperature (36°C) inhibits the growth of *Fusarium, Penicillium,* and *Rhizopus* while the incidence of *Asparagillus* increased on maize grain (Barney *et al.*, 1995).

2.4.4.2. Pre-harvest Infestation or Infection

Seeds already infected under field conditions or prior to storage may deteriorate faster, since the storage fungi such as *Aspergillus* can continue to invade the seed tissues (Narayanasamy, 2006). Mechanical damage during and after harvest may offer entry to the fungal spores either in maize cobs or grains and the type of maize cultivar may also influence fungal infection such as; maize cultivars with upright cobs are likely to be more susceptible to *Fusarium* infection (Fandohan *et al.,* 2003). *Fusarium spp.* are commonly considered as field fungi invading more than 50% of maize grains before harvest (Kaaya and Kyamuhangire, 2006; Moretti, 2009) however, damage continue during storage of grain (Oladele and Osipitan, 2011). Although *Fusarium spp.* were survives for years in dry grains under good storage conditions (Sone, 2001).

2.4.4.3. Infestation of seeds by arthropods

Insects and mites by themselves can cause seed deterioration directly; the damage caused by the insects may provide avenues of entry for the fungi (Narayanasamy, 2006 and Muthomi *et al.,* 2009). Report shows that the survival of *F. moniliforme* increasing as broken seed and foreign matter increased (Sone, 2001). Furthermore, they can spread the spore when they interact with storage fungi in addition, the metabolic activity of insect increase temperature and moisture within the grain storage environment that sustains the activity and proliferation of moulds (Yakubu, 2009).

2.5. Loss in Nutritional Quality During Storage

Maize compared with wheat and rice is higher in fat, iron and fiber content but the protein quality is low since around a half of its protein is made up of zein, which is low in two essential amino acids, lysine and tryptophan (FAO, 2003).Fungi lack chlorophyll and unable to produce their own food by photosynthesis. Therefore; they grow by breaking down complex substrates such as carbohydrates, proteins and lipids by enzymatic hydrolysis, absorbing the simpler compounds through their cell wallsand continued growth of fungi within the grain can lead to eventual food loss. (Golob *et al*., 2002). In addition to this the viable grain kernels, insects, moulds, mites and other organisms in the stored grain are livingthings and they are respire; during resipiration process loss in nutrient especially loss in carbohydrate. Ifthe moisture content of the grain increases, the respiration rate also increases(USID, 2011). Moreover; maize with higher moisture content resulted higher contamination by fungi and lower in nutritional quality especially carbohydrate content (Kumar and Kweera, 2013).Bhattacharya and Raha (2002) reported declining of carbohydrate content of maize from 74.7% to 57.0% after twelve month storage due to fungi damage and also, Farhan (2013) reported declining of carbohydrate from 62.2± 0.7 to 61.3 ± 0.1 after 90 days of storage due mite infestation of stored maize.

Another factor is storage condition such as:- temperature and relative humidity of the store and maize grain storage at elevated temperature was adversely affect nutritional quality; according to Rehman, (2006) total solube sugar of dreid maize was declined from 3.60±0.1 to 2.0±0.3 after six month storage in 45^{o}C .the same authore reported that protein diestability declined from 58.0% to 17.7% after six month storage at 45^{o}C. Reed et al (2007) who described the effect of storage duration and high grain moisture content on nutritional quality of maize the authore repoted decling of fat content of maize stored at 25^{o}C and 85% relative humidity from 3.25% to 3.02% as a result of high intial grain moisture content.

Most of study result reported that loss of nutritional quality of during storage period due to poor post-harvest handling, natural respiration of grain and damage caused by storage pest such as fungi (Yebuk, 2009; Golob *et al.*, 2002; Rehman, 2006; Reed *et al.*, 2007; Olorunsola,2010; Farhan *et al.*, 2013; Paraginski *et al.*,2013 Stefanello et al., 2015).

3. MATERIALS AND METHODES

3.1. Studies Area Description

Field Studies

The study was conducted in Jimma Zone, which is situated in southwestern part of Ethiopia 360 km away from Addis Ababa; at the latitude of about 7°15´ N and 8°56´ N, and longitudes 36° 00´ E and 38°38´ E. The elevation of the zone ranges from 900 to 3360 m.a.s.l. The area experiences average annual rain fall of 1600mm.The temperature of the zone varies from the maximum of 25 to 30 ^{o}C and the minimum of 7 to 12 ^{o}C. The zone is divided in to 18 districts (hosting a total population of over 2.49 million) with an agro-ecological setting of high lands (15%), midlands (67%) and lowlands (18%) (CSA, 2009; ZoFEDO,2013). In this study, five districts namely Dedo from highland part; Kersa, Omonada and Mana from midland and Sokoru from lowland part of Jimma zone were purposely selected based on their high maize production potential. The selection of those districts was in order to represent different agro-ecologies and the potential maize producing district of the zone. Detail description of selected five districts listed bellow (Table 1).

Table2: Description of study districts

Location	Average annual rain fall (mm)	Temperature (^{o}C)	Altitude (m.a.s.l)	Co-ordinates	
				N	**E**
Dedo	1920	13 – 22	2500 - 3360	07^{o}13’-07^{o}39’	36^{o}43’–37^{o} 12’
Omo-nada	1880	16 – 27	1500 -2500	07^{o} 17’-07^{o}38’	37^{o}00-37^{o}28’
Mana	1500	13 – 24	1470 - 2610	07^{o}45’-7^{o}50’	36^{o}45’36^{o}50’
Kersa	1500	16 -26	1500 - 2660	07^{o}5’- 08^{o}00’	36^{o}46’-37^{o}14’
Sekoru	1467	15 – 32	1000 - 1500	07^{o}45’-08^{o}47’	37^{o}20’-37^{o}25’

Source: ZoFEDO, (2013)

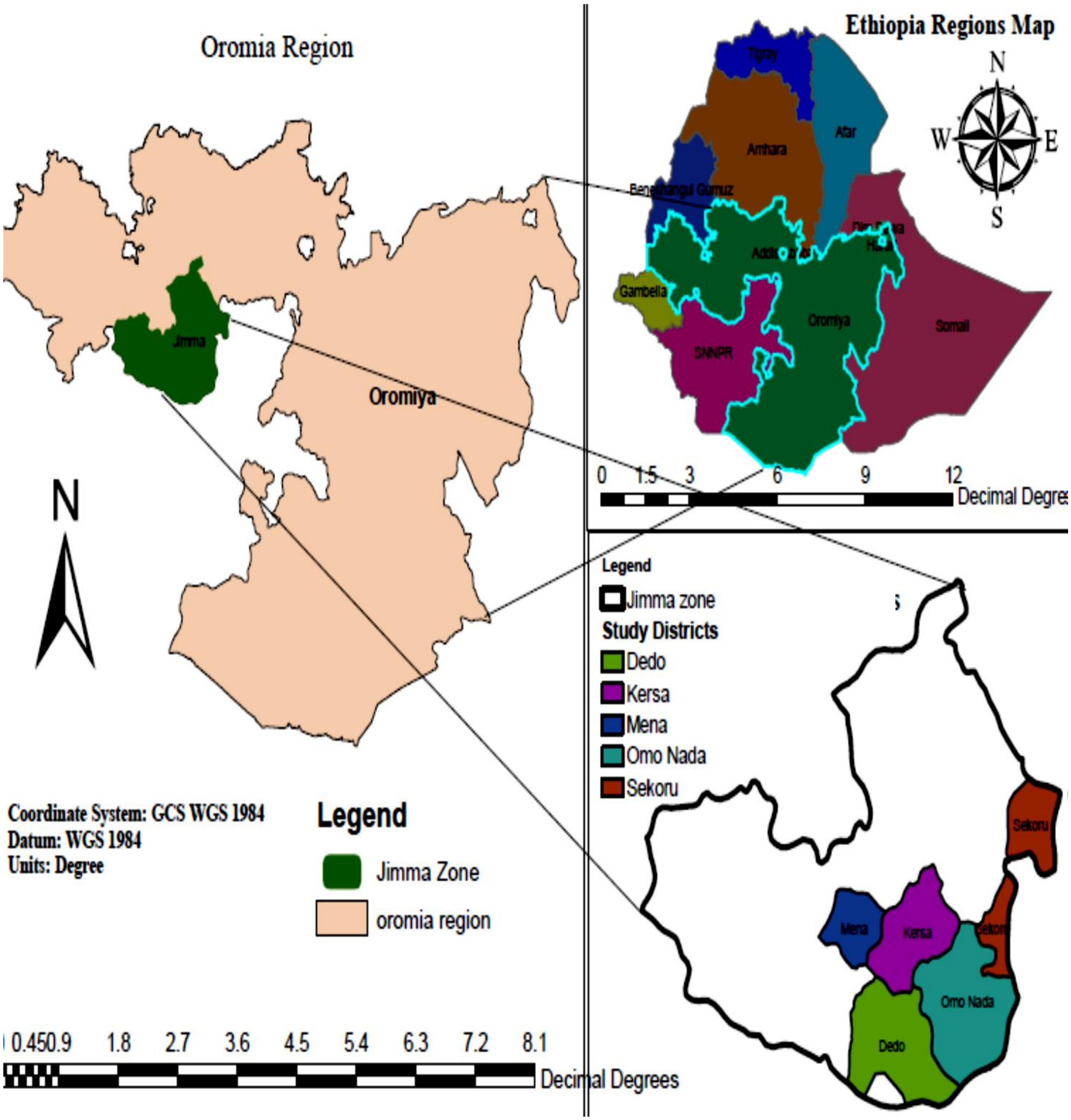


Figure 1: Map of the study districts

Prepared by Melkamu Mamuye, (2015)

Laboratory Analysis

The laboratory work was conducted at Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM) and Ethiopian Public Health Institute (EPHI). Fungi identification was done at plant pathology laboratory of JUCAVM, while nutritional and anti-nutrional analysis were carried out at Ethiopian Public Health Institute (EPHI) laboratory based at Addis Ababa, Ethiopia.

3.2. Survey and Sample Collection

Survey were conducted in five afore-mentioned districts (Table 1) of Jimma zone, Southwestern Ethiopia, starting from January 2014 to June 2015 and a multi-stage sampling procedure was used to select Jimma zone, districts, peasant associations and target group (farmers, collectors and wholesalers).Districts were selected based on secondary data from zonal agricultural office information. After discussion with each district agricultural office experts three peasant associations (*kebeles*) were selected based on agro-ecological characteristics and potential for maize production. From each peasant association three farmers were selected randomly but produce BH-660 variety which dominantly produced and store their maize in local storage structure called *Gombisa*. Three local collectors also selected for disease assessment and sample collection. Disease assessment and sample collection were conducted after harvest and at monthly interval up to six month of storage mostly till stored product depleted. Similarly, three wholesalers from Jimma town also included for the same purpose as they also responsible and main actors in maize transaction in zone.

3.2.1. Assessment of storage technologies and associated constraints

Semi-structured questionnaire was used to collect all detailed information on the maize harvesting and post-harvest practices. Sample size was determined using Yamane's sampling formula with a 95% confidence level as indicated in Singh and Maskuhu (2014).

$$n = \frac{N}{1 + N(e)^2}$$

Where: - n = sample size for research use e = level of precision at 5 %
N= total number of maize producing house hold in selected PA's

After determination of sample size farmers, developmental agents, district level experts, collectors at each districts and wholesalers from Jimma town were selected randomly using randomization techniques of Minitab version 16 from five districts. To check validation of the information collected key informants were interviewed from each districts. In total 342 respondents were interviewed.

3.2.2. Sample collectionand mould incidence in cob

Assessment of maize cobs infection with fungal pathogens was conducted during storage starting from month storageuntil sixth month with a monthly interval. From farmers storage sixty cobs were picked from different location of each storage structure (top, centre and bottom) through PVC pipe fitted at the middle and bottom of the storage structure (*gombisa*) which was allow removal of sample cobs from the store and to avoid entrance of moisture from external environmentPVC pipe outside was covered with plastic sheet. Twenty cobs were removed from each layer after mixed together the cobs were replicated in to three which means 20 cobs per replication (Atukwase *et al*., 2012) and then visual observation of kernels infection on each cob was made and number of infected and normal cobs were recorded. At the same time, moisture content of the sample grains was determined using digitally calibrated moisture tester (Wile[55] TR serial number 554601 by Farm comp Agro-electronics, France) immediately after picking maize from the store (Farhan *et al.,* 2013). Finally, disease incidence was calculated using the following formula (Meer *et al*., 2013).

$$\text{Disease incidence} = \frac{\text{No. of infected cobs}}{(\text{Healthy} + \text{diseased})} \text{X100}$$

During each disease assessment, six cobs were collected randomly from each farmer store. From traders (collectors’ and wholesalers’) 1kg grain from each store were sampled through deep probe from different sack which stored in different part of the store and mixed together and brought to plant pathology laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM) for laboratory experiment.

3.3. Laboratory Assessment

3.3.1. Disease severity and weevil damage

After shelling of six maize cob with three replication (two cobs per replication) then 200 kernels were randomly sampled per replication and used for mould infection (Atukwase *et al*., 2012) and insect damage assessment. Infected and normal kernels were separated visually by the help of hand lens and counted separately using seed counter (CANTADOR 14175996, Kitzingen).Similarly, count method was used to determine weevil damage (Waktole and Amsalu, 2012) and it was done visually supported by hand lens. Finally, disease severity and weevil damage were calculated using the following formulas(Raju and Naik, 2009;Wambugu *et al*., 2009; Dubale *et al.*, 2012).

$$\text{Disease severity} = \frac{\text{No. of infected kernels}}{\text{Total no. of kernels}} \text{X100}$$

$$\text{Weevil damage} = \frac{\text{No. of damaged kernels}}{\text{Total no. of kernels}} \text{X100}$$

3.3.2. Germination test

Germination test were done by randomly taking 150 maize kernels from each sample lot. The test was done in triplicates 50 kernels per replication. Maize kernels were sown in 9 cm Petri-dishes lined with filter paper (Whatman No.1) and moistened with distilled water and then placed on clean laboratory bench at room temperature (25°C) for 7 days. The germinated seeds were visually examined for appearance of radicle and/or plumule and the percent germination was calculated as follows (Tesfu and Emana, 2013).

$$\text{Germination(\%)} = \frac{\text{No. of germinated kernels}}{\text{Total no. of plated kernels}} \text{X100}$$

3.3.3. Mould incidence in kernel

Blotter test was used to determine occurrence of mould on maize kernel (Masomeh *et al*., 2012) and test was carried out following ISTA (2002). A total of 360 maize kernels in three replicates were tested from each sample. After disinfection using 5% sodium-hypochlorite solution (NaOCl) maize kernels were plated directly on top of three layers of well-soaked sterileblotterpaper. Ten seeds were plated on plastic Petri-dish of 9cm diameter by surface disinfection. The plated kernels were incubated in growth chamber (LEEC, model PL2, PL3, PL33. Notthgham, UK) at 25±2°C for 7 days under alternate cycles of 12hr light and 12hr darkness. After incubation plated kernel were examined for the growth of seed borne pathogen and the infected and healthy seeds was counted and recorded. Finally incidence was calculated as follow:-

$$\text{Disease incidence on kernel } = \frac{\text{No. of infected kernels}}{\text{Total no. of kernels}} \text{X100}$$

3.3.4. Isolation and identification of fungal pathogens

The fungal pathogens were isolated and identified to the genus level from maize kernels sampled from each store during storage periods starting from one month of storage until six month storage with monthly interval following standard isolation procedures (Narayanasamy, 2006; Pitt and Hocking, 2009).

3.3.4.1. Isolation of fungal pathogens

Potato Dextrose Agar (PDA) was used as growth media for isolation of fungal pathogen. Media were prepared by dissolving 39 gm of commercially formulated PDA powder in to one liter of distilled water. The mixtures were boiled while stirring with a magnetic stirrer for 10 minutes to completely dissolve the powdered agar and then autoclaved at 121°C for 15 minutes to sterilize the media. The liquid media were maintained under aseptic condition and allowed to cool to about 50°C, then dihydrosteroptomycin sulphate(0.1ml/l) were added to suppress bacterial growth and the media were poured into sterilized Petri-dishes inside laminar air flow. The agar media were then allowed to cool and solidify before being used for plating the maize kernels (Narayanasamy, 2006 andPitt and Hocking, 2009).

Maize kernels from each sample lot were surface sterilized with 5% sodium-hypochlorite solution for one minute and rinsed three times with sterile distilled water and dried in a laminar flow cabinet, then five seeds per Petri-dish aseptically plated on the solidified media with three replication; totally fifteen kernels from each sample were plated and then the plated kernels were incubated (Heraeus Kendro 50042301, Germany) under alternating periods of 12 hr darkness and 12 hr of daylight at 25^{o}C±2 for 7 days (Narayanasamy, 2006 ;Atukwase *et al*., 2012). Finally fungi colony emerged from each kernel were counted based on colony color in reference to RGB color chat which used by Arega, (2006).

3.3.4.2. Purification and identification of fungal pathogen

The colonies emerged from each plated kernels were purified and sub-cultured on PDA (Hocking, 2006;Magnoli *et al*., 2003) then incubated (Heraeus Kendro 50042301, Germany) under alternating periods of 12 hr darkness and 12 hr of daylight at 25 ^{o}C±2 for 7-10 days. Fungal pathogens were identified to the genus level first based on colony characteristics mainly color on both plate sides in reference to RGB color chart which used by Arega (2006) and morphological appearance of conidiophores and conidia under the microscope (400x) (Deacon, 2006; Pitt and Hocking, 2009). The isolated fungal genera incidence, frequency and relative density were calculated (Mostafa and kazem, 2011; Meer *et al*., 2013).

$$\text{Incidence of fungal genera} = \frac{\text{No. of infected kernels}}{\text{Total no. of kernels}} \text{X100}$$

$$\text{Fungal frequency} = \frac{\text{No. of particular fungus colony observed in plates}}{\text{Total no. of colonies of fungi}} \text{X100}$$

$$\text{Relative density} = \frac{\text{No. of isolate of genus}}{\text{Total no. of fungal genus}} \text{X100}$$

3.4. Nutritional Analysis

3.4.1. Experimental design

Four by three factorial design was used for determination of nutritional composition of maize kernels stored under farmers traditional storage structure "*Gombisa*". Altitudinal agro-ecologies with three level (highland, midland and lowland) and storage duration with four level (at harvest, second, fourth and sixth month storage). Whereas for collectors 3×3 factorial design were used including agro-ecologies with three level (highland, midland and lowland);

storage duration with three level (second, fourth and sixth month of storage) and for wholesalers complete randomized design was used.

3.4.2. Sampling method and sample collection

Dedo district represent highland maize producing district while Omonada represent midland and Sekoru represent lowland maize producing districts were selected for nutritional analysis including three farmers storage from each district. Similarly, three collectors from each afore mentioned districts and three wholesalers / assemblers from Jimma town were included for the study. Sample was taken randomly from different part of the store and the same sampling method was used for both nutritional analysis and fungal pathogen identification (3.2.2). After shelling of maize kernel 500 g were used for all nutritional analysis.

Nutritional analysis on proximate composition, mineral content and anti-nutritional factors were done from two season production (2012/13 and 2013/14) (Farhan *et al*., 2013). The averages of the two production seasons data were used for analysis. Analysis was conducted at Ethiopian Public Health Institute (EPHI). Analysis was done based on AOAC method and in triplicate.

3.4.3. Proximate analysis

Determination of moisture content: Grain moisture content was measured immediately after picking the sample from the store using digitally calibrated moisture tester (Wile ^{55}TR serial number 554601 by Farm comp Agro-electronics, France). Finally converted to dry base by using the following formlas (Golob *et al.*, 2002; Farhan *et al.*, 2013).

$$\text{moisture (dry basis)} = \frac{\text{wet base}}{100 - \text{wet base}} \text{X } 100$$

Determination of total ash content: Ash content of maize flour was determined by (AOAC, 2005) method 923.03. The porcelain crucibles were cleaned and dried in oven (Memmert, Germany) at 120^{o}C and ignited at 550^{o}C in furnace (GALLENKAMP, model FSL 340-0100, UK) for 30 min. The crucibles were removed from the furnace and were placed in desiccators to cool down to room temperature. The mass of crucibles were measure by analytical balance and the reading was recorded as (M1). About 2.5 g of maize flour were weighed in to crucibles (M2). Dishes were placed on a hot plate under a fume-hood and the temperature was slowly increased until smoking ceases and the samples become thoroughly charred. After charring sample was placed in furnace at about 550^{o}C until free from carbon and the residues appear grayish white (for about 8 hrs). The sample was removed from the furnace and placed in the desiccator and then weighed using sensitive balance (M3) and ash content calculated using the following formula:-

$$Totalash(\%) = \left(\frac{M3 - M1}{M2 - M1}\right) x100$$

Where:- M_1= weight of crucible
M_2= weight of crucible with sample before ashing
M_3= weight of crucible with sample after ashing

Determinationof crude protein: The crude protein content of maize kernel was analyzed by Kjeldahl method of nitrogen analysis as per the (AOAC, 2005) method 979.09. About 0.5 g of maize flour was weighed in a Tecator tube and 6ml of acid mixture (5 parts of concentrated orthophosphoric acid and 100 parts of concentrated sulfuric acid) was added and mixed, and 3.5 ml of 30% hydrogen peroxide was added step by step. As soon as the violent reaction had ceased, the tubes were shaken and placed back to the rack. Three gram of catalyst mixture (ground 0.5 g of selenium metal with 100 g of potassium sulfate) was added into each tube, and allowed to stand for about 10 minutes before digestion. When the temperature of the digester attained 370^{o}C, the tubes were put into sample digester. The digestion was continued until a clear solution was obtained, about for 1hr. The tubes in the rack were cooled in a fume hood; 30ml of deionized water was added and shaken to avoid precipitation of sulfate in the solutionand then, ammonia was distilled off after adding 25 ml of NaOH (40%) into receiving flask (25 ml of boric acid with 10 drops of indicator solution). Finally, the distillate was titrated with standardized 0.1N HCl to a reddish color using Kjeldehal apparatus (Foss Tecator, Kjeltec 2300Analyzer unit, USA).The crude protein content was estimated using the following equation

Calculation =Total nitrogen, percent by weight

$$Totalnitrogen = \frac{(T - B)xNx14.007\ x\ 100}{w}$$

Where: T-Volume in ml of the standard acid solution used in the titration for the test material

B - Volume in ml of the standard acid solution used in the titration for the blank determination

N - Normality of standard hydrochloric acid

W - Weight in grams of the test material

Crude protein = 6.25 * total nitrogen

Determination of crude fat content: Crude fat of maize flour was determined by Soxhlet extraction according to (AOAC, 2005) method, 2003.06. The extraction flasks were cleaned, dried in drying oven (Memmert, Germany) at 95^{o}C for 1hr, cooled in desiccators (with granular silica gel) for 30 minutes and then weighed. The bottom of the extraction thimble was covered with about 2cm layer of fat free cotton. About 2.0 gram of maize flour were added into the extraction thimbles and then covered with about 2cm layer of fat free cotton. The thimbles with the sample content were placed into soxhlet extraction chamber (Foss Tecator, Sweden). The cooling water was switched on and a 50.0 ml of diethyl ether was added to the extraction flask through the condenser. The extraction was conducted for about 6 hrs. The extraction flasks with their content were removed from the extraction chamber and placed in the drying oven at 120± 2^{o}C for about 1hr, cooled to room temperature in the desicator for about 30 minutes and re-weighed. The crude fat was determined by the following formula:-

$$Crudefat(\%) = \frac{F - T}{S} x\ 100\%$$

Where: F = Weight of extraction flask and fat residue

T= Weight of empty extraction flask

S = Weight of test portion

Determination of Crude Fiber: The crude fiber was determined by the non-enzymatic gravimetric method (AOAC, 2005, 922.16). First test sample was grinded using cutting mill fitted with 20 mm mesh screens at bottom of cutting chamber. Then 0.5g of test sample was weigh to nearest milligram and transferred 600ml beaker, 200ml of 1.25% H_2SO_4 was added, and boiled gently exactly for 30 minutes placing a watch glass over the mouth of the beaker. During boiling, the level of the sample solution was kept constant with hot distilled water. After 30 minute boiling, 20ml of 28% KOH was added and boiled gently for a further 30 minute, with occasional stirring. Gooch crucible containing glass woolwhich filled with 10 mm sand layer was used for filtration of sample solution. First crucible containing sand wetted with a little distilled water andthe solution in each beaker was then filtered through crucibles containing sand filter by placing each of them. During filtration the sample was washed with hot distilled water. The final residue was washed with 1% H_2SO_4 solution, hot distilled water, 1% NaOH solution, 1% H_2SO_4, hot distilled water and finally with acetone.Each crucible with its content was dried for 2 hrs in an electric drying oven (Memmert, Germany)at 130^oC and cooled for 30 min in the desiccator (with granular silica gel), and then Weighed. The crucible was transferred to a muffle furnace (GALLENKAMP, model FSL 340-0100, UK) and incinerated for 30 min at 550^oC. The crucible was cooled in the desiccator and weighed. Then the fiber was calculated as a residue after subtraction of the ash.

$$\text{Crude fiber \%} = \frac{\text{M1} - \text{M2}}{\text{weight of sample}} \text{ x } 100$$

Where: - M_1 = mass of crucible and residue after drying

M_2 = mass of crucible and residue after ashing

3.4.4. Determination of carbohydrate:Total carbohydrate content of maize was determined by difference method by using the following mathematical expression (FAO, 2003).

$$CHO(\%) = 100 - (\%moisture + \%\,fat + \%Ash + \%Crudefiber + \%Crudeprotein)$$

3.4.5. Determination of Calorific Value/Energy Value Calculation: Calorific value of maize (in Kcal) was determined by multiplying each gram of protein, fat and carbohydrate obtained from laboratory analysis by their respective conversion factor (FAO,2003).

$$\boldsymbol{Caloricvalue = (protein \times 4) + (carbohydrate \times 4) + (fat \times 9)}$$

3.4.6. Mineral analyses

Calcium, zinc and iron analysis: Calcium, zinc and iron were determined by Flame Atomic Absorption Spectrophotometer (AAS) (Auto sampler AA 6800, Japan) method as per the (AOAC, 2005) method, 985.35. Flask used for filter the digested ash was washed with 10%HNO3(nitric acid) and Ashes were obtained from dry ashing was wetted completely with 5ml of 6N HCl and dried on hot plate by low temperature. A 7ml of 3N HCl was added to the dried ash and heated on the hot plate until the solution just boils. The ash solution was cooled to room temperature at open air in a hood and filtered through a filter paper (Whatman 42, 125mm) into a 50ml graduated flask and 5ml of 3N HCl was added into each crucible dishes and re-heated until the solution just boiled,then cooled and filtered into the flask. The crucible dishes were again washed three times with de-ionized water; the washings were filtered into the flask. A 2.5ml of 10% Lanthanum chloride solution was added into each graduated flask to suppress interferences during calcium reading. Then the solution was cooled and diluted to the mark (50ml) with de-ionized water. A blank was prepared by taking the same procedure as the sample. Then the solution was used to determine Ca, Zn, Fe and P. Standard stock solution of iron, zinc, calcium and phosphorus was made by appropriate dilution. The sample and standard were atomized by using reducing air-acetylene for Ca and oxidizing air-acetylene for zinc and iron as a source of energy for atomization.

For Ironcontent determination absorbance was measured at 248.4 nm and iron was estimated from a standard calibration curve prepared from analytical grade iron with a range of 0, 2, 4,6,8 and 10 ml. For zinc concentration determination, absorbance was measured at 213.9 nm and zinc level was estimated from a standard calibration curve prepared from analytical grade zinc with a range of 0, 0.5, 1, 1.5, 2 and 2.5 ml. For calcium content determination, absorbance was measured at 422.7 nm. Calcium content was then estimated from standard solution 0, 2, 4, 6, 8 and 10 ml prepared from CaCO3.Mineral content were calculated using the following formula:-

$$Mineralcontent\left(\frac{mg}{100g}\right) = \frac{[(A - B) * V]}{10W}$$

Where: W= Weight (g) of samples;
V= Volume (V) of extract;
A= Concentration (µg/ml) of sample solution;
B = Concentration (µg/ml) of blank solution

Phosphorus determination: Phosphorus content of maize sample was determined by using UV-Vis spectrophotometer(Beckman DU-64- spectrophotometer, USA)according to (AOAC ,2005) method 965.17. From previously prepared clear mineral solution 1ml were transferred to 100ml volumetric flask and diluted by de-ionized water. The standard solution with the concentration of 0.1, 0.2, 0.4, 0.6 and 0.8 were prepared through diluting 0.4388g sodium hydrogen phosphate by 1ml sulfuric acid (H_2SO_4). About 1ml from each solution(sample and standards) were transferred to clean test tubes and then 0.5ml ammonium molybdate and 0.2ml Aminonaphtholesulphonic acid (1-2-4 amino) were added to solutions and the solution was mixed on a Vortex mixer for 5 seconds. After 10 minute the absorbance of the solutions (both the sample and standard) were measured at 660nm by using de-ionized water as a blank. The amount of phosphorus was calculated using the standard curve. Calibration curve was constructed from the series of standard solution using SPSS-15. A standard curve was made from absorbance versus concentration and the slope was used for calculation. Phosphorus concentration was calculated by using the following formula:-

$$Phosphoruscontent\left(\frac{mg}{100g}\right) = \left(\frac{(A - B)}{S}\right) x \left(\frac{DF}{W}\right) x100$$

Where: - A= absorbanceof sample DF= dilution factor
B= absorbance of blank W = weight of sample after ashing S= slope

3.4.7. Determination of anti-nutritional factors

Determination of phytate content: Phytate was determined by the method ofVaintraub Lapteva (1988). About 1.0 g of maize flour was extracted with 10ml 1% HCl in methanol usi`ng mechanical shaker (Eberbach) for 1hr at an ambient temperature and centrifuged at 3000rpm for 30 minute. The clear supernatant was used for phytate estimation. A 2ml of wade reagent (containing 0.03% solution of $FeCl_3.6H_2O$ and 0.3% of sulfosalicilic acid in water) was added to 3ml of the sample solution (supernatant) and themixture was mixed on a vortex (Maxi Maxi II) for 5 second. The absorbance of the sample solutions were measured at 500nm using UV-Vis spectrophotometer (CE1021, England). A series of standard solution were prepared containing 0, 5, 10, 20 and 40 μg/ml of phytic acid (analytical grade sodium phytate) in 0.2N HCl. A 3ml of standard was added into 15ml of centrifuge tubes with 3ml of water which was used as a blank. A 1ml of the wade reagent was added to each test tube and the solution was mixed on a vortex mixer for 5 seconds. The mixtures were centrifuged for 10 minutes and the absorbances of the solutions (both the sample and standard) were measured at 500nm using deionized water as a blank. The amount of phytic acid was calculated using phytic acid standard curve. A standard curve was made from absorbance versus concentration and the slope and intercept were used for calculation.

$$Phytic\ acid\ in \left(\frac{mg}{100g}\right) = \frac{(Absorbace\ \ - Intercept)}{(Slop\ x\ Density\ x\ \ Sample\ weight)}$$

Condensed tannin determination: Tannin content was determined by the method ofMaxson and Rooney (1972). About 1.0 gram of maize flour was weighed in a screw cap test tube. The maize flour was extracted with 10ml of 1% HCl in methanol for 24 hours at room temperature with mechanical shaking. After 24 hrs shaking, the solution was centrifuged at 1000rpm for 5 minutes. A 1ml of supernatant was taken and mixed with 5 ml of vanillin-HCl reagent (prepared by combining equal volume of 8% concentrated HCl in methanol and 4% Vanillin in methanol).

D-catechin was used as standard for condensed tannin determination. A 40mg of D-catechin was weighed and dissolved in 1000 ml of 1% HCl in methanol, which was used as stock solution. A 0, 0.2, 0.4, 0.6, 0.8 and 1 ml of stock solution was taken in test tube and the volume of each test tube was adjusted to 1ml with 1% HCl in methanol. A 5ml of vanillin-HCl reagent was added into each test tube. After 20 minutes, the absorbance of sample solutions and the standard solution were measured using UV-Vis Spectrophotometer (CE1021 England) at 500nm by using water as blank and the calibration curve was constructed from the series of standard solution using SPSS-15. A standard curve was made from absorbance versus concentration and the slope and intercept were used for calculation.

$$Tannin\ in\ \left(\frac{mg}{100g}\right) = \frac{(Absorbace\ - Intercept)}{(Slop\ x\ Density\ x\ \ Sample\ weight)} x10$$

3.5. Data Processing and Analysis

Statistical analysis was carried out using SPSS version 20.0 for survey data and finally descriptive statistics such as frequency and percentage were used. After checking ANOVA (Analysis of variance) assumption and trying different data transformation methods finally; fungal pathogen incidence, frequency and relative density were analyzed by SPSS using non-parametric test.

Data such as disease incidence, severity, insect damage, germination test, nutritional and anti-nutritional content were analyzed using SAS version 9.0 after checking ANOVA assumption. ANOVA were carried out using general linear model (GLM). Wherever significant difference were found for means were separated using Tukey's Honestly Significant Difference (HSD) test at the 5% probably level.

Also, correlation tests were done using SAS to determine the degree to which response variables were associated. Finally, Excel statistical software was used for graphs and figures.

4. RESULTS AND DISCUSSIONS

4.1. Demographic and Socio-Economic Characteristics of Respondents

4.1.1. Age, religion and educational status of respondents

Age is one of the household characteristics important to describe households' situation and can provide a clue on working ages of households. More than 50 % of respondents for farmers, key informants, collectors and wholesalers were between 30-50 years old. , However almost all respondent experts were less than 30 years old.Similarly 18-70 years old age status of respondent farmers around Jimma zone was reported by Yisehak(2008). Debebe*et al.* (2015) also reported 45.35±8.85year wasa mean age of maize producer farmers around Jimma zone. The majority of the respondents were Muslim (95.4%) followed by Christians (4.6%). About 95 % of the respondents had primary education followed by who had informal education (NFE); who had secondary education and who had basic education (Table 3).

Table 3: Age and educational status of respondents

Socio-characteristics	**Respondent (%)**				
	farmers	key informants	experts	collectors	wholesalers
Age range					
<30	17.60	24.70	100.00	31.30	16.70
30-50	59.60	55.90	0.00	56.30	66.70
51-60	18.10	16.10	0.00	12.50	0.00
>60	4.70	3.20	0.00	0.00	16.70
Educational status					
NFE	17.6	10.8	0.00	0.00	0.00
BE	15.5	28.0	0.00	0.00	0.00
1-6	48.7	40.9	0.00	50.00	0.00
7-10	17.6	11.8	0.00	37.50	33.30
>10	0.5	8.6	100.00	12.50	66.70

BE= basic education and NFE= who had informal education

About74 % of the respondents had family size ranges 5-10 followed by those who had 11-15 were 14.5%. But 10.4% of the respondent had family size less than 5 and 1.6% had greater than 15. Around 58% of the respondents farmers had working force in the household less than

5in number followed by those who had more than 5 (36.8% of the respondent farmers). Similarly, 5.2% had 5 member of the family capable for work. Yisehak (2008) was reported10.6 average family size of maize producer farmers in Jimma zone.Similarly 5.5 ±2.05mean family size of maize producer farmers around Jimma zone was reported by Debebe*et al.* (2015).

4.1. 2. Farmers access for major services

Most of the respondents had access for drinking water and telephone services but only 34.7 % of the respondents were provided electricity service. 98.5% of the respondents have access for road with less than 30 minute walk. Similarly around 75.2 % of the respondents have access for health service and 90.7% have access for school with less than30 minutes walk (Table 4).

Table 4: Farmers access for major services

Services/resource	**Drinking water (%)**	**Electricity (%)**	**Telephone (%)**
Yes	57.00	34.70	64.80
No	43.00	65.30	35.20
Walk in minute	**DFHC (%)**	**DFS (%)**	**DFR (%)**
<30	75.20	90.70	98.50
30-60	23.80	8.80	0.50
>60	1.00	0.50	0.00

DFHC = distance from health centre DFS=distance from school DFR= distance from road

4.1.3. Maize production and importance

More than 33% of the respondents farmers were experienced in maize production for 21-30 years followed by 10-20 years of experience inmaize production. But about 12% of the respondent's farmers were experienced for more than 40 years.Debebe*et al.* (2015) reported 22.67±9.21mean years experience of farmers in maize production around Jimma zone. However most of respondent traders and all respondent experts had experience of less than 10 years (Table 5). On average, 68.4% of the respondents produce maize on less than 1 hectorof land; whereas 23.8% were produce on 1 hector and 7.8% of the respondents were produce on greater than 1 hector of land in 2013/14 production season. Average farm size of 1.63±0.67 hectare of maize producer farmers around Jimma zone was reported by Debebe*et al.*

(2015).Proportion of the farmers (51.3%) allotted up to 50% of their production land for maize, while 34.7% of the farmers allocated up 75% out of total land owed, the rest allotted quarter of their land for maize in 2013/14 production season.

Table 5: Experience of respondents with regards to maize production and trading (%)

Experience (years)	Farmers	Experts	Collectors	Wholesalers
<10	11.40	100.00	50.00	83.30
10-20	25.90	0.00	43.80	16.70
21-30	33.20	0.00	6.30	0.00
31-40	17.10	0.00	0.00	0.00
>40	12.40	0.00	0.00	0.00

Maize produced mainly for house hold consumption by most of the respondent farmers (67.9%), but 32.1% of the producers used for both consumption and sale, indicating all producers can use maize for consumption. However, almost all respondent farmers were sold surplus product.According to ECX (2009) crop utilization survey report around 76.03% of produced maize was utilized for household consumption.

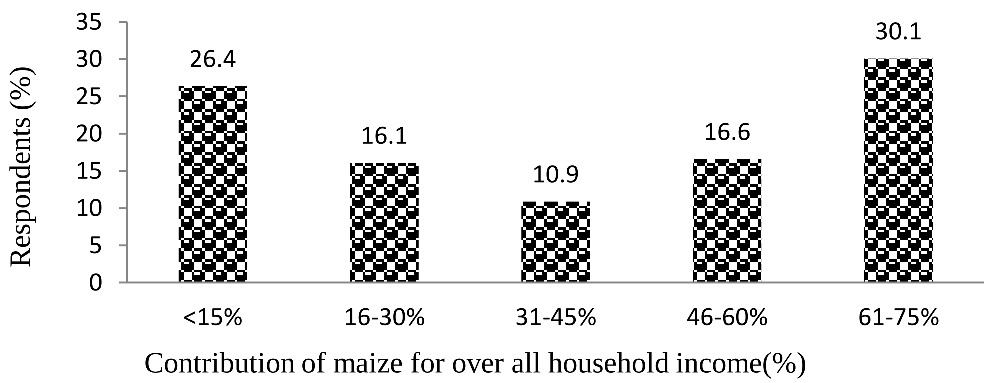


Figure 2: Importance of maize for over all household income of farmers in the study areas

Maize production was one of income source for farmers who lived in the study areas. Around half of the respondent farmers (49.7%) were sold about 25% of maize for different expenses and 12.4% of respondent farmers were sold 26-50% of harvested maize but 37.9 % of the respondents were produce maize for house hold consumption only.Around 43.0% of the respondents have no constant buyer whereas 57.0% were sold their product for constant customers. However, most of the respondents (73.6%) have no reason for this but some of them sold their product for constant buyer due to lack of another option (21.2%), 2.1 % for social benefit, 2.1% based on the return they get and contract with buyer about 1% of the total respondents. About 42% of the respondent farmers were sale maize for individual consumer the remaining 12.4% of respondents were sale their product for both retailer and collectors. Also, 6.2 % respondents sale for wholesalers whereas, 5.7% for local maize collectors and 2.1 % for retailer. Only 0.5% of respondents sale their maize product for co-operatives union. However, in the study area around 30.1% farmers were earn 61-75% of their income from maize (Figure 2) and 72% respondents were earn their additional income from other agricultural commodities and 21% of respondents from other off farm activities.

The results of the household surveys showed that maize was the major cereal crop in all the study areas and almost all (99.5%) of the respondent agree with production of maize were important (Figure 3).

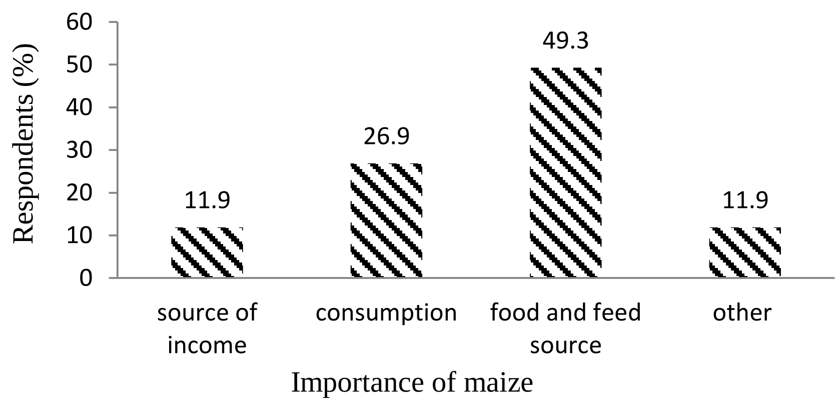


Figure 3: Percent of the respondenton the use of produced maize for different purpose

Farmers produced different maize varieties and 46.6% of the respondent exclusively grown improved maize varieties: BH660 (46.07%), BH540 (34.5%) and shone (19.5%), whereas the remaining 48.49% grow both improved and local varieties (Figure 4B). But BH660 variety considered as the commonly grown improved variety in all districts by most of the farmers; around 51.3% of the respondent were grow this variety with the range of 76 - 100 % (Figure 4A) mainly due to its adaptability and productivity. Among improved varieties BH660 maize variety is one of improved variety currently with large adoption in most part of the country including south western(Ethiopia ATA, 2013). Study conducted around Bako, Ambo and Hawassa showed that late maturing variety BH660 wasgetting more appreciation by maize producer farmers (Groote *et al.*, 2013).

Considering seed source of improved maize varieties, 61.1% of the respondent received from unions and 33.2 % from ministry of agriculture/district agriculture office; the remaining 5.3 % were provided by other source such as NGOs. According to EthiopiaATA (2013) report ministry of agriculture; primary cooperative and unions supply input for farmers across the country. However, according to respondent farmers, the quantity of seed supplied to the farmers is often insufficient and not aligned with farmer demand. Another major problem raised by respondent farmers was seed impurity issue such as mixture of seed with sand, other cereals grains and other maize varieties. Similarly, timely unavailability of improved seeds during early on-set of rainfall was the major challenge in seed supply system and this is a common problem in different parts of the country (Ethiopia ATA, 2013).

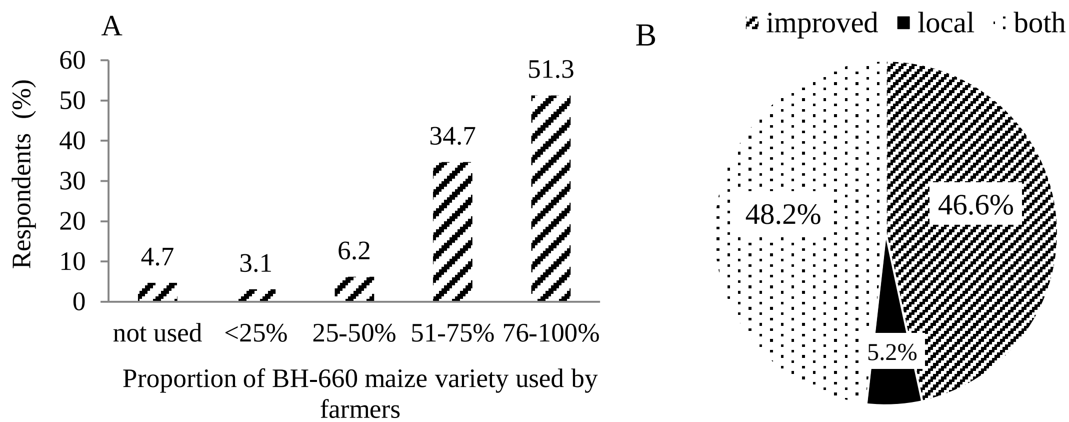


Figure 4: A) Percent of farmers who grow BH-660 variety B) maize varieties used by farmers in the study areas

Farmers spent most of their time for pre-harvest activities and give very little attention for post- harvest activities (Table 6). Due to less awareness of farmers about post harvest loss less attention were given for post-harvest activities.

Table 6: Days required for maize production activities (Mean± SE)

	Mean number of days required to complete each activities (per hectare)				
Activities	**Dedo**	**O/nada**	**Kersa**	**Mana**	**Sokoru**
Lp	22.9±1.4	36.1±3.1	18.9±1.2	17.2±1.7	33.5±7.5
Sowing	3.0±0.3	3.5±0.3	4.6±0.5	2.4±0.3	4.1±0.9
Weeding	12.6±0.8	14.9±1.1	15.4±1.1	14.3±1.7	28.2±7.9
PFWA	65.8±4.9	40.8±3.5	60.8±9.2	111.8±12.0	58.1±13.8
PFDA	179.5±1.3	158.3±4.8	124.7±12.4	147.1±12.0	116.4±21.5
Total	**283.8±1.8**	**253.7±2.6**	**224.4±4.9**	**292.9.1±5.6**	**240.4±10.3**
Harvesting	4.5±0.4	4.8±0.4	4.5±0.4	4.1±0.4	12.5±2.5
PHD	1.8±0.5	3.8±0.7	1.3±0.5	4.6±0.6	9.8±2.7
TS	2.3±0.2	3.8±0.3	4.8±0.5	1.8±0.6	4.5±0.9
Shelling	6.0±0.6	5.4±04	7.6±0.7	5.2±0.5	8.9±2.7
Seling	4.0±0.6	1.4±0.4	2.1±0.6	2.6±0.8	3.9±2.7
IPC	1.7±0.1	1.7±0.1	2.5±0.3	1.0±0.1	56.2±18.6
MM	2.1±0.2	3.2±0.4	2.4±0.3	1.8±0.2	2.9±0.9
RC	87.1±10.8	96.5±8.1	52.5±13.4	91.0±14.4	125.2.0±21.7
Total	**109.6±1.7**	**120.4±1.4**	**77.8±2.0**	**112.1±2.2**	**223.7±6.9**

Lp= land preparation, PFWA= protection from wild animals, PFDA= protection from domestic animals, PHD= post-harvest drying, TS= transportation and storage, IPC= insect pest control, MM= mould management and RC= rodent control

Almost all traders were store and sell both local and improved variety of maize mixed together. Most of the collectors collect maize from nearby PA's of the district. However, the Dedo and Mana district collectors were additionally collect from PA's of nearby districts such as Dedo collectors from Chida district which is a part of SNNPRs. Similarly, Mana district collectors buy maize product from Limu district of Jimma Zone. Fifty percent of wholesalers were collect maize from Jimma zone of different districts and the rest 50% were collect from both Jimma zone and Chida district collectors and also some times from maize producing farmers.

About 50% of collectors were sold their maize for individual consumer but 37.5 % of them were sold their maize for Jimma town, Addis Ababa and Becho wholesalers. Similarly, wholesalers were also sale their maize for both local trader and consumers (33.3%) and for Addis Ababa traders (50%). Low quality of maize especially discoloration and irregularity of maize supply is the major trading problem both at collectors and wholesaler. The main reason for irregular supply of maize throughout the year was seasonal production and most farmers were selling their surplus grain immediately after harvest because of fear of storage loss (IFPRI, 2010).

4.1.4. Post-harvest activities in maize production

Post-harvest operations of maize grains follow a chain of activities starting from field as the crop reach physiological maturity until it is consumed.During this stages a set of activities undertaken by the farmers to preserve maize quality. In the study area around 12 major post-harvest management practices were identified at producers' stage and some of them were also performedby traders (collators' and wholesalers) to preserve post-harvest maize quality. However, most of the management activities are traditional and some activities such as:- on-farm drying, temporary storage through heaping in the field, shelling maize through biting by stick and the design of storage structure are not effective to preserve harvested maize quality (Kaaya *et al*.,2006) due to this reason large amount of maize were lost after harvest. In Ethiopia the major maize production challenge for farmers was high post-harvest loss which ranges from 15 to 30% (IFPRI, 2010). Initially before storage 2.5% of maize damage by insect pests was reported by Dubale *et al.*(2012) around Jimma zone this could be insect infestation of standing plant due to delayed harvesting of maize to facilitate on farm drying before harvest. The importance and limitation of post-harvest practices were listed below in Table 7.

Table7: Percentrespondents, importance and limitation of the major post-harvest practices in maize productionacross study area

Major post-harvest practices	Percentage	Importance	Limitation
On farm drying	75.1	To control mould development in the store	Weevil problem if over dry
Harvesting	100	To collect product on right maturity stage	Done manually and rain during harvest
Temporary storage	46.1	For drying and sorting out	theft and loss due to animals
Transportation using pack-animals	53.0	Less cost and easy for transportation	Loss through spillage
Sorting out	76.8	reduce contamination, reduce deterioration and keep maize quality	Sometimes mixing of less damaged one

Sheath removal from the cob before storage	75.6	For sanitation and ease for management	-
Construction the storage with hole (ventilated)	75.6	Facilitate drying after storage and reduce store temperature during hot season	Less protective from external environment like RF, rodent and other small animals
Cleaning the store before storage	99.5	For sanitation, keep quality of stored maize and to control storage pests	Not perfectly keep quality of stored product
Chemical insecticides	92.2	To control insect pest and enhance storage period of maize	Cost of chemicals, dosage problem, and treated maize not consumed immediately
Using trap and cat	82.2	To control rodent	Less effective
Maize shelling through biting by stick	82.4	Easy for insecticide treatement	Physical damage
Maize selling	65.3	Income source	Less amount and lower price

4.1.4.1. Harvesting, drying, transportation and maize shelling method

Physiological maturity monitoring style was used by most of the respondent farmers to ensure timely harvesting. Of the respondent farmers 97.4 % were start harvesting three weeks after attaining physiological maturity and remaining 2.6% were harvest in between two to three weeks after attaining physiological maturity. Farmers were used different methods to check maize ready for harvest; most of the respondents (61.1 %) decided maize harvesting through visual observation such as turning of the cob down and drying of leave and stalk. Calendar method also used by 28.8 % of the respondent farmers. Shelling and checking seed hardness were another method used by 8.8 % and 2.1% of the respondents, respectively to check maize ready to be harvested. However there is no respondent indicate use of moisture tester use for harvesting of maize to determine the optimum moisture to harvest their product, as result most of the product harvest above moisture content to be harvest maize. High grain moisture above 12% favour fungi development in the store (Gregori *et al*., 2013) therefore, in either mechanical or manual harvesting maize grain must be dried to safe moisture levels of about 12% (FAO and World Bank, 2011).

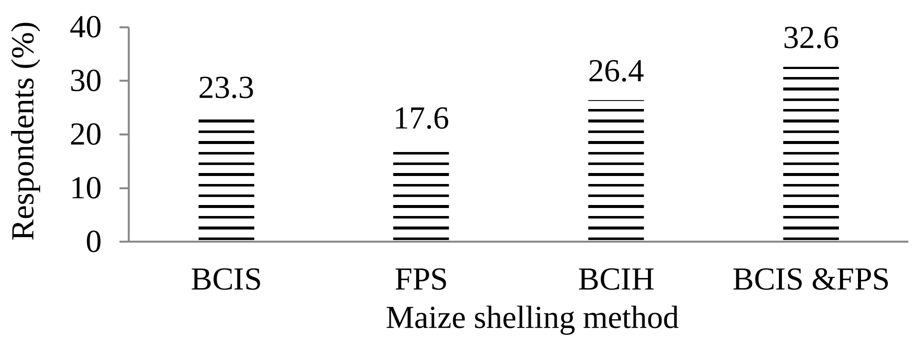
Maize harvesting in the study area started in October and ended at the end of December or the beginning of January. 66.8 % of respondent farmers were harvest maize mid-November to mid- December; 29.0% were harvest mid-October to mid-November and 4.1% were harvest mid- December to beginning of January. All of the respondent farmers in the study area carry out harvesting manually either pick the cobs by hand or cut the whole plant and place in pile in the field to dry for some days or weeks however; most farmers were store maize immediately after harvest.

For a safe storage the maize must be dried since the moisture content at harvest is generally higher than the desirable moisture content for storage and higher moisture is the main factor which affects mould development during storage but most of the respondent (75.1%) were not dry maize after harvest rather they harvest after drying in the field this may exposes maize to insect pests and fungal damage (Girma *et al.,*2008; Dubale *et al.,* 2012) while, some of the respondents (24.9%) were dry maize after harvest. The drying process were done through heaping or spreading the cob on bare ground (6.5%) or on maize stalk (18.1%) but drying crop in the field through such methods fail for attaining safe moisture level for storage in addition, field drying were exposes to unexpected rain because harvesting time is coincide with rainy season this create favorable condition for infection of field fungus. Alakonya *et al.* (2008) reported delayed harvesting was cause maize ear rote. *Fusarium* spp. is the principal pathogenic fungi which responsible for rotting of maize ear (Pitt and Hock, 2009) such fungi will continue infection in the store. *Fusarium* was reported from stored maize around Jimma zone with high (90%) frequency (Dubale *et al.,* 2014). *Aspergillus* spp. was often encountered on maize seeds that were allowed to dry on the field before harvest (Owolade *et al.,* 2005)

The length of time for post-harvest drying of maize were vary depending on weather conditions and the initial moisture content; some of the respondents were dry for less than a week (11.4%) and others were dry maize for 1-2 weeks (23.3%). Farmers were check proper drying of maize before storage by using different methods such as visual observation (53.9 %) through checking kernel hardness by tooth (21.2 %), through shaking shelled maize by hand and listening sound (8.8%) through hitting maize cob each other and listening sound (8.3%) and checking weight loss of cob by hand (7.8%). Those methods are not appropriate to check the moisture content of maize for storage because didn’t show us the exact moisture content of the grain which is safe for storage (FAO, 2003; FAO and World Bank, 2011).

The maize crop harvested requires to be moved from the field to the storage but the distance may vary from several meters to kilometers. There are different ways to transport harvested crop from the field to its destination such as: - carrying on head or back of the persons and transportation using pack-animals or trucks, etc. The transport system choice were depends on several factors, such as the socio-economic level, amount of production, distances to be crossed, infrastructures availability and availability of animals. About 55.0% of the respondents were transport harvested maize using pack-animals and the remaining 45.6% were by human labour. The use of animals such as: - donkey and mules were most convenient in small scale transport and the method were suitable on plain surface but also feasible in hilly and mountainous areas that why most of the farmers use such method. Pack animals especially donkey and mule used for transportation of goodsin most part of the country (Fernando and Starkey, 2004; Tolera and Aster, 2007).

Maize shelling traditionally was done by hands mostly by women and child but it is tedious work due to this reason in study area most of the farmers were shell maize through biting maize cob with the stick either inside the house (BCIH) or inside the sack (BCIS) and finally they were finish unshelled grain by finger palm shelling (FPS) (Figure5 and appendix figure 8). Such type of activities cause physical damage (breaking, splitting or cracking) on grain which prone the grain to insects and fungal damage and resulted reduction of product quality (Tadesse and Basedow, 2004; Kaaya *et al*., 2006; Hodges and Farrell, 2004; IFPRI, 2010;USID, 2011). Fandohan*et al*. (2006) reported Damage caused during shelling favour fusarium infection. However, mechanical shelling was reduced fumonisin levels in maize by 57%-65%.



BCIS= biting cob inside the sack, FPS= finger palm shelling and BCIH =biting cob inside the house

Figure 5: Proportion of farmers using different methods of maize shelling in the study areas

4.1.4.2. Storage

In the study areas, 53.9% of the farmers directly store after harvest while, 46.1% of respondent farmer temporarily store maize before main storage for different reasons such as:- for sorting out of damaged and undamaged maize (25.4%), for drying (10.9%) and for both drying and sorting (19.7%) (Appendix figure 9). Most of the respondents (21.2%) were temporarily store around home while others in the farm (15%) and inside the house (1.6%) due to fear of theft and problem of wild animals. In this condition maize wastemporarily store for less than one week (24.4%) and 1-2 weeks (13.0%). Similarly, most of the respondentstemporarily store harvested maize on bare ground for drying or sorting out the mouldy maize before storage which cause contamination by mouldy forming fungal pathogens. Maize temporary storage in heaps in the field, in the courtyard and in a room was practice by farmers in Benin (Hell et al., 2000).

4.1.4.3. Post-harvest management practices

Basically three (*Gambisa*,modified and bag) storagewere identified during survey period (Figure 6A). But materials used for construction of those storage structures were differ based on availability of the materials and the financial capacity of the farmers. Both *Gombisa* and modifiedstorage structures were typically used to store maize with cobs either with sheath or without sheath and while non air tight sacks were used to storeshelledmaize. The most common maize storage systems used by farmers across all agro-ecological zones were storing cobs without sheath inside *gombisa* and shelled grain inside the house using sack or polythene bags. Similarly, Dubale *et al.*(2012) reported *gombisa* and sack were used by farmers around Jimma zone to store maize cobs and grain. Another study conducted in five regional state of the country reported that *gotera* and sack were used to store maize by most of the farmers across the country (Tadesse and Basedow, 2004). Traditional granary (cribs) usually made up of locally available materials such as timber, bamboo, etc were used in humid countries for drying and as same time for storage of maize (Nukenine, 2010).

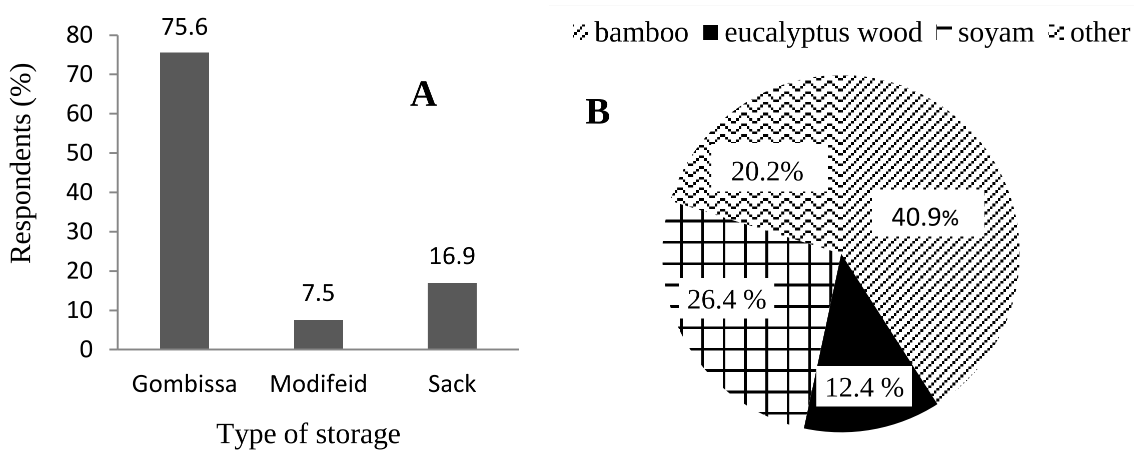


Figure 6: A) Percent of respondents farmers using different type of storage structures B) Materials used for construction of storeby farmers

Most of the storage structures were located nearby homestead (92.2%) others 7.8 % of respondent farmers were store maize inside the house. *Gambissa* or circular granary basket was very common in study area (Figure 6A) and can be woven from a variety of material and constructed by local artisans. Bamboo or any locally available wood which were resistant to insect attacks were used for pole. Roof was covered by natural grass and walls were bamboo splits (40.9%) or flexible woods such as eucalyptus and *Soyama.* Some of the respondents also use sorghum stalk or other (Figure 6B). Newly constructed store especially which constructed from bamboo or other woods were used for about 10 years due to durability and high cost of construction, most of the farmers use the same structure every year such practice expose the stored maize for contamination because Hell *et al.* (2000) reported most storage structures were used up to 5 years and with increasing age of the storage structure, the risk of contamination was increased. 94.8% of farmers were store their new maize separate from old maize (if available) while, 5.2 % of the farmers mixed with old maize. Similarly, respondent farmers were store maize separately from other cereals according to respondent farmers the reason for separate storage was to prevent stored maize from insect damage(73.6%) to avoid difficulty during storage management (11.9%) and to control mould problem(8.3%) while, the remaining 6.2% of respondent farmers were store mixing with other cereals such as sorghum or *teff*.However,according to Hell *et al.*(2000) report mixed storage of maize with other crops cause contaminationmaize by mould.

Maize were stored in different forms at farmers level but most of the farmers in study area were store de-husked cob (75.6%), both shelled and cob without sheath (21.2%) and maize cob with sheath (2.6%).Similarly, in Benin maize was stored in different forms such as: - with sheath, without sheath and shelled grain depending on regional preference (Hell *et al.*, 2000). Maize storage with sheath was only common around sokoru district which is the low land part of the study sites and farmers store maize in such form mainly to protect maize from weevil damage. A study conducted at Bako research centre reported good sheath cover is considered a key to protect the ear from insect and fungi damage (Girma *et al.*, 2008). The reason for storage of maize with cob were either for saving (40.4%) or to control insect pest (28.5%) and luck of time to shell maize (15.5%). For unshelled maize most farmers (88.6%) were used *Gombissa*. Maize with cobs were stored on average for six months in the *Gombisa* then maize were shelled and stored inside the house with sack for about three months or less in most cases. But duration of maize storage depends on the production capacity of farmers.However, this traditional storage structure"*gombissa*" gives less protection for stored maize from storage pests moreover, plant materials used for construction of storage were easily destroyed by rodent and favour other sources of infestation (Nukenine,2010). Furthermore, the perforated wall of traditional farmers' storage does not well protective from external environment like rain fall and high temperature which facilitate the development of fungi in the store. As Dubale *et al.* (2012) finding the average temperature of *Gombissa* in Jimma zone was 18.50 to 30.00°C and 30.83 to 54.67% relative humidity under intermediate agro-ecology whereas; under lowland agro-ecology it was 21.30 to 35.00°C and 39.17 to 51.00%. This condition was favourable for the growth and development of storage fungi (Narayanasamy, 2006).

Collectors and wholesalers stores were constructed from wood of different plant tree and corrugated iron sheet and in most case the inside and outside wall were sealed by mud (81.5%) or cement (18.8%) and the floor either cemented (56.3%), mud (25%) or mud covered with plastic (18.8%). Only 18.8% of respondents maize collectors store have window and most of the store have no ventilation system. But half of the respondent wholesalers store were with window and have ventilation system such as wholes on wall near to roof.

Most of the respondent farmers were apply pre-treatments to control storage problems such as spraying pesticide, cleaning store and surrounding and sealing store floor with manure.

Almost all (99.5%) of the respondent farmers clean the store before transferring harvested maize to store. 56.5% of respondents were clean the store to control weevil problem; 19.2 % were for sanitation and weevil control and to manage mould development (12.4 %) and the other 6.1% were for sanitation and 4.7% were to control rodents. Around 77.7% of the respondents were spread *teff* straw on store floor after cleaning and 17.6 % were apply insecticide after cleaning before storage of maize the remaining 4.7% of the respondents were repair the store before maize storage mainly to protect stored maize from external environment and to control loss of maize through spillage.

Around 18.1% of the respondent farmers were aerate the storage through opening the roof of the store for some hours and through opening the window (11.4%) especially during hot season whereas, most of the farmers were not aerate the store because they expect that the storage structure were already constructed as aerated (70.5%). Maize storage structure fumigation is not applied by most of the respondent farmers (99.0%) however; 1.0% of the respondents fumigate the store using pepper. 88.6% of the respondents were inspect deterioration of stored maize through visual observation every week during taking of maize for household consumption or for sale. The remaining 6.7% of the respondents were inspect the store through hearing sound produced by weevils and 4.1% were not check deterioration because they believe that if they touch the stored maize it favours development of weevil.

Most farmers (92.2%) were used insecticides to control storage insect pests and the other 2.1% of the respondents were use plant materials such as:- *Abayi* (*Maesa lanceolata*), *Shinfa* (*Lepidium atvuim)*andcabbage (*Brassica Oleracea*) seed powder mixing with water or as powder form. However, 5.7% of the respondents use other different methods like spraying cold water during hot season. Similarly,Farmers in Benin use traditional protectants such as: - neem leaves (*Azadirachta indica*), pepper (*Piper guineense*), ash, ash mixed with sand, kerosene, smoke or manure (Hell *et al.,* 2000).Insecticides such as: - Malathion 5% dust (71.5%) and DDT (22.3%) dust were used by most of the respondents farmers and only small numbers of farmers (0.5%) were use Actellic dust. Similarly, marathon and DDT were widely used to control storage insect pests in all part of the country (Tadesse and Basedow, 2004). Chemical insecticides were provided for the farmers by district agriculture office (46.6 %) and private suppliers (40.4%). During application of insecticides farmers were take some precautions such as:-covering mouth with cloth (75.6%) and washing hand with soap after application (4.1%). Some of the respondents (11.4%) were not consumed treated maize for 3-6 months.

When the farmers compared the efficiency botanical with the commercially available products, the indigenous substance rated as less efficient, but still some farmers used botanical because they had no access to or could not afford chemical products. Botanicals were used to control storage insect pest in different parts of the country but less effective to control pests (Tadesse and Basedow, 2004; Nukenine, 2010). Fifty one percent of the respondent farmers were control rodent by using cat and others using trap (32.2%), poising chemicals (11.9 %), maintain the store to avoid entrance of rodent and cleaning surrounding of the store (4.1%).

Cleaning the store before maize storage, store maintenance and sorting out the damaged maize before storage were used as a measure to control fungal contamination by most of the respondent farmers but sometimes the less damaged cobs were mixed together with the undamaged maize during storage (Figure 7). Some of the farmers were store the damaged and undamaged cobs together due to lack of awareness. Similar pre-treatments were used in some part of Africa such as; in Uganda farmers were use synthetic insecticide, poising chemicals and cleaning the store before storageto control storage pest (Kaaya *et al.*, 2006) and sorting out the damaged maize before storage practiced in Benin (Hell *et al.*, 2000).

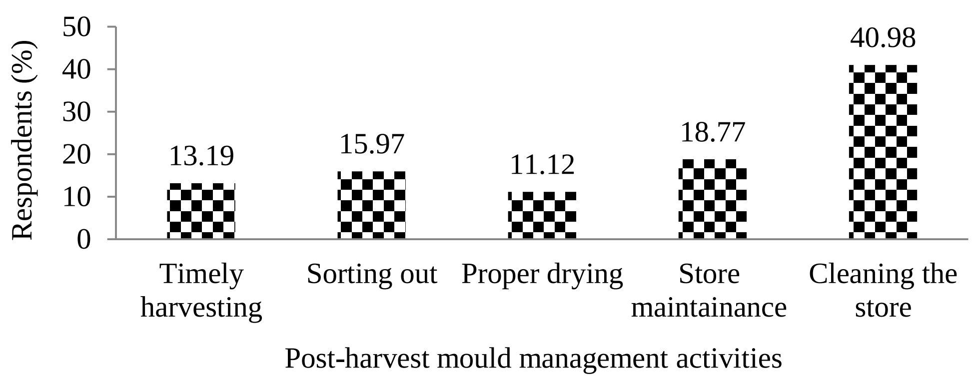
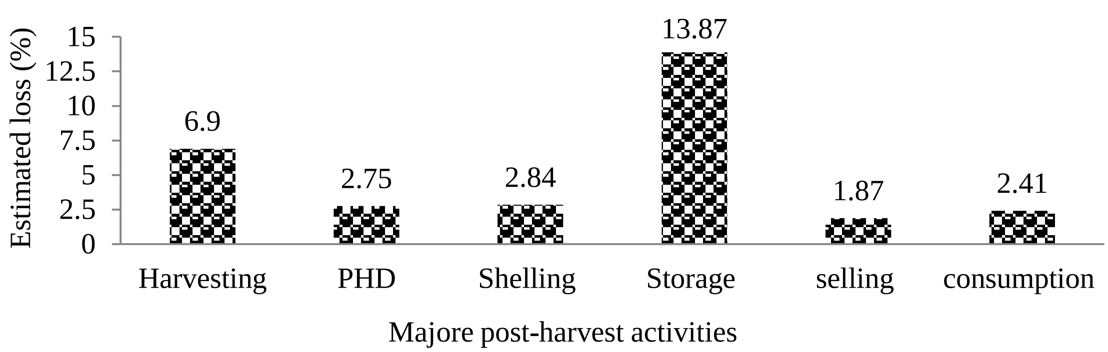


Figure 7: Post-harvest mould management activities used by farmers

Similarly traders (collectors and whole sellers) were applying some pre-storage treatments and store management to preserve maize quality. Such as cleaning store, applying insecticide before storage, bagging of grain, spreading plastic sheet on store ground especially when the floor in bare ground sometimes winnowing and cleaning of grain before storage.

4.1. 4.4. Estimated postharvest loss at producer stage

During harvesting, handling, processing and transportation grain may be scattered and/or mechanically damaged as result subjected to bio-deterioration. Key issues that leads to critical post-harvest loss during each activity observed were luck of optimal moisture content of maize to be stored at harvest and poor management during storage. However, successful drying alone is not a remedy against all post-harvest losses since insects and rodents may attack well dried grain in the field before harvest or in the stores after harvest. In this specific study area farmers estimated the highest post-harvest loss occurred during storage, which estimated to 13.87% of total production (Figure 8). Total post-harvest loss during major post-harvest management was estimated to 30.64%. According to Lipinski, *et al.* (2013) report in sub-Sahara Africa the highest loss was occurs during storage and handling it is around 37%. Similarly; APLIS (2014) reported in sub-Sahara Africa high post-harvest losses were occurs during harvest/field drying (4-8%) and during storage period (2-5%) as compared with other major post-harvest activities.



PHD = Post-harvestdrying

Figure 8: Farmers estimation of post-harvest loss occur during major activities

According the respondents post-harvest losses due to biological agents were start as the crop reaches physiological maturity and the crop is close to harvest while the crop still standing in the field. At this stage storage insect pests were make their first attack and dumping of unseasonal rainfall were resulted with the growth of mould. Farmers estimated about 17.75 % produced maize were lostduring post-harvest due to mould(Figure9).

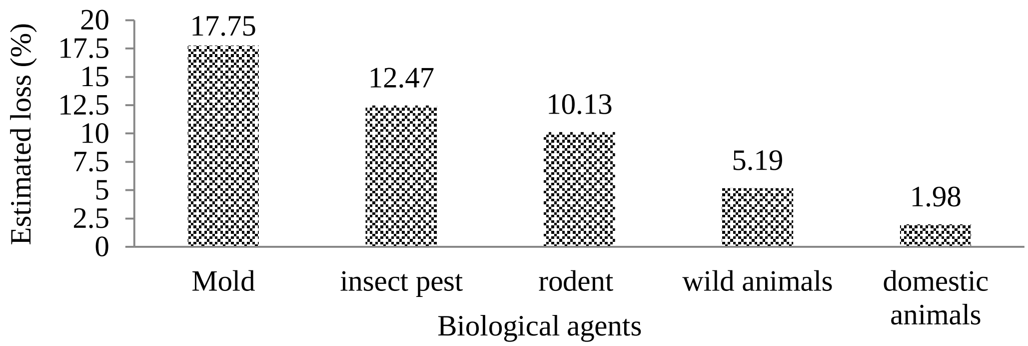


Figure 9: Farmers estimation of post-harvest loss due to biological agents in the study areas

4.1. 4.5. Storage problem

Almost all of the respondent farmers (99.90%) were agreed with storage problems in the study areas but the degree of importance were vary based on the agro-ecology of study areas. In most cases insect pests were the major storage problems which reported by 60.10% of the farmers; mould (31.60%) and rodent (6.20%) as second and third important storage problems respectively, According to respondent farmers estimation 17.75% of harvested maize were lost due to mould damage during post-harvest stage and it is higher than other causes of loss (Figure 8). Dubale *et al.*(2014) also reported that in Jimma zone mould is the second important problem next to insect. Similarly, Tadesse and Basedow (2004) reported that insect pest, rodent and mould are major causes of loss during maize storage in all part of the country.

According to respondent farmers rain during harvest was one cause of fungal damage and the damage may continue on stored maize. During harvest rain may stay for one week (58.5%) or two weeks (23.8%) but the duration varies between the agro-ecological locations of the study areas.*Fusarium* and *Aspergillus* infection of stand maize on the field were reported by Owolade *et al.*(2005) andAlakonya *et al.* (2008).According to respondent farmers mould development also starts after storage due to different reasons such as improper drying of maize before storage (33.2%) and problem related with storage structure (31.1%) are the main causes mould development in the store. Germination of stored maize is undesirable during storage also affect product quality; some of the respondent farmers (18.7%) were reported this problem which occurs due to high grain moisture content during storage period.

Some of the respondent farmers (2.1%) were raised problems related with the design of the storage structure which is not well protective from storage pests. Plant materials used for construction of store wereeasily damaged by rodents and this favours other sources of infestation (Nukenine, 2010). Furthermore, the perforated wall of traditional farmers' storage "gombissa" does not well protective the product from external environment. As Dubale *et al.*(2012) finding the average temperature and relative humidity of maize stored in *Gombissa* in Jimma zone was 21.30 to 35.00°C and 30.83 to 54.67% under intermediate agro-ecology whereas, under lowland agro-ecology it was 18.50 to 30.00°C and 39.17 to 51.00%. This condition was favourable for the growth and development of storage fungi (Narayanasamy, 2006) and insect pest (Hayma, 2003).

According to the farmers' perception, improved maize varieties susceptible for both mould and insect pest damage than local maize varies. BH-660 maize variety is the most susceptible for both insect pest and mould (Figure 10). Fikremariam *et al.*(2009) reported that maize verities BH-660 and BH-540 are moderatelysusceptible for insect pests and Tongjura *et al.* (2010) reported maize variety susceptibility to weevil damage depends on the moisture content and seed size. The authors also stated that, increase in moisture was cause susceptibility of maize to weevil infestation and smaller seeds are hard and compact, had less moisture and more resistant to the maize weevil attack than larger seed.The variety susceptible for insect pest may also susceptible for mould because damage caused by insect provide entry for fungi and insect pests alsodissimilate fungi spore (Kankolongo *et al*., 2009; Hell *et al.*, 2000)

Mouldy maize used for different purposes in the study areas (Figure 10). Around 37.8 % of the respondent considered, consuming mouldy maize have health impact but they did not know exactly what it cause. However, 60.1% of the respondents were thought that mouldy maize has no health impact. None of the respondents were experienced about acute response of consuming mouldy maize and; most of them (82.9%) were not trained about maize mould can cause on health impact, management practice and other related issues. According to respondent farmers, mouldy maize resulted with qualitative and quantitative loss and also reduction of market price (56.5%); some of them reported that it causes only qualitative loss (24.9%), price reduction (14.0%) and quantitative loss (4.7%).

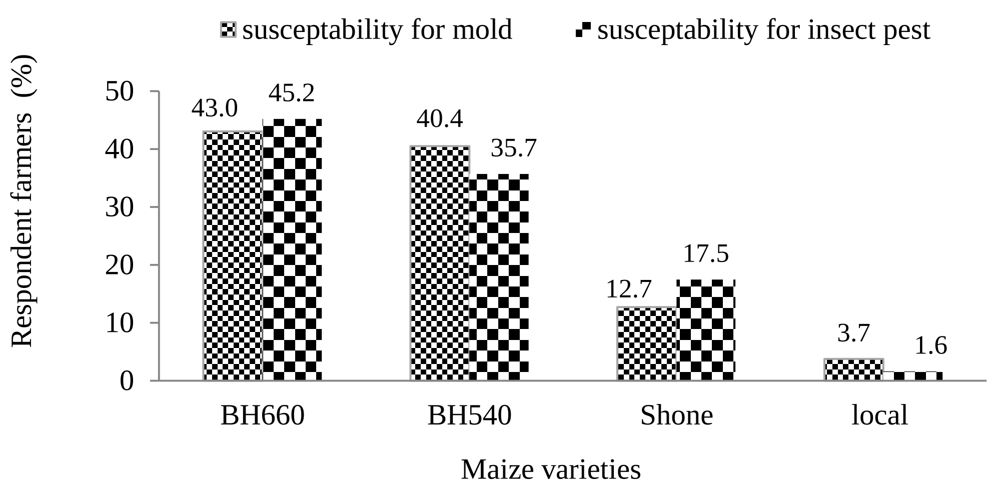


Figure 10: Farmers estimation onsusceptibility of different maize varieties for mould and insect pest damage

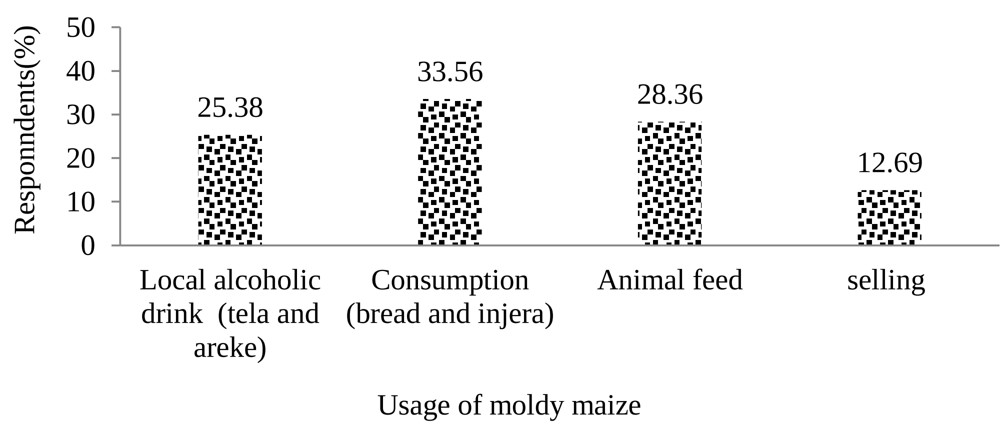


Figure 11: Usage of mouldy maize at producers'stage in the study areas

At traders stage (collectors and wholesalers) mould and insect pest were the major storage problems which affect maize quality.Almost all traders (100% collectors and wholesalers) reported insect pests. Similarly, mould problem reported by 93.8% of maize collectors, 100.0% of wholesalers. According to respondents'traders, the main cause for fungus development in the store was high grain moisture content (75.0%) and mould infection of maize at farmers' condition (12.2%). Furthermore, storage condition and poor management wereother causes of mould development in traders' store. However, main causes of weevil damage in their store were high storage temperature (62.2%) and pervious damage of maize by weevil at farmers' stage. Most of the respondents (81.5%) were reported that the trend of both mould and weevil damage were increasing year after year.

About 86.0 % of the respondent farmers reported there was no support provided by non-governmental organizations. However, the extension service assigned by district agricultureoffice and most of the time they focus on pre-harvest activities. Half of the respondent experts were known about maize mould (52.2%) through experience. Some of the experts were trained farmers about maize mould management during harvesting season (39.1%) informal advice. However, there is no formal plan in their annual activity plan for post-harvest loss reduction to carry out with farmers.

4.2. Laboratory Analysis

4.2.1. Moisture content of stored maize grain

Significant ($P<0.01$) interaction effect of storage duration and agro-ecologies result was observed on moisture content of maize grains stored under farmers storage condition (Appendix table 1). Non significant result observed for samples stored under collectors' condition for interaction effect. However, highly significant ($P < 0.0001$) results were observed for both storage duration and agro-ecological conditions (Appendix table 2). Similarly, maize grain stored under wholesalers store was significantly ($P < 0.02$) affected by the length of storage period (Appendix table 3). The highest grain moisture content was observed on maize collected from highland agro-ecology of the study area in both farmers (20.3 % ±0.5%) and collectors (13.4±0.1%) samples at harvest and during 1st month storage, respectively (Figure 12 A-C). The moisture content was declined along the storage period and the trend was similar in all actors of maize supply chain which addressed by this study (Figure 12 A-C and Table.8). However; during 5th and 6th month storage period the moisture content of maize stored under farmers storage showed increment mainly due to at the end of data collection it was rainy season (Appendix Fig .6) and the moisture enter to the storage through perforated wall of *gombisa* and resulted increment in moisture content of stored maize.

The highest (20.3±0.5%) and the lowest (11.1±0.3%) grain moisture were recorded from maize stored under farmers storage at harvest in highland agro-ecology and during 4th month storage in lowland agro-ecology, respectively. The grain moisture content which recorded until fourth month storage was above the recommended moisture for maize storage (FAO, 2003 and FAO and World Bank, 2011) and favours the development of most storage fungi. A study result shows that highest fungi contamination of maize stored with moisture content 20% and 16% as compared to 12% (Niaz *et al.,* 2011). Study conducted in Jimma zone reportedthat initial moisture content of maize stored in *gombisa* were 13.23% in midland and 14.58% lowland (Dubale et *al*., 2012 and 2014) and the same author reported that declining of the moisture content of maize from 14.58% to 10.07% within 60 days of storage (Dubale *et al.,* 2014). Another report showed that after nine month storage increment of moisture content of maize from 12.30% to 22.88% under traditional farmers' storage and declining from 12.30% to 9.31% under other storages such as metal silo, plastic silo and bag in Uganda and Burkina Faso (WFP, 2014). This showed that the moisture content of maize stored under traditional farmers storage structure were depends on the surrounding environmental condition.

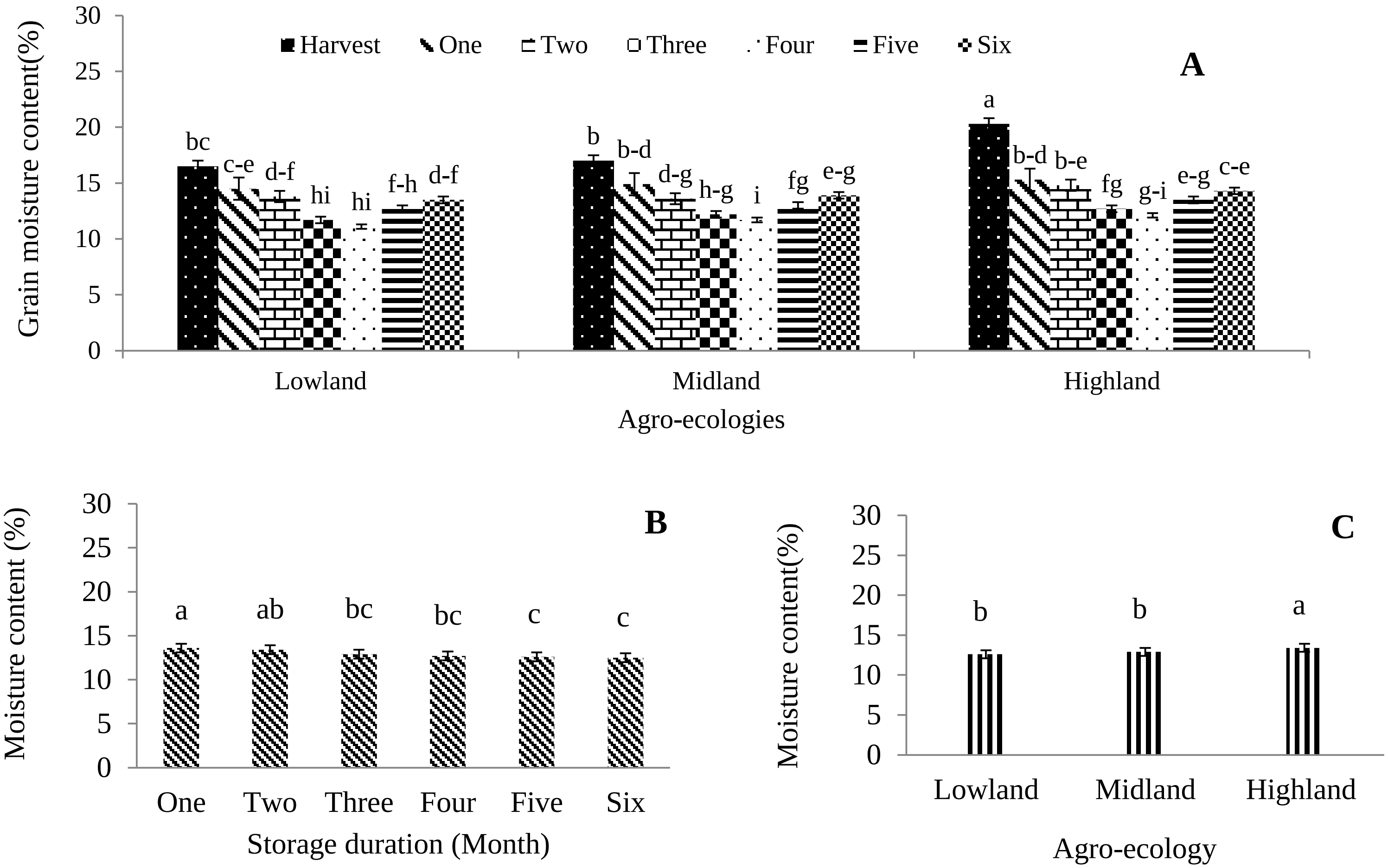


Figure 12:Moisture content of maize stored under A) Farmers storage along the storage duration and agro-ecologies;B) Collectors storage along the storage duration C) Collectors storage including differentagro-ecologies

P= 0.01 for farmers and P<0.0001 forcollectors

Values mean±SE of triplicate samples and means with similar letter(s)do not significantly difference among each other at P<0.05 along the storage duration and agro-ecologies

4.2.2. Maize kernels germination test

Germination percentage is a very important quality parameter of seed because it indicates the viability potential of seed. In current study significant difference (P<0.01) was observed as interaction effect of storage duration and different altitudinal agro-ecologies on germination percentage of stored maize under farmers storage condition, but there was no interaction effect on maize stored under collectors storage. However, both storage duration and altitudinal change across agro-ecologies have highly significant (P<0.0001) effect on germination percentage of maize grain stored under collectors storage. Under wholesalers' storage condition it was significantly affected by storage duration(P<0.001) (Appendix table 1, 2 & 3). At farmers stage the highest germination percentage was 93.1 ±1.7 % it was recorded during 1st storage month in lowland agro-ecology and the lowest germination result (65.2 ±1.7%) recorded during 6th month storage in highland agro-ecology of the study areas (Table 8).However, at collectors stagegermination percentage declined from 91.6±2.2%to 47.4±2.2% after six month storage and it was high in highland agro-ecology (80.0±1.8%) and low in lowland agro-ecology (64.0±1.8%) (Fig.13A&B).

The lowest germination was recorded in highland altitudinal agro-ecology of the study area of maize stored under farmers' storage (65.2±1.7%). Under collectors storage condition in lowland agro-ecology kernel germination was lower (47.4±2.2) due to higher weevil damage. Furthermore, declining of germination percentage along the storage duration was observed under all actors'storage condition mainly due to increment of mould and insect damage. Therefore, current study shows that high fungus and insect damage were resulted in reduction of maize kernel germination.This result was in accordance with Dubale *et al*, 2014reported that around Jimma zone after six month storage, germination of maize grain which stored under traditional farmers storage were decrease from 98% to 68.5% in intermediate and 97.5% to 70.17% in lowland agro-ecologies. Tabatabaei (2013) also reported that declining of germination percentage of stored maize to 28% after 180 days of storage at 35 ^{o}C with14% moisture content. Somda *et al.* (2008) and Govender *et al*. (2008) reported that fungal infection cause reduction in germination of maize seed.

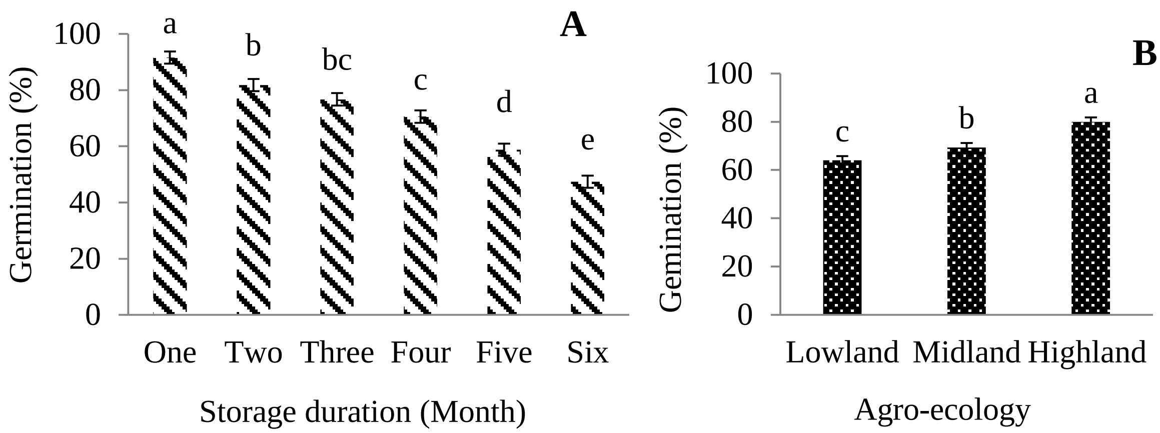


Figure 13: Germination percentage of maize stored under collectors storage A) Along storage duration and B) In different agro-ecologies

P<0.0001 for both storage duration and agro-ecology

Value are mean ±SE of triplicate samples and means with the same letter (s) are no significant difference among each other along the storage duration and along the agro-ecologies at P<0.05

Table 8: Germination (%) of stored maizeunder farmers' storage in the study areas

	Storage duration (Month)						
Agro ecology	**One**	**Two**	**Three**	**Four**	**Five**	**Six**	**P-value**
Low land	93.1±1.7 [a]	82.2±1.7 [b-d]	83.3±1.7 [b c]	78.5±1.7 [c-f]	77.1±1.7 [c-f]	71.2±1.7 [fg]	0.01
Midland	86.9±0.9 [a]	86.2±0.9 [b]	83.5±0.9 [b c]	80.7±0.9 [cd]	79.2±0.9 [cd]	72.6±0.9 [fg]	
Highland	83.6±1.7 [bc]	84.1±1.7 [bc]	78.1±1.7 [c-f]	74.6±1.7 [d-f]	72.9±1.7 [e-g]	65.2±1.7 [g]	

Values are mean ±SE of triplicate samples

Means follow the same letter among columns or rows are notsignificantly different from each other at P<0.05

Table 9: Moisture content, kernel germination, Weevil damage, incidence and severity of mould on maize sample collected from wholesalers'storage condition in the study areas

	Storage time(month)						
Response variables	**One**	**Two**	**Three**	**Four**	**Five**	**Six**	**P-value**
Germination (%)	91.9±3.9[a]	83.2±3.9[ab]	81.3±3.9[ab]	76.7±3.9[a-c]	64.7±3.9[bc]	61.9±3.9[c]	0.0012
Weevil damage (%)	1.8±1.6[b]	3.9±1.6[b]	5.9±1.6[b]	7.0±3.9[ab]	9.5±1.6[ab]	14.8±1.6[a]	0.0021
Incidence of mould (%)	12.5±5.6[c]	18.4 ±5.6[bc]	27.2±5.6[bc]	32.5±5.6[a-c]	40.8±5.6 [a b]	56.6 ±5.6[a]	0.0017
Severity of mould (%)	16.6±2.3[d]	24.5±2.3[cd]	33.8±2.3[bc]	35.0±2.3[bc]	41.9±2.3[b]	58.1±2.3[a]	<.0001
Grain moisture content (%)	13.2±0.2[a]	13.0±0.2[ab]	12.6±0.2[ab]	12.4±0.2[ab]	12.2±0.2[ab]	12.1±0.2[b]	0.0202

Values are mean ±SE of triplicate samples

Means follow with same letter (s) along rows are non-significant difference (P<0.05) among each other

4.2.3. Weevil Damage

Weevil damage of stored maize under farmers condition showed highly significantly ($P<0.0001$)affected by both storage duration and agro-ecologies. Significant ($P<0.0007$) interaction effect were observed for maize stored under collectors storage condition. (Appendix table 1 & 2). Maize stored under wholesaler store also significantly ($P=0.002$) affected by storage duration (Appendix table 3).

Under farmers storage weevil damage was increased from 12.8±0.9% to 29.3±0.9% after six month storage. Comparing different agro-ecologies the highest damage was observed in lowland agro-ecology at both farmers (24.3±0.7%) and collectors (57.9±3.0%) storage condition (Figure 14 A-C). At collectors condition the damage was higher the main reason for this was local collectors collect both the damaged and undamaged grain and sold the damaged grain by lower price for local market mostly for local alcoholic beverage maker and they were sale the undamaged maize for wholesalers. Furthermore, the storage structure at collectors' stage has no window or other ventilation system. Moreover, maize stored with cobs under farmers but under collectors conditions stored as loose grains whichfavor weevil damage. Under wholesalers condition it increased from 1.8±1.6% to 14.8±1.6% after six month storage (Table 9).

Generally, as the storage month increasedweevil damage was increased and damage was high in lowland altitudinal agro-ecology of the study area (Figure14 A,B&C and table 9). Study done in Jimma zone was reported that weevil damage with the ranged of 54 to 75% between three to six months storage period (Waktole and Amsalu, 2012). However, Dubale *et al.*(2012) reported that 20.92% insect damage on maize stored under traditional farmers storage out of this 10-20% loss were caused by weevil. Report from Uganda on insect pest damage on maize stored under traditional farmers storage (granary basket) were reported that 73.9±0.9% damage on cob and 99.0 ± 0.7% on shelled maize during 6thmonth storage period (Atukwase*etal.*,2012).

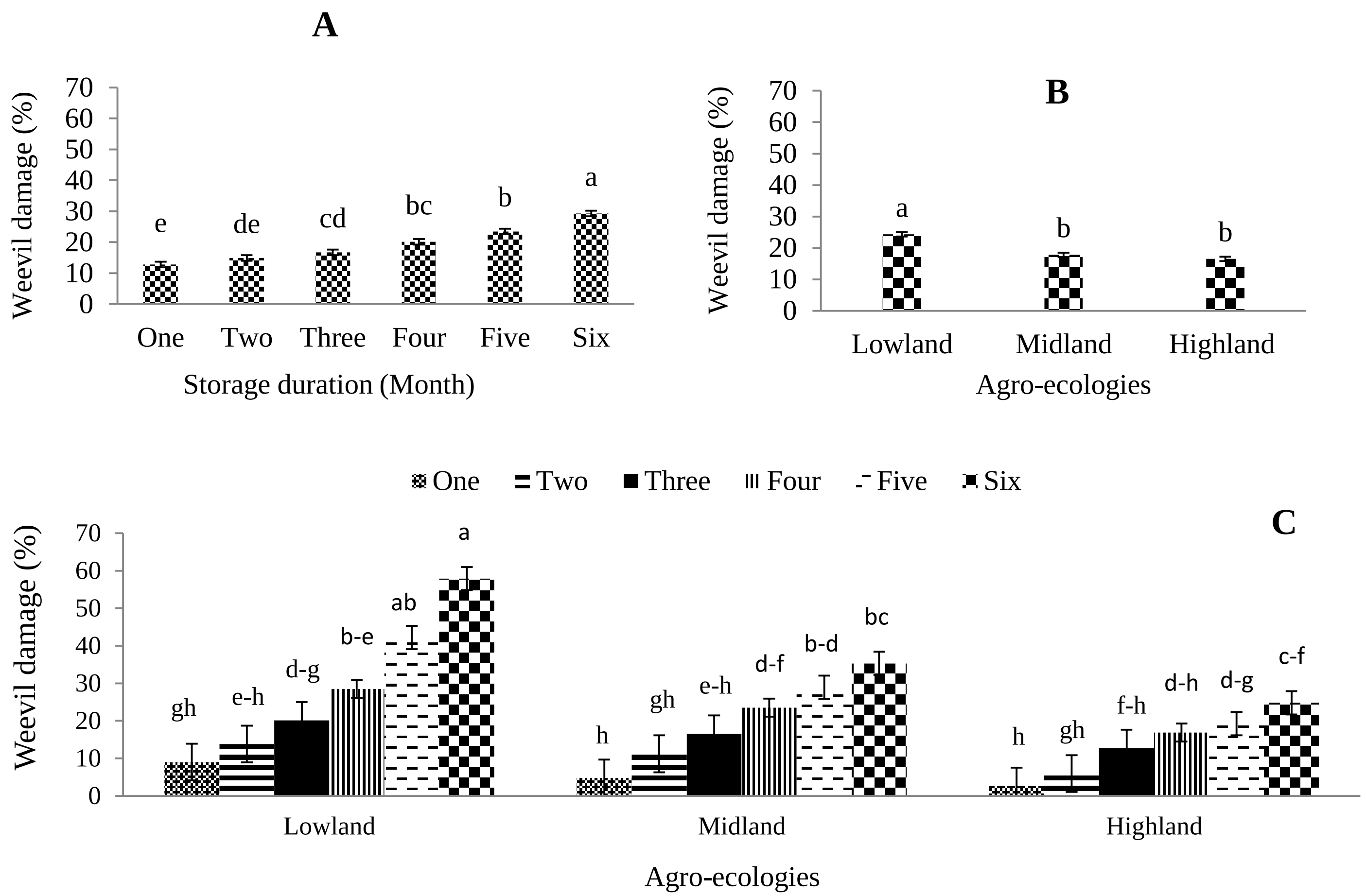


Figure 14: Weevil damage A) Along the storage duration under traditional farmers' storage; B) Across different agro-ecology under traditional farmers' storage; and C) under collectors' storage in different agro-ecology and storage duration.

P-value = for farmers $P < 0.0001$ along the storage duration and $P < 0.0001$ in different agro-ecologies and $P = 0.0007$ for collectors. Values mean of triplicate samples and means with similar letter (s) have no significant difference to each other ($P<0.05$) along the storage duration and different agro-ecologies

4.2.4. Mycological analysis

4.2.4.1. Incidence and severity of mould on the stored maize

Both storage duration and different altitudinal change across agro- ecologies showed highly significant ($P<0.0001$) effect on mould incidence on maize cob stored under farmers storage. However, significant ($P=0.05$) interaction effect of agro-ecologies and storage duration were observed on mould incidence of maize grain sampled from both farmers and collectors storage(Appendix table 1&2). At wholesalers stage mould incidence was significantly ($P<0.001$) affected by storage duration (Appendix table 3).

From farmers sample the highest mould incidence in cob was recorded from highland agro-ecology (47.2±1.1%). Mould incidence on cob was increased along the storage duration and high during 6^{th} month storage(52.0 ± 1.4%) under farmers'condition. Similarly mould incidence on kernel was high on maize collected from highland agro-ecology during 6^{th} month storage on both farmers (78.9±2.7%) and collectors (87.1±3.4%) samples (Table 9 and Figure 15). Mould incidence on maize kernel was the highest (56.6 ±5.6%) under wholesalers' stored product for 6^{th} month storage (Table 9). In all stage of maize supply chain which covered by this study the trend shows that increment of mould incidence along the storage duration. Mould incidence results also indicate it is not reliable to store for prolonged duration of maize product.

Highly significant ($P<0.0001$)difference resultof storage duration and agro-ecologies were observed on severity of mould on maize stored under farmers and collectors conditions (Appendix table 1 & 2). As the result displayed, figure 17 severity of mould was increased along the storage duration. However, the highest mean percentage severity of mould was recorded during six month storage and it was 60.8±1.2% and 45.3±2.5%on maize stored under farmers and collectors, respectively. Similarly, under both storage conditions highest severity was recorded at highland altitude of agro-ecology (Figure 17). Severity of mould on maize grain stored under wholesaler store were highly significantly ($P < 0.0001$) affected by the length of storage duration(Appendix table 3).

Both mould incidence and severity were higher in highland part of the study area, this related with the higher grain moisture content and relative humidity of the air outside which are the two important factors for fungal growth. Suleiman *et al.* (2013) stated that insufficient drying and humid condition favour the development of fungi in tropics. Also, Groot (2004) stated that humidity is crucial for the development of fungi; even at a low temperature some mould development may occur if the relative humidity of the air is high.Similarly, Garuba *et al.* (2011) reported that occurrence and frequency of mould were higher on maize stored with higher (19.0%) moisture and higher grain moisture above 12% that favour fungi development in the store (Niaz *et al.*, 2011 and Gregori *et al.*, 2013). The trend shows increment of both incidence and severity of mouldalong the storage period in all studied maize value chain. This was associate with increments in weevil damage which serve as entry for fungi moreover, weevil transfer fungi spore from infected to healthy grain(Kankolongo *et al*., 2009 and Suleiman *et al*., 2013).Furthermore, maize harvested during dry season, then after rainy season starts and continues till end of data collection (January to June) (Appendix Figure 6). At the same time farmers storage structures are highly ventilated and allow entry of moisture from external environmental condition.

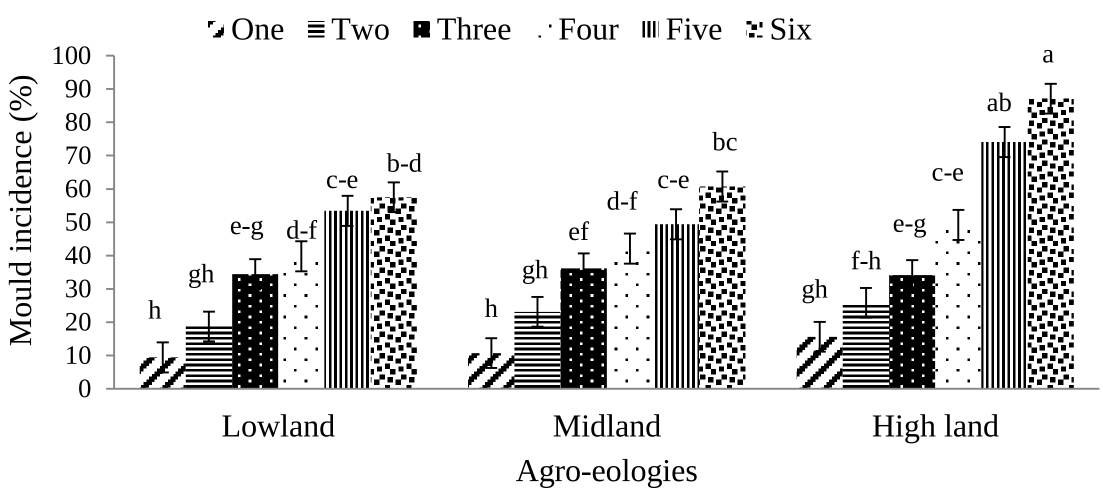


Figure 15: Mould incidence on maize kernel stored under collators' storage

P= 0.005

Values are mean ±SEof triplicate samples and means with the same letter (s) are not significantly different from each other at P<0.05 both along the storage duration and agro-ecologies

Table 10: Mould incidence (%) on maize kernel stored under farmers storage

	Storage duration (Month)						
Agro-ecologies	**One**	**Two**	**Three**	**Four**	**Five**	**Six**	**P-value**
Lowland	10.5±2.7 [k]	24.7±2.7 [hi]	30.9±2.7 [g-i]	37.8±2.7 [e-h]	45.2±2.7 [d-f]	51.8±2.7 [b-d]	0.001
Midland	17.1±1.6 [jk]	27.6±1.6 [hi]	34.2±1.6 [f-h]	41.7±1.6 [d-g]	49.6±1.6 [cd]	61.6±1.6 [b]	
Highland	21.8±2.7 [i-k]	28.4±2.7 [g-i]	41.9±2.7 [d-g]	49.2±2.7 [c-e]	59.9±2.7 [bc]	78.9±2.7 [a]	

Values are mean ±SE of triplicate samples

Means with the same letter(s) are no significantly different among each other along the columns and/or rows at (P<0.05)

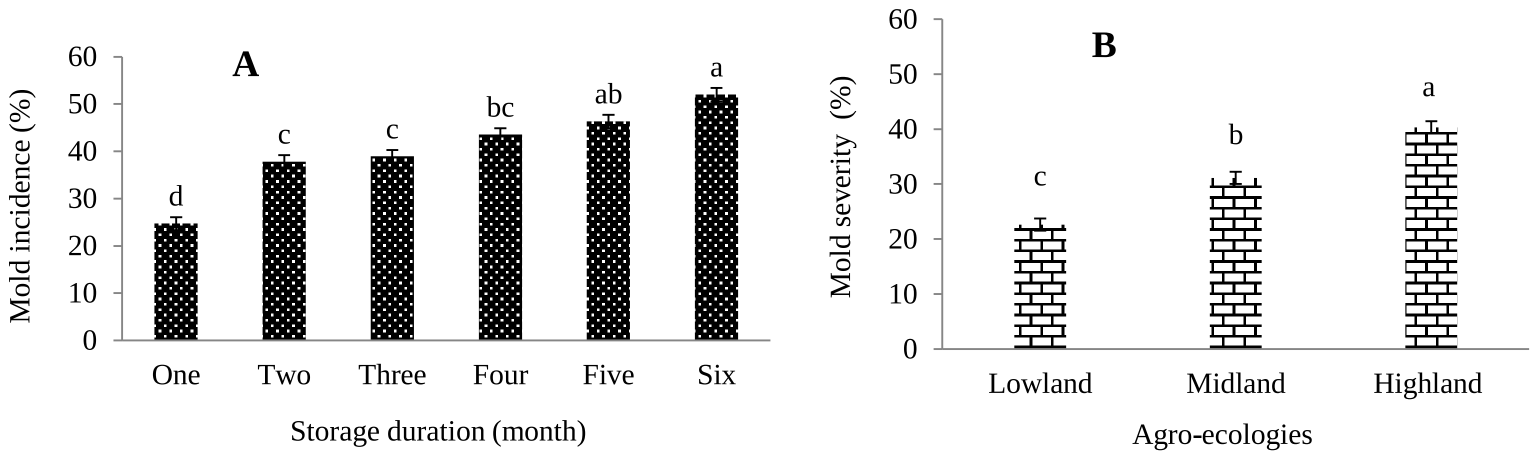


Figure 16: Mould incidence on maize cob stored under farmers storage A) Along storage duration B) across agro-ecologies

P<.0001 for both storage duration and different agro-ecologies

Values are mean ±SE of triplicate samples and means with the same letter(s) are no significant difference among each other at (P<0.05)

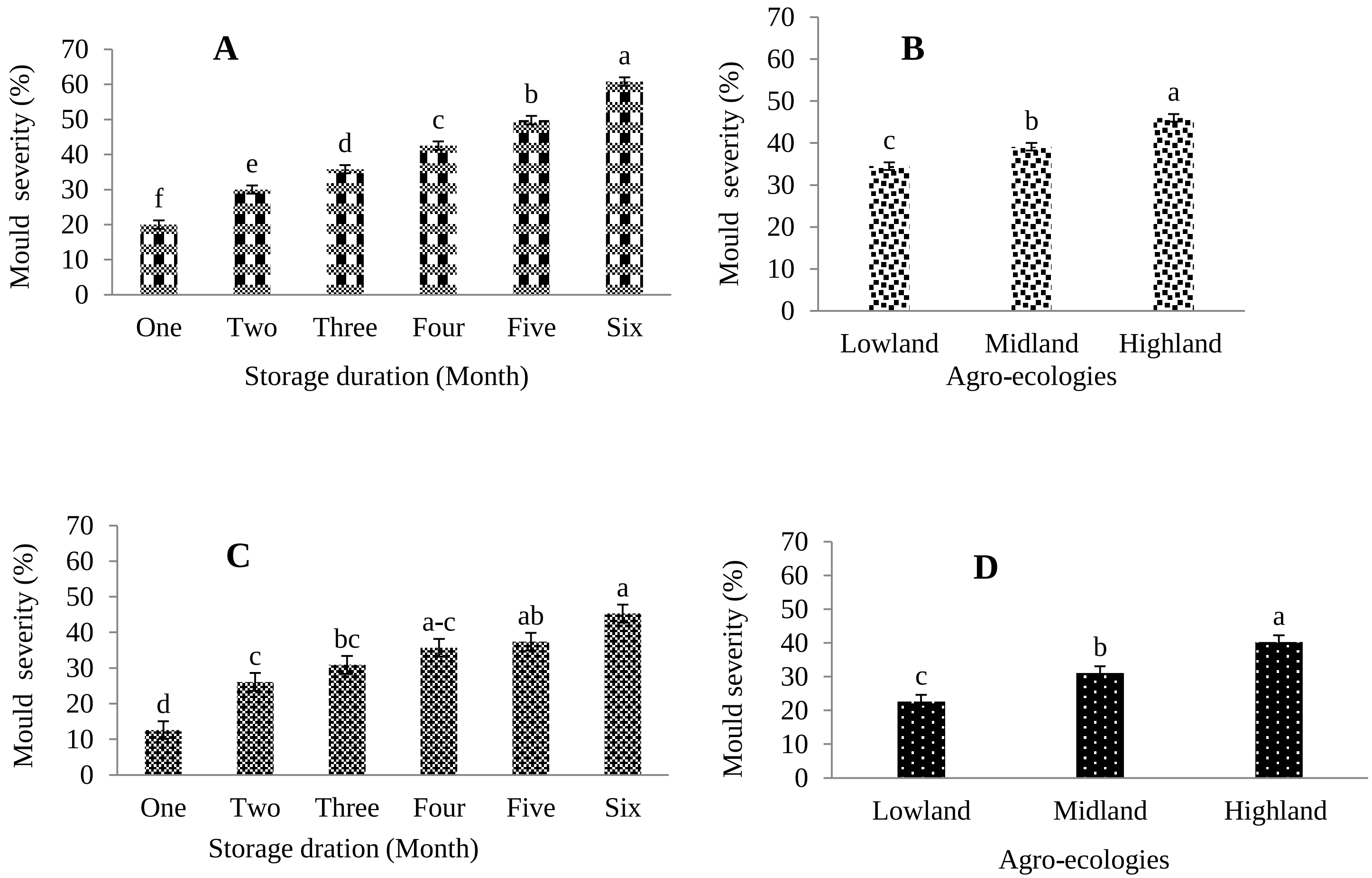


Figure 17: Severity of mould A) Farmers sample stored for different duration B) for farmers sample from different agro-ecologies C) for collectors sample stored for different duration D) for collectors sample from different agro-ecologies.

$P<0.0001$ for both farmers and collectors sample along the storage duration and across different agro-ecologies

Values are mean ±SE of triplicate samples and Means with the same letter(s) are no significant difference among each other at ($P<0.05$)

4.2.4.2. Fungal pathogens isolation and identification

A total of seven fungi genera were identified from maize grain collected from farmers and collectors store. But six fungi genera were identified from maize grain collected from wholesalers' store. However, *Fusarium* spp., *Pencillium* spp.and *Aspergillus* spp. were predominantly identified from sample collected from farmers, collectors and wholesaler store.

The colony colour ofmost frequently isolated *Fusarium* spp. werewhite and light pink to pink reverse light salmon to salmon colour. Whereas, *Pencillium* spp. dark sea green and sea green reverse yellow and orange colour. Pure cultures of frequently isolated Aspergillus spp. were black reverse white or yellow and golden yellow reverse golden yellow (Appendix table 4, 5& 6 and appendix figure 12 &13). Current finding inline with some previous studies of Fandohan *et al*.(2005); Giorni *et al*.(2007b); Okoth *et al*.(2012).

Fusarium spp. was the most frequently isolated fungi genera followed by *Pencillum* spp. and *Aspergillus* spp. during the storage period in all district.Tesfaye and Dawit, (2000) also reported that, *Fussarium, Pencillium* and *Aspergillus* were the most important toxigenic fungal pathogens of maize in Ethiopia among which *Fusarium* is the most common. Hailegiorgies,(2013) was reported five fungi genera from stored maize around Jimma zone however; according to the author *Fussarium, Pencillium* and *Aspergillus* were the most dominant. Similarly recent study conducted in Jimma zone by Dubale *et al.,* (2014) reported that identification of *Fussarium, Pencillium* and *Aspergillus* from maize stored under farmers storage condition in both *Gombisa* and sack. Both Hailegiorgies, (2013) and Dubale *et al.,* (2014) reported those fungi genera at producer stage however, in current study those fungi genera were pre-dominantly identified from farmers, collectors and wholesalers sample along maize value chain. Kaaya *et al*., (2006) reported that *Fussarium, Pencillium* and *Aspergillus* were pre-dominantly identified from trader sample collected from different agro-ecologies of Uganda. On the other hand, study conducted at Cameron indicated that, highest level infection of stored maize by *Aspergillus* (4-96%), *Pencillium* (62-63%) and *Fusarium* (8-32%) (Tagne *et al.,* 2003). Similarly several studies reported that those three fungi genera are the most important in stored maize (Kulkarni and Chavan, 2010; Tizaki and Mostafa, 2011; Toffa *et al.,* 2012; Bosah and Omorusi, 2014).

Cloudosporium, Geotrichum, Drechslera and *Phoma* were less frequently identified fungi genera. The distribution of fungal pathogens isolated from maize grain stored under farmers storage were significant ($P<0.05$)except *Geotrichum* spp. and *Cloudosporium* spp.However, only *Fusarium* and *Cloudosporiu*m frequency were significant ($P<0.05$) on maize stored under collector and whole sellers store.

Current study indicates, from farmers sample the highest *Fusarium* incidence were recorded during 2nd month storage in midland altitudinal agro-ecology of the study area it was 94.1%, 92.6% and 92.6% in Mana, Omonada and Kersa districts respectively, similarly the frequency of identification was higher in those three districts during 5th month storage (Appendix table7). However, on collectors sample *Fusarium* frequency was higher in midland during (100%) 2nd month storage and also in lowland agro-ecology during 5th month storage both incidence (93.3%) and frequency (97.78%) were higher(Appendix table 8); it may be related with higher weevil damage in lowland collectors sample because Pitt and Hocking (2009) stated that *Fusarium* spp. invade seed through site of insect damage. In wholesalers sample the incidence were higher during 1st and 2nd month storage. In all above mentioned stage of maize value chain the trend showed the occurrence of *Fusarium* were relatively decrease with the storage duration (Table 11 & table 13) this may be due to declining of grain moisture along the storage period which was not conducive for the growth of fungi such as *Fusarium* spp. (Bhattacharya and Raha,2002).Kaaya *et al*. (2006) reported that in midland agro-ecology of Uganda under trader storage 0-60% infection of maize grain by *Fusarium* after six month storage and study conducted at Uganda reported that the highest *Fusarium* incidence (82.0±6.6%) on shelled maize than unshelled maize (73.5±2.4) which stored under traditional farmers storage condition for two month storage period(Atukwase *et al.,* 2012). *Fusarium* (25.8-30.8%) was reported from store maize seed in Nigeria (Chukunda, 2013).

Pencillium was the second important fungi genera which frequently identified next to *Fusarium.*From farmers' sample, occurrence (42.20%) and frequency (62.23%) of *Pencillium* spp. were recorded as highest from midland agro-ecology during 4th month storage (Appendix table 7). From collectors' store, the highest incidence (68.90%) and frequency (82.22%) were observed in lowland agro-ecology during 6th month stored product (Appendix table 8). Similarly, from wholesalers sample during 4th month storage period the occurrence was high with frequency of 68.90% (Appendix table 7).*Pencillium* spp. was reported from stored maize grain in Nigeria (Amad and Adeniyi, 2009). High *Penicillium* (99.0%) infection of maize kernel collected from midland agro-ecology (Muthomi *et al.,* 2009). Most study reported that *Pencillium* spp. were the most important toxigenic fungi genera of store maize grain (Tagne *et al.,* 2003; Kulkarni and Chavan 2010, and Chukunda, 2013).

Aspergillus spp.occurrence from farmers' sampleswas higher from midland agro-ecology during 6th month storage with frequency of 32.57% (Appendix table 7). Muthomi *et al.* (2009) reported that *Asperagillus* infection of stored maize in midland agro-ecology with highest frequency of 41-50%. However, from collectors sample frequently (33.33%) identified from highland agro-ecology during 6th month storage (Appendix 8). However, sample from wholesalers *Aspergillus* spp. high frequently (66.70%) recorded from 4th month stored maize product (Table 12).The occurrence of*Aspergllius* on maize stored under traders storage with frequency of 45.6-50.6%was reported by (Chukunda, 2013), Also Kaaya *et al*. (2006) reported that 0-100% infection of maize by *Aspergillus* which stored under trader condition in Uganda for six month. From current study across all actors included for the study, occurrence of *Aspergillus* spp. was relatively increased with the storage duration increase (Table 11, 12&13).Most study result were reported *Aspergillus* spp. from stored maize (Atehnkeng *et al.*, 2008;Muthomi *et al.*, 2009; Yakubu, 2009; Niaz *et al.,* 2011 and Kos *et al.*, 2013). This shows that most toxinogenic fungi occurrence was increase as storage duration increase.

Phoma, *Geotrichum*, *Cloudosporium*and*Drechslera* were less frequently identified fungi genera as compared to *Fusarium,Aspergillus* and *Penicillium* from stored maize all actors of the value chain. However, Drechsleraspp. were identified only from farmers and collectors sample. Kulkarni and Chavan (2010) reported *Fusarium*spp., *Aspergillus* spp., *Pencillium* spp., *Drechslera* spp., *Cloudosporium* spp., and *Phoma* spp.using direct plating method on PDA from stored maize. Similarly, some study were reported those fungi genera from stored maize.(Ghiasian *et al.,* 2004; Somda *et al.,* 2008; Srenivasa *et al.,* 2011; Bosah and Omorusi, 2014;Dubaleetal.2014).

Table 11: Occurrence of fungi genera from stored maize under farmers storage

Storage duration (Month)	Fungi genera																				
	Pencillium spp			*Asparagillus spp*			*Fusarium spp*			*Phoma spp*			*Geotrichum spp*			*Cloudosporium spp*			*Drechslera spp*		
	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)
One	8.3	2.2	5.8	3.4	1.1	2.7	81.3	25.4	83.6	3.6	1.4	3.8	0.0	0.1	0.3	2.8	0.8	1.7	3.7	0.9	1.9
Two	2.8	3.4	3.4	3.6	1.5	4.7	83.1	29.1	86.1	0.0	0.0	0.0	0.4	0.5	1.2	3.4	1.6	4.5	0.0	0.1	0.2
Three	30.1	12.4	26.5	6.5	2.7	3.8	60.3	27.0	64.4	1.5	0.5	1.2	0.9	0.5	1.1	0.2	0.3	1.0	0.0	0.0	0.0
Four	28.3	34.1	24.4	9.7	11.2	7.8	54.6	66.6	53.9	0.6	0.6	0.5	2.6	5.2	1.1	3.8	8.8	4.2	0.3	1.3	0.8
Five	21.2	26.2	18.7	10.4	12.7	9.3	63.3	72.6	66.4	0.5	1.0	0.8	1.3	1.2	0.8	3.3	4.7	3.4	0.1	0.9	0.6
Six	29.6	36.3	26.1	13.7	17.6	16.4	52.9	67.6	49.6	0.0	0.0	0.0	0.7	1.9	1.5	1.0	1.9	1.3	0.1	0.4	0.4

RD= relative density, Fr=frequency and In =incidence

Table 12: Occurrence of fungi genera on maize grain stored under collectors storage

Storage duration (Month)	Fungi genera																				
	Pencillium spp			*Asparagillus spp*			*Fusarium spp*			*Phoma spp*			*Geotrichum spp*			*Cloudosporium spp*			*Drechslera spp*		
	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)
One	10.1	6.9	8.5	3.0	1.8	0.4	69.9	81.4	91.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Two	12.4	12.5	9.7	3.0	0.4	0.4	82.7	70.3	83.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Three	23.6	23.8	20.8	14.2	3.3	10.6	52.0	49.8	47.5	0.0	0.0	0.0	6.7	4.9	6.2	0.9	1.3	1.5	0.0	0.0	0.0
Four	38.7	41.8	39.0	7.6	4.0	5.5	48.9	46.7	39.6	0.0	0.0	0.0	1.8	3.1	2.2	3.1	4.0	3.9	0.9	2.7	3.1
Five	19.1	24.9	21.2	19.1	12.0	17.3	54.2	70.2	52.1	0.0	0.0	0.0	2.7	8.0	6.6	4.0	4.9	2.9	0.0	0.0	0.0
Six	46.2	58.2	42.4	12.9	14.2	15.8	39.6	48.4	41.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.4

RD= relative density, Fr=frequency and In =incidence

Table.13: Occurrence of fungi genera from maize stored under wholesalers storage

Storage duration (Month)	Fungi genera																				
	Pencillium spp			***Asparagillus spp***			***Fusarium spp***			***Phoma spp***			***Geotrichum spp***			***Cloudosporium spp***			***Drechslera spp***		
	In (%)	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**
One	3.3	28.8	9.2	1.6	1.6	5.6	83.0	60.9	78.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Two	6.7	32.0	9.0	4.4	6.7	11.3	84.4	60.9	72.5	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Three	17.8	0.0	0.0	17.8	44.4	8.9	64.4	8.1	24.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Four	42.2	68.9	44.4	6.7	66.7	27.8	46.7	0.0	0.0	6.7	66.7	11.1	2.2	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0
Five	31.1	48.9	34.4	17.8	17.8	16.6	46.7	57.8	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Six	26.7	35.6	24.3	35.6	48.9	29.9	40.0	30.6	45.8	0.0	0.0	0.0	0.0	0.0	0.0	24.7	40.0	15.2	0.0	0.0	0.0

RD= relative density, Fr=frequency and In =incidence

4.2.5. Nutritional Analysis

All nutritional compositions such as Proximate composition, mineral, carbohydrate, calorific value and anti-nutrient content of maize stored under farmers, collectors and wholesalers storage condition were determined in dry weight base.

4.2.5.1. Proximate composition of stored maize

Moisture content: - Moisture content showed highly significant (P=0.003) different withinteraction of storage duration and different altitudinal agro-ecologies of maize stored under traditional farmers storage(Appendix table 9). Whereas, moisture content of maize stored under collectors and wholesalers storage were significantly (P<0.05) affected only by the length of storage duration (Appendix table 10&11).

The highest (24.9±0.5%) and the lowest (13.0±0.5%) moisture content was recorded from maize stored under farmers storage in highland agro-ecology (during harvest) and lowland agro-ecologies (4^{th} month storage) (Table 14), respectively. Under all actors' storage condition the trend showed slightly declining in moisture content except the moisture content of maize stored under farmers' storage at the end of data collection which was increased.The main reason for this was at the end of data collection it was rainy season(Appendix figure6) and the moisture enter in to the storage through perforated wall of *gombisa*and increased grain moisture content. SomeStudies were reported that declining of moisture along the storage period (Oladele and Osipitan, 2011 and Dubale *et al.*, 2012) and also increment of moisture content of maize grain from 12.30% to 22.30% during the storage period under traditional farmers' storage in Uganda and Burkina Faso reported by WFP (2014). Similarly Bhattacharya and Raha (2002) also reported that declining of moisture content of maize grain 14.0% to 10.6% after eight month storage and then it was increased to 13.0% during twelve month storage, the same author stated that increment of moisture content during twelve month storage as a result of absorption of moisture from surrounding atmosphere.

Protein content: -Only storage duration significantly (P<0.05)affected protein content of maize stored under farmers storage(Appendix table 9). Similarly, protein content of maize grain collected from wholesalers store was significantly (P<0.001) affected by storage duration(Appendix table 10). While,significant ($P<0.01$) interaction effect of storage duration and agro-ecological condition were observed on protein content of maize grain stored under collectors storage condition (Appendix table 11).

The protein content of stored maize was significantly affected by storage duration in all case of studied maize supply chain. From farmers sample the highest (9.1±0.3%) protein content were recorded at harvest and the lowest (7.2±0.3%) were obtained during 6^{th} month storage (Table 14). Temesgen and Waktole, (2013) were reported that 7.10% average protein content of BH-660 maize variety at producer stage which was collected from Jimma zone. Furthermore, during 2^{nd} month storage period the highest (11.2±0.2%) protein content was recorded from collectors sample in highland altitudinal agro-ecology. Tongjura *et al.*, (2010) reported that crude protein content of different verities of white maize with a range of 8.47 to 12.20%.

Under all storage condition protein content declined as the storage duration increase. Study result reported by Farhan *et al.*(2013) showed that after 90 days of storage period protein content of stored maize decrease from 13.11% to 12.65% due to mite infestation of the grain. The same authors stated that selective feeding by some insect larvae pests preferentially on the germ part of the grain reduce protein content of the grain. Fungi also invade and cause damage on the germ and endosperm part of the grain (Meronuck,1987) and cause declining of protein content of grain (Bhattacharya and Raha, 2002). Furthermore, grain respiration, mould and insect damage cause reduction of protein in stored maize (Yakubu, 2009). However, declining of protein from 10.13% to 9.37% after nine month storage in plastic bag under room temperature was also reported by Stefanello *et al.*(2015).

Fat content: -The fat content of stored maize was significantly ($P<0.05$) affected by both the length of storage duration and agro-ecological difference under both farmers and collectors storage condition (Appendix table 9&10). Fat content of maize grain collected from wholesalers store was significantly ($P<0.002$) affected by storage duration (Appendix table 11).Under all storage condition the fat content was decreased as the storage duration increased.

The fat content of maize was 4.5 ±0.1% at harvestand decreased to 3.8±0.1% after 6th month storage under farmers condition. Comparing three agro-ecology, the highest fat content were recorded in lowland (4.5±0.1%) followed by midland (4.3±0.1%) and the lowest (3.9±0.1%) wasrecorded from highland agro-ecology (Table 14). Similarly, from collectors sample the highest fat content was recorded from 2 month stored product (5.0±0.1%) but at the end of data collection it was declined to 4.2±0.1%. Similar trend was observed between agro-ecologies(Table 14 and Table 15). Higher mould incidence and severity on maize stored in highland agro-ecology of the study area under both farmers and collectors' storage condition were observed and this resulted reduction in fat content. Samples from wholesalers fat content declined from 5.2±0.1% to 4.7±0.1% after six month storage. Form all actors' storage condition the fat content of stored maize declined along the storage duration (Table 14, 15 & 16). In high moisture grain 28-31% loss in fat content was reported by Reed *et al.* (2007) and another study conducted by Farhan *et al.* (2013) reported that declining of fat content of maize from 5.86% to 5.25% after 90 days of storage due to damage by storage mites and also declining of fat content of maize grain from 5.79% to 5.04% after nine month storage in plastic bag under room temperature was reported by Stefanello *et al.*(2015).

Fiber content: -The fiber content of maize stored under farmers storage was showed a highly significant ($P < 0.0001$) increment as the length of storage duration increased(Appendix table 9).At harvest it was 4.2±0.2% but it increased to 8.4±0.3% after six month stored maize (Table 14). Similar results were observed for collectors and wholesalers condition as indicated on table 15 & 16, respectively. After 90 days of storage increment in fiber content of stored maize from 2.20% to 2.29% due to damage by storage mite was reported by Farhan *et al.*(2013).However, increment is very low compared to current study finding. The same author stated that the fiber content increased as a result of selective feeding of mitepreferentially the endosperm part and fiber content of maize grain much higher in bran(14.0%) than endosperm (0.1%) (Golob *et al.*, 2002).Rashad *et al.*(2013) also reported increment of fiber along the storage period.

Ash content: -Both storage duration and agro-ecological condition were significantly ($P=0.05$)affect the ash content of maize stored under traditional farmers storage structure(Appendix table 9). The ash content showed increment as storage duration increase and different result were recorded in different agro-ecologies. Ash content of freshly harvested maize, during 2nd, 4th and 6th month storage it was 0.7±0.1%, 0.9±0.1%, 1.0±0.1% and 1.1±0.1%, respectively (Table 14).However,ash content of maize stored under collectors store were highly significantly ($P < 0.0001$) affected by storage duration and similar result was recorded for wholesalers sample (Appendix table 10&11).After 90 days of storage the ash content of stored maize were increased from 1.9% to 1.91% as reported by Farhan *et al.*, (2013). The ash content of different verities of maize with the range of 1.7±0.2 to 2.4±0.05 mg/100gm of was reported by Hassan *et al.*(2009). Mashilla *et al.*(2004)reported increment of ash content of sorghum from 2.17% to 8.38% after 17 month storage in soil pit. Similarly Also Stefanello *et al.*(2015) reported that increment of ash from 1.45% to 2.03% after nine month storage in plastic bag under room temperature. Rashad *et al.*(2013) stated that selective feeding of insect larvae preferentially the endosperm part may cause less damage on the bran resulted incensement in ash content of stored maize due to the ash content higher in maize bran (5.8%) than endosperm (0.3%) (Golob*et al*., 2002).

Table 14: Proximate composition of maize grain collected from farmers storage

		Storage duration (Month)					
Response variables	**Agro-ecology**	**Harvest**	**Two**	**Four**	**Six**	**Agro-ecology effect**	**P-value**
Moisture	Lowland	19.2±0.5^{bc}	16.4±0.5^{c-e}	13.0±0.5^{f}	15.6±0.5^{d-f}		0.0003
	Midland	20.6±0.5^{b}	16.8±0.5^{c-d}	13.4±0.5^{f}	15.2±0.5^{d-f}		
	Highland	24.9±0.5^{a}	18.0±0.5^{b-d}	13.9±0.5^{e-f}	16.9±0.5^{c-d}		
Protein (%)	Storage duration effect	9.1±0.3^{a}	8.6±0.3^{ab}	7.7±0.3^{bc}	7.2±0.3^{c}		0.001
Fat (%)	Lowland					4.5±0.1^{a}	0.0003
	Midland					4.3±0.1^{a}	
	Highland					3.9±0.1^{b}	
	Storage duration effect	4.5±0.1^{a}	4.5±0.1^{a}	4.2±0.1^{a}	3.8±0.1^{b}		0.0002
Fiber (%)	Storage duration effect	4.2±0.2^{d}	5.4±0.3^{c}	7.2±0.3^{b}	8.5±0.3^{a}		<.0001
Ash (%)	Lowland					1.1±0.1^{a}	0.02
	Midland					0.8±0.1 ^{b}	
	Highland					0.9±0.1^{ab}	
	Storage duration effect	0.7±0.1^{b}	0.9±0.1^{ab}	1.0±0.1^{a}	1.1±0.1^{a}		0.003

Values are mean ±SE of triplicate samples

Means with the same letter(s) are no significantly different among each other at P< 0.05 along the storage duration and agro-ecologies for moisture; only along storage duration or agro-ecologies for fat, fiber and ash and only along the storage duration for protein

Table 15: Proximate composition of maize grain sampled from collectors store

Response variables	Agro-ecology	Storage duration (Month) Two	Four	Six	Agro-ecology effect	P-value
Moisture	Storage duration effect	16.1±0.2[a]	14.5±0.2[b]	14.0±0.2[b]		<.0001
Protein	Lowland	9.1±0.2[b]	9.6±0.2[b]	7.2±0.2[c]		0.01
	Midland	8.6±0.2[b]	9.3±0.2[b]	7.0±0.2[c]		
	Highland	11.2±0.2[a]	9.8±0.2[b]	8.7±0.2[b]		
Fat	Lowland				4.8±0.1[a]	0.0003
	Midland				4.7±0.1[a]	
	Highland				4.3±0.1[b]	
	Storage duration effect	5.0±0.1[a]	4.7±0.1[b]	4.2±0.1[c]		<.0001
Fiber	Storage duration effect	4.4±0.5[b]	6.7±0.5[a]	8.4±0.5[a]		0.0005
Ash	Storage duration effect	0.7±0.1[b]	0.9±0.1[b]	1.1±0.1[a]		<.0001

Values are mean ±SE of triplicate samples

Means with the same letter(s) are no significantly different among each other at P< 0.05 along the storage duration for moisture, fiber and ash; along storage duration and agro-ecologies for protein and only along the storage duration or agro-ecologies for fat

Table 16: Proximate composition of maize stored under wholesalers storage condition

	Storage duration (Month)			
Response variables	**Two**	**Four**	**Six**	**P-value**
Moisture	15.5±0.2[a]	14.1±0.2[b]	13.5±0.2[b]	0.004
protein	10.5±0.2[a]	10.3±0.2[a]	8.3±0.2[b]	0.001
Fat	5.2±0.1[a]	5.1±0.1[ab]	4.7±0.1[b]	0.02
Fiber	5.2±0.6[b]	6.6±0.6[ab]	8.1±0.6[a]	0.04
Ash	0.5±0.1[b]	0.8±0.1[ab]	1.1±0.1[a]	0.005

Values are mean ± SE of triplicate samples and means with the same letter (s) for each response variables along the row are not significant different among each other at P < 0.05

4.2.5.2. Carbohydrate content

Carbohydrate content of maize stored under farmers and collectors storage was significantly (P<0.05) affected by both storage duration and different altitudinal agro-ecologies. And, carbohydrate content of maize stored under wholesalers storage significantly (P<0.05) affected by storage duration. (Appendix table 9, 10&11).

At harvest the carbohydrate content of maize stored under farmer's storage was 68.1±0.7% however, during 6 month storage it declined to 60.6±0.6% (Fig. 19A). Similar trend was observed from maize stored under collectors (Figure 18 D) and wholesalers (Figure 18 E) storage conditions.

The highest carbohydrate content was recorded in midland agro-ecology under both farmers (65.5±0.6%) and collectors (68.9±0.5%) storage condition and the lowest result was recorded in highland agro-ecology both for farmers (62.6±0.6) and collectors (64.9±0.5) (Figure18A& C). It is mainly related with higher fungal damage on maize collected from highland agro-ecology as compared to midland and lowland (Figure 14, 15 &16 16 and table 9). Higher moisture content of maize stored in highland agro-ecology enhance grain respiration rate and resulted reduction of carbohydrate content (USID, 2011). Moreover, maize with higher moisture content resulted higher contamination by fungi and lower in nutritional quality especially carbohydrate content (Kumar and Kweera, 2013).The result inline with previous studies which were reported declining of carbohydrate along the storage duration due to damage caused bio-deteriorates. Mashilla *et al.*(2004) who reported declining of carbohydrate content of sorghum stored in soil pit for 17 month.Farhan (2013) study result showed that declining of carbohydrate from 62.2± 0.7 to 61.3 ± 0.1 after 90 days of storage due mite infestation of stored maize.Bhattacharya and Raha (2002) reported declining of carbohydrate content of maize from 74.7% to 57.0% after twelve month storage due to fungi damage.Yakubu (2009) also reported reduction of carbohydrate as a result of fungi damage on stored maize. Olorunsola (2010) also reported declining of carbohydrate content ofmaize stored in metal silo from 66.9% to 60.6% as a result of improper storage.

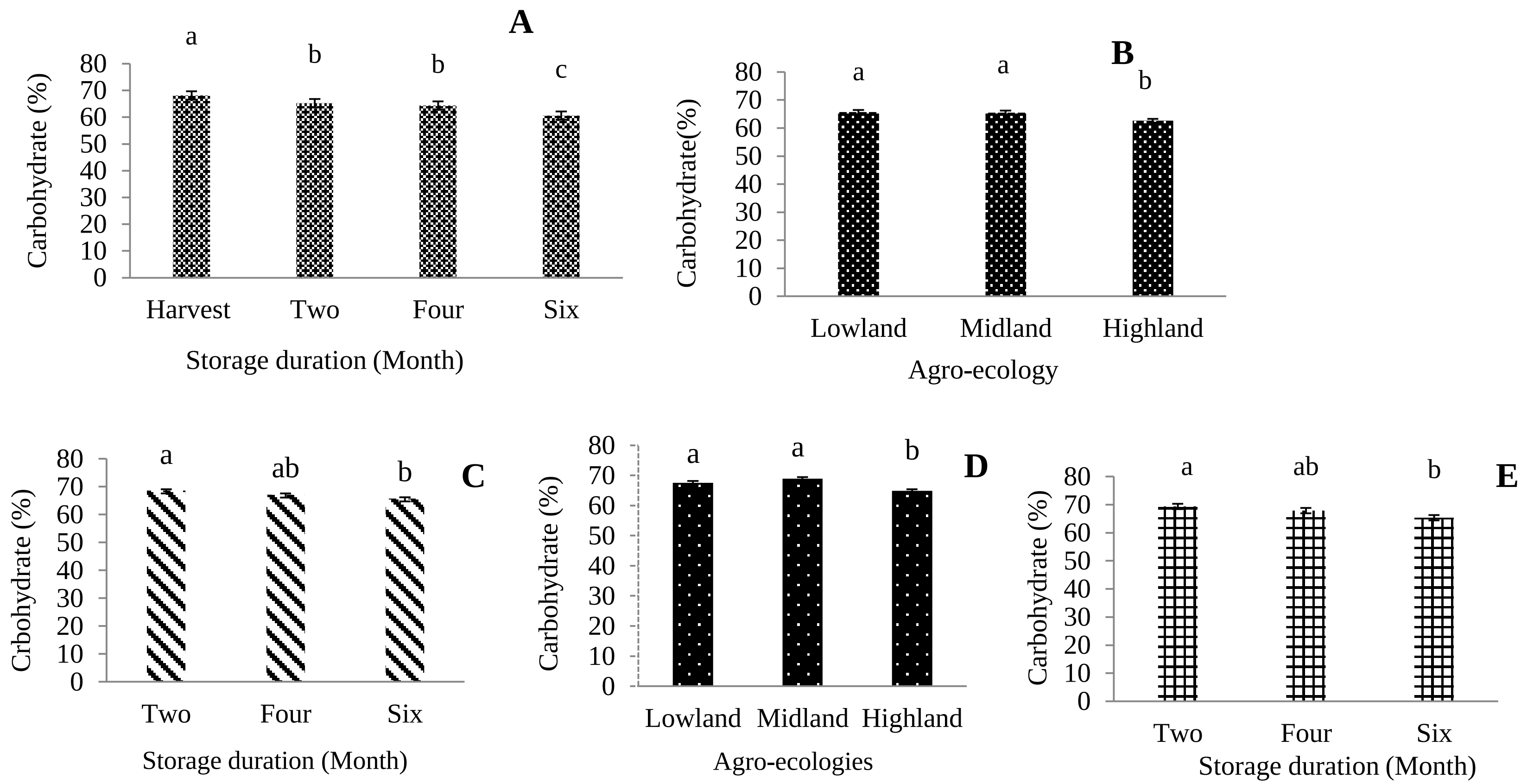


Figure 18: Carbohydrate content of stored maize A) under farmers storage along the storage duration B) Under farmers storage at different agro-ecologies C) Stored under collectors storage along the storage duration D) Stored under collectors storage at different agro-ecologies and E) Stored under wholesalers storage along the storage duration

P-value = farmers $P < 0.0001$ for storage duration and $P = 0.003$ for agro-ecology; Collectors $P= 0.002$ or storage duration and $P< 0.0001$ agro-ecologies and $P < 0.0001$ for wholesalers (storage duration).

Values are mean ±SE of triplicate samples and means with the same letter (s) are not significant different among each other at $P<0.05$

4.2.5.3. Calorific value

Significant effects of storage duration ($P<0.0001$) and agro-ecology ($P=0.003$) were observed on calorific value of maize stored under farmers storage(Appendix table 9). However, under collectors and wholesalers storage condition the calorific value only significantly ($P<0.05$) affected by storage duration (Appendix table 10&11).Calorific value was declined along the storage duration for all actors of maize value chain in the study areas (Figure 19 A, B, C &D). Under farmers storage the highest value was recorded in lowland (334.2±2.9 Kcal) and the lowest value was recorded from highland agro-ecology (319.7±2.9 Kcal) (Figure 19 B).

The lowest calorific value was recoreded in highland agro-ecology mainly due to high mould damage on maize stored under farmers storage in highland agro-ecology as compared to midland and lowland (Table 10& figure 16 B). The trend showed that declining of calorific value of maize along the storage duration however, mould incidence and severity were increased along the storage duration. Kumar and Kweera (2013) reported that maize with higher moisture content resulted high fungal contamination and lower in nutritional quality. Reed *et al.* (2007) also reported that reduction of energy value of stored maize as a result of mould damage.The calorific value of freshly harvested different white coloured maize varieties grown in Pakistan were reported with the range of 371 to 380 kcal/100g of sample (Ullah *et al.,* 2010).However, the caloric value of different varieties of maize grain grown in North America with the rage 400±0.2 -401±0.0 kca/100g in dry weight base were reported by Hambidge (2004).

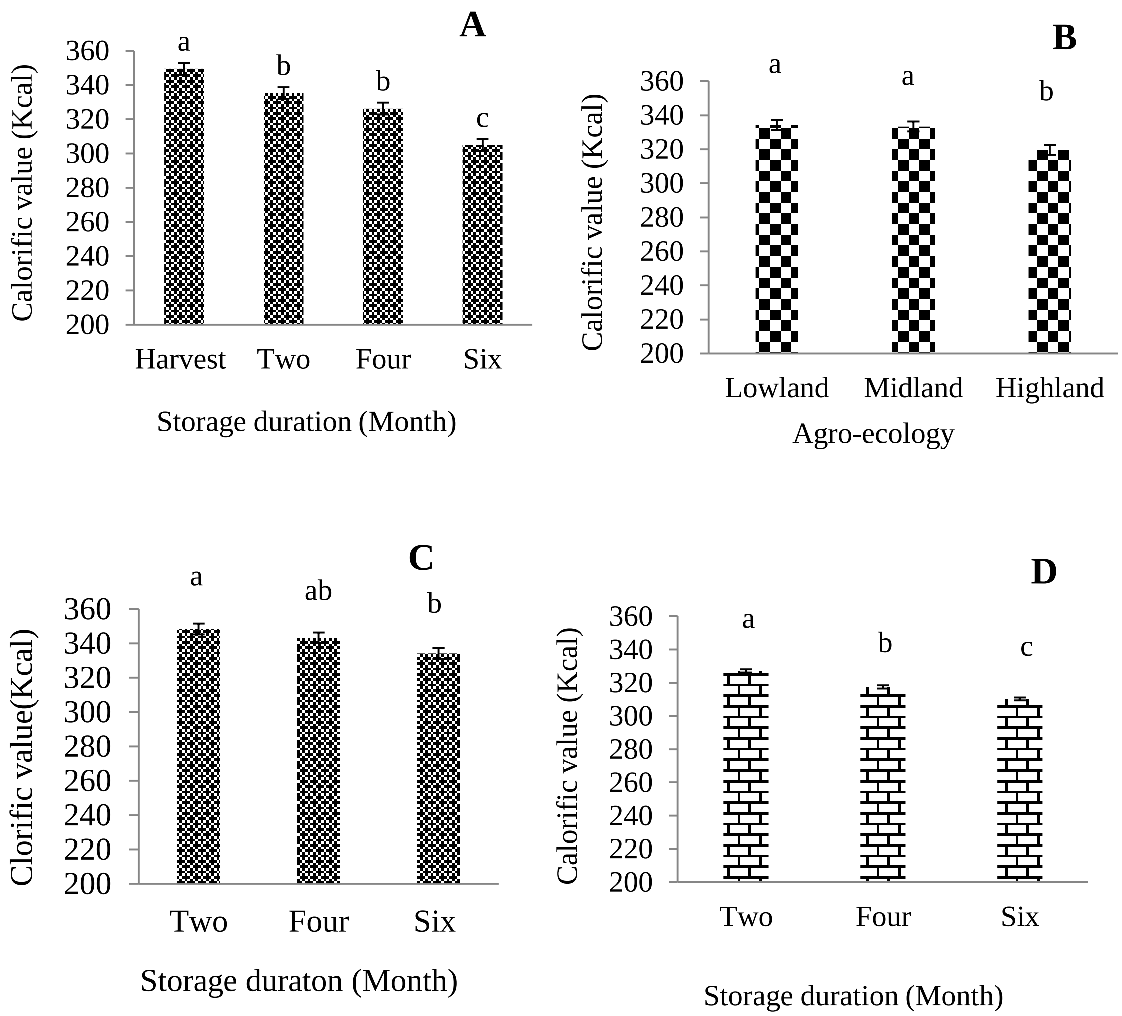


Figure 19: Calorific value of maize A) Stored under farmers storage along the storage duration B) under farmers storage at different agro-ecologies C) Stored under collectors storage along the storage duration and D) Stored under wholesalers storage along the storage duration

P-values = Farmers P <0.0001 for storage duration and P=0.003 for agro-ecology; Collector P= 0.01 and Wholesaler P< 0.0001for storage durations

Values are mean ±SE of triplicate samples and means with the same letter(s) no significant difference among each other at P<0.05

4.2.5.4. Determination of some minerals content of stored maize

Storage duration and different altitude of agro-ecologies were showed significant ($P<0.05$)interaction effect on Fe, P and Ca content of maize stored under farmers and collectors storage. However, Zn content was significantly affected by both storage duration and altitudinal change of agro-ecologies for each separately(Appendix table 9&10).The mineral content of maize stored under wholesalers storage also significantly ($P=0.05$) affected by storage duration (Appendix table 11).

Calcium, iron and zinc content were increased along the storage period. From farmers sample the highest and the lowest calcium content was recorded in lowland agro-ecology initially at harvest it was 2.9±2.3mg/100g of sample and it was increased to 77.1 ±2.3mg/100g after six month storage (Table 17). For collectors' sample, calcium content was high in midland agro-ecology (67.1±12.5mg/100g) during six month storage period (Table 18). Similar trend were observed on wholesalers sample, it also increased along the storage duration (Figure 20A). The highest iron content was recorded after sixmonth storage in all actors' storage condition. Similarly, Zn content was showed increment along the storage time and the highest result was recorded after six month storage 1.9±0.1, 1.7±0.1and 1.7±0.1mg/100g of sample collected from farmers, collectors and wholesalers storage conditions, respectively (Table 17& 18 and, Figure 20 B). According to Farhan *et al.* (2013) selective feeding of insect larvae preferentially the endosperm part and resulted increment of mineral (Fe, Ca and Zn) content. Tongjura *et al.* (2010) reported that increments of calcium as a result of weevil infestation of stored maize.

However, the trend in phosphorus content was inconsistent along the storage period in farmers sample (Table 17). In collectors and wholesalers samples increment of phosphorus content along the storage duration were observed (Table 18& Figure 20 A). The highest value were recorded from farmers sample at harvest in highland agro-ecology (316.5±22.5 mg/100g); in collectors sample during 6th month storage in lowland agro-ecology (373.9±17.7 mg/100gm) and in wholesalers sample during 6th month storage 80.4±11.8 mg/100g (Table 17 to 18 and Figure 20). Enyisi *et al.* (2014) reported that mineral content was much higher in maize bran however the carbohydrate content of maize bran was lower and storage pests mainly depend on carbohydrate for their growth. Similarly, Mashilla *et al.* (2004) stated that due to selective feeding of fungi especially the carbohydrate from organic matter of sorghum grain ash content was increased along the storage duration; this also observed in current study and may resulted increment of mineral content.Furthermore, weight loss occurred as a result of storage pest damage may result in increment of amount of sample per gram and this may cause increment in mineral content along the storage duration. weight loss ofmaize stored under traditional storage(gombissa) in Jimma zone with the range of 41 to 80% as a result of storage insect damage between three to six months were reported by Waktole and Amsalu (2012) Similarly under traditional farmers storage 2.33% weight loss in maize cob and 3.10% winnowed and botanical (*Hyptis spicigera)*treated maize grain due to damage by storage pests were reported by (Gueye, 2013). Tadele *et al*. (2011) also reported 6.8% to 67.1% weight loss of stored maize due to insect damage (Tadele *et al*., 2011).

Table 17: Mineral content of maize grain stored under farmers storage

Response variables	Agro-ecology	Storage duration (Month)				Agro-ecology effect	P-value
		At harvest	Two	Four	Six		
Fe (mg/100g)	Lowland	0.6 ± 0.3^{de}	$1.3\pm0.3^{c-e}$	$2.9\pm0.3^{a-c}$	4.3 ± 0.3^{a}		0.01
	Midland	0.5 ± 0.3^{e}	$1.9\pm0.3^{b-e}$	$2.4\pm0.3^{b\,c}$	4.4 ± 0.3^{a}		
	Highland	0.4 ± 0.3^{e}	$2.0\pm0.3^{b-e}$	$3.5\pm0.3^{a\,b}$	$4.7\pm0.3^{a-c}$		
Zn (mg/100g)	Lowland					1.2 ± 0.1^{b}	0.001
	Midland					1.2 ± 0.1^{b}	
	Highland					1.5 ± 0.1^{a}	
Storage duration effect		0.4 ± 0.1^{c}	1.3 ± 0.1^{b}	1.5 ± 0.1^{b}	1.9 ± 0.1^{a}		<.0001
Ca (mg/100g)	Lowland	2.9 ± 2.3^{g}	13.3 ± 2.3^{fg}	43.0 ± 2.3^{c}	77.1 ± 2.3^{a}		<.0001
	Midland	3.2 ± 2.3^{g}	18.8 ± 2.3^{ef}	30.2 ± 2.3^{de}	60.4 ± 2.3^{b}		
	Highland	6.6 ± 2.3^{g}	$23.9\pm2.3^{e\,f}$	$38.5\pm2.3^{c\,d}$	55.2 ± 2.3^{b}		
P (mg/100g)	Lowland	$261.2\pm22.6^{a-c}$	$221.1\pm22.6^{a-d}$	$291.9\pm22.6^{a\,b}$	107.9 ± 22.6^{de}		0.002
	Midland	$261.5\pm22.6^{a-c}$	$230.4\pm22.6^{a-c}$	$195.5\pm22.6^{b-d}$	57.3 ± 22.6^{e}		
	Highland	316.5 ± 22.6^{a}	$209.6\pm22.6^{a-d}$	$167.9\pm22.6^{c-e}$	67.4 ± 22.6^{e}		

Values are mean ±SE triplicate samples

Means with the same letter(s) are no significantly different among each other at P< 0.05 along storage duration and agro-ecologies for Fe, Ca and P; along the storage duration only or agro-ecologies for Zn

Table 18: Mineral content of maize grain stored under collectors storage in the study areas

Response variables	Agro-ecology	Storage duration (Month) Two	Four	Six	Agro-ecology effect	P-value
Fe (mg/100g)	Lowland	3.4±0.3 [c d]	4.1±0.3 [b-d]	7.5±0.3[a]		0.02
	Midland	2.7±0.3 [d]	3.4±0.3[cd]	5.6±0.3 [b]		
	Highland	2.9±0.3[cd]	4.6±0.3 [b c]	5.3±0.3[b]		
Zn (mg/100g)	Lowland				1.5±0.1[a]	0.0006
	Midland				1.2±0.1[b]	
	Highland				1.4±0.1[a]	
Storage duration effect		1.1±0.1[c]	1.3±0.1[b]	1.7±0.1[a]		<.0001
Ca (mg/100g)	Lowland	23.4±2.5 [ef]	32.9±2.5 [de]	53.9±2.1 [bc]		0.006
	Midland	18.3±2.5 [f]	30.1±2.5[d-f]	67.1±2.5 [a]		
	Highland	23.3±2.5[ef]	41.3±2.5 [cd]	61.0±2.5[ab]		
P (mg/100g)	Lowland	167.7±17.7 [c]	257.7±17.7[b]	373.9±17.7[a]		0.04
	Midland	52.2±17.7 [d]	139.6±17.7[cd]	178.2±17.7 [b c]		
	Highland	67.2±17.7[d]	206.9±17.7 [b c]	214.3±17.7 [b c]		

Values are mean ±SE triplicate samples

Means with the same letter(s) are no significantly different among each other at P< 0.05 along storage duration and agro-ecologies for Fe, Ca and P; along the storage duration only or agro-ecologies for Zn

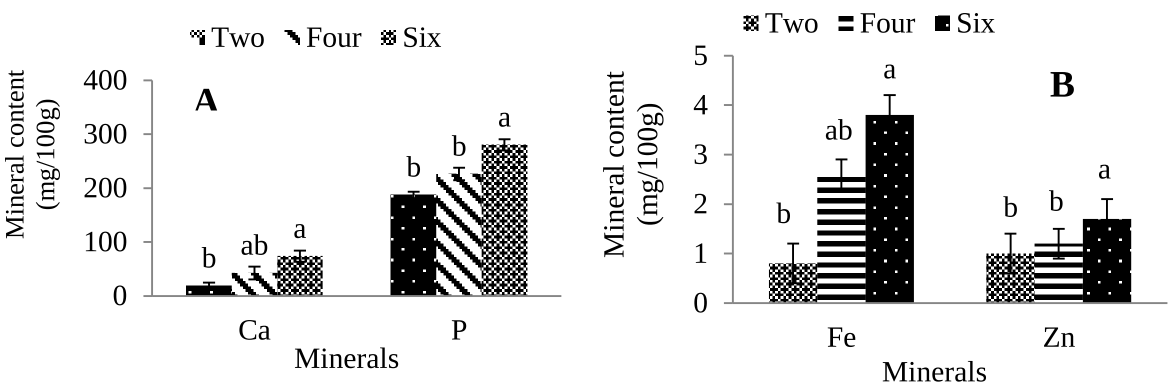


Figure 20: Mineral content of maize stored under wholesalers storage **A)** Phosphorus and calcium and **B)** Iron and zinc

P= 0.001 for Ca; P=0.004 for P; P=0.009 for Fe and P=0.007 for Zn

Values are mean ±SE of triplicate samples and means with the same letter (s) for each response variables across storage duration are not significant different among each other at P<0.05

4.2.5.5. Anti-nutrient content of stored maize

The phytate content of maize stored under farmers storage was significantly (P=0.05) affected by length storage duration and change in different altitudinal agro-ecologies (Appendix table 26).The highest phytate content was recorded from maize stored under farmers' storage in highland altitudinal agro-ecology (120.9±4.3mg/100gm). The trend in phytate content was inconsistent along the storage period under farmers' storage condition; however the highest result was recorded during 4th month storage (113.6±5.0 mg/100g) (Figure 21 A & B).Duration of storage period and agro-ecology have a highly significant (P<0.0001) interaction effect on condensed tannin content of maize stored under farmers storage. However, the highest tannin content was registered at harvest in lowland agro-ecology (3.9±0.2mg/100gm) but statistically similar with value which recorded at harvest in midland and highland agro-ecology (Figure 21C).Under wholesalers' storage condition both phytate and tannin were not significant affected by storage duration. However, the result of maize sampled from collectors store were showed a significant (P<0.01) interaction effect of storage duration and altitudinal agro-ecologies on anti-nutrient content of stored maize. Both tannin and phytate contents decrease as the storage duration increase (Figure 22 A&B). However, the highest anti-nutrient content was recorded from maize storage in highland altitudinal agro-ecology during 2nd month storage as 143.7±6.2

and 13.6±0.3 (Figure 22A&B) mg/100g of phytate and tannin, respectively.Study conducted in Pakistan reported that anti-nutrient content of different maize varieties with the range of 30.0±0.03 to 33.3±7.8mg/100gm tannin and 330.6±1.8 to 670.7±5.6 mg/100gm phytate (Hassan*etal.*, 2009).Similarly,Hambidge*et al*. (2004) reported phytate contentof different variety of maize grain grown in North America with the range of 380±0.1 to 750±1.1 mg/1001g in dry weight.Akaninwor and Okechukwu (2004) reported 64.4 and 0.10 mg/100gm of average phytate and tannin content of maize flour with moisture content of 8.9±1.2; as compared with current result it is lower due to the concentration of phytate in matured cereal grain largely depend plant nutrient consumption and its stage of maturity at harvest (Oberleas, 1973).

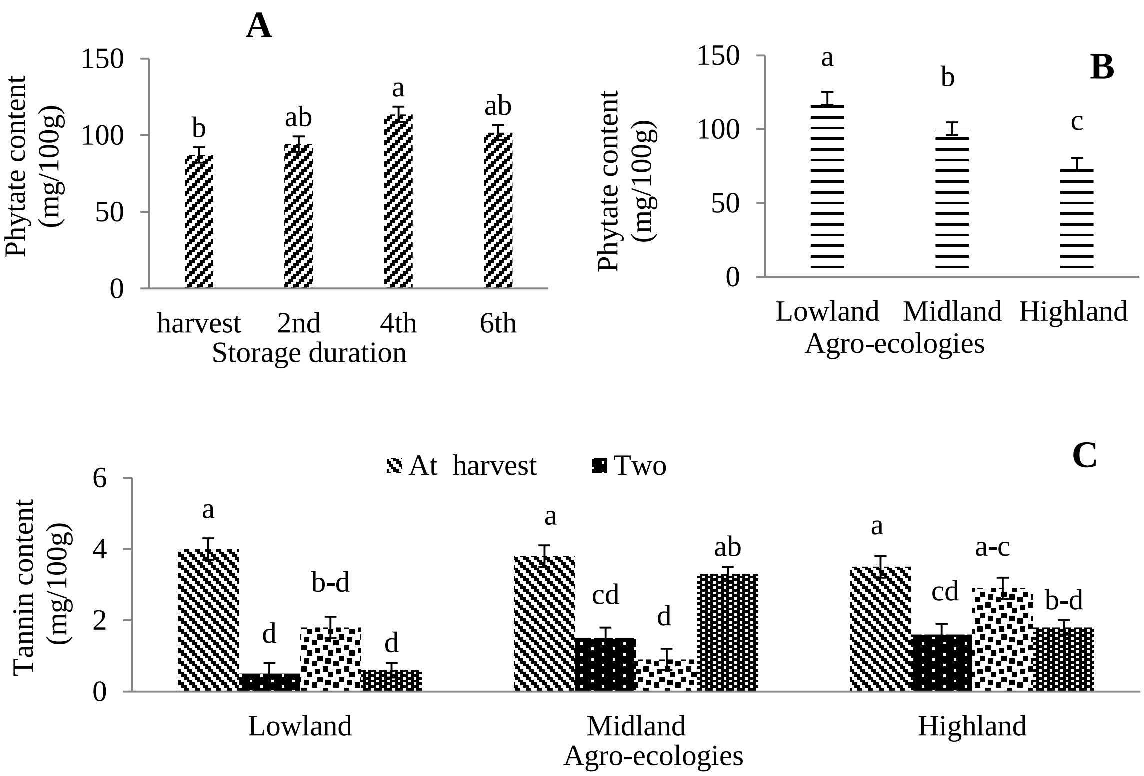


Figure 21: Anti-nutrient content of maize stored under farmers' storage A) Phytate along the storage duration; B) Phytate in different agro-ecologies and C) Tannin along the storage duration in different agro-ecologies

P-value = for phytate P=0.007 storage duration and P<.0001 different agro-ecologies and Tannin P<.0001

Values are mean ± SE of triplicate samples and means with the same letter (s) for each response variables are not significant different among each other at P<0.05 along the storage duration

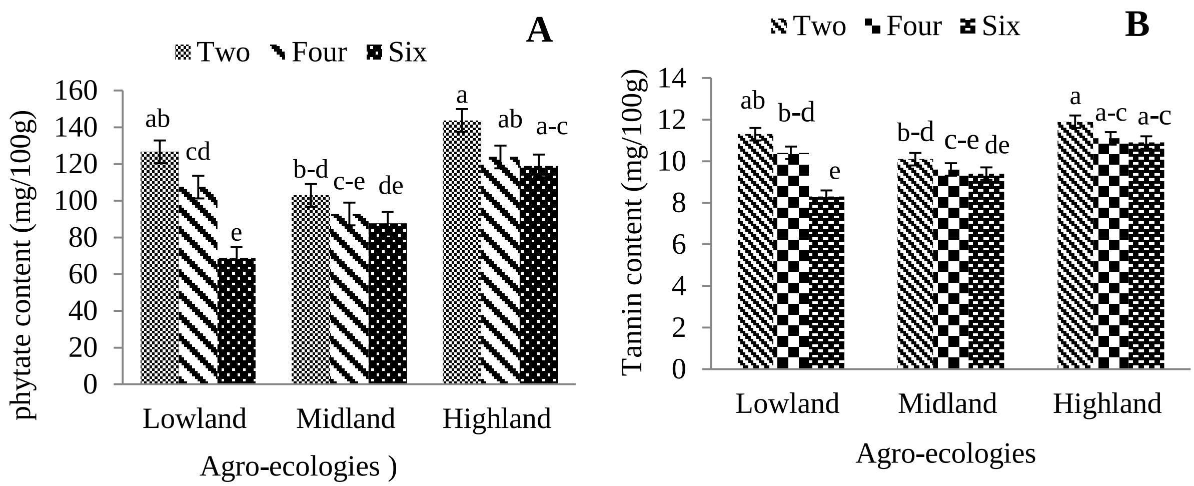


Figure 22: Anti-nutrient content of maize stored under collectors' storage A) Phytate content and B)Tannin content

P-value = for phytate P= 0.01 and P=0.01 for tannin

Values are mean ± SE of triplicate samples and means with the same letter (s) for each response variables across storage duration are not significant different among each other at P<0.05 across the storage duration

4.2.6. Correlation analysis of selected response variables

Mould incidence, mould severity and insect damage were showed a positive and significant correlation each other in all stages (farmers, collectors and wholesalers) of maize value chain (Table 19, 20 & 21). For instance at farmers stage mould incidence and mould severity were positively(r=0.94) and significantly (P=0.0002) correlated each other. Similarly, mould severity and insect damage (r=0.46) also positively and significantly (P=0.01) correlate each other.This shows that the damage caused by insect pests favour the development of storage fungi through the damaged caused by insect pest serve as entry for fungi and insect pests disseminate spore of fungi further more, metabolic process of insect pests favour the storage condition for fungi development through increasing the temperature of the store (Kankolongo *et al*., 2009 and Suleiman *et al*., 2013).

However, mould incidence, mould severity and insect damage were negatively correlated with germination, carbohydrate, calorific value and proximate composition except fiber and ash in all stages (farmers, collectors and wholesalers) of maize value chain (Table 19, 20 & 21).Under farmers storage condition proximate composition except fiber and ash negatively correlated with mould incidence, mould severity and insect damage. Fiber content positively and significantly correlated with mould incidence in cob(r=0.54 and P=0.004), mould severity (r=0.78 and P<.0001) and insect damage(r=0.60 and P=0.0009). Fat content negatively and significantly correlated with mould incidence in cob (r=-0.58 and P=0.007) and mould severity (r=-0.71 and P=<.0001). However, moisture protein and ash were not significantly correlated. Carbohydrate content were negatively and significantly (r=-0.59 and P=0.001) mould incidence and severity(r=-0.74 and P<.0001). Similarly calorific value were negatively and significantly correlated with mould incidence (r=-0.60 and P=0.0009), mould severity (r=-0.84 and P<.0001) and insect damage (r=-0.38 and=0.04)(Table19). Almost similar trend were observed under collectors and wholesalers stage (Table20 and 21). This shows that the damage caused by storage pests resulted declining of organic matter of stored maize and finally resulted increments of fiber and ash content (Mashilla *et al.* 2004 ; Yakubu, 2009; Farhan *et al.*, 2013;Rashad *et al.,* 2013)

Mineral content (Zn, Fe and Ca) except phosphorus positively correlated with insect and mould damage in all stages of maize supply chain which covered by current study. However, phosphorus was positively correlated with mould incidence and severity under collectors and wholesalers storage condition whereas, negative under farmers storage condition. However, Anti-nutrients such as: - Phytate negative and significantly correlated (r=-0.57 and 0.006) with moisture under farmers condition however, under collectors condition positive and non-significant. Under farmers condition tannin content negative and under collectors' condition it is positive and in both case non-significantly correlated with moisture content (Table 19& 20). The positive correlation of storage pest damage and mineral content shows that the increment of mineral as a resalt of storage pest damage. The main reason for increments of minerals (Ca, Fe and Zn) was selective feeding of storage pests especially carbohydrate part which is high in endosperm part of maize grain and low in pericarp due to this the pericarp less damaged which is high in mineral content and finally resulted increment of mineral contentofstoredmaize (Golob *et al*.,2002;Rashad*etal.*,2013).

Table 19: Pearson correlation coefficients of response variables determined on farmers sample

Var	Fib	Moi	Pro	Fat	Ash	Fe	Zn	Ca	P	CHO	Cal	Phy	Tan	Ger	Ins	IC	IK	Siv
Fib	1.00																	
Moi	-0.35ns	1.00																
Pro	-0.41*	0.27^{ns}	1.00															
Fat	-0.57**	0.04^{ns}	0.18^{ns}	1.00														
Ash	0.37*	-0.25^{ns}	-0.35ns	0.18^{ns}	1.00													
Fe	0.74**	-0.33^{ns}	-0.43*	-0.46*	0.44^{ns}	1.00												
Zn	0.65**	0.03^{ns}	-0.28^{ns}	-0.75**	0.35^{ns}	0.58**	1.00											
Ca	0.79**	-0.20^{ns}	-0.40*	-0.56**	0.58**	0.75**	0.76**	1.00										
P	-0.68**	0.03^{ns}	0.54**	0.60**	-0.15^{ns}	-0.53**	-0.68**	-0.65**	1.00									
CHO	-0.48*	-0.24^{ns}	0.19^{ns}	0.49*	-0.01^{ns}	-0.22^{ns}	-0.58**	-0.46*	0.56**	1.00								
Cal	-0.62**	-0.10^{ns}	0.45*	0.68**	0.15^{ns}	-0.41*	-0.71**	-0.59**	0.71**	0.93**	1.00							
Phy	0.17^{ns}	-0.57**	-0.13^{ns}	0.26^{ns}	0.37^{ns}	0.30^{ns}	-0.14^{ns}	0.21^{ns}	0.15^{ns}	-0.42*	0.35^{ns}	1.00						
Tan	0.40*	-0.18^{ns}	-0.04^{ns}	-0.61**	-0.03^{ns}	0.40*	0.52**	0.25^{ns}	-0.29^{ns}	-0.22^{ns}	-0.34^{ns}	0.01^{ns}	1.00					
Ger	-0.70**	0.08^{ns}	0.38^{ns}	0.63**	-0.48*	-0.50**	-0.80**	-0.79**	0.74**	0.69**	0.78**	0.01^{ns}	-0.31^{ns}	1.00				
Ins	0.60**	-0.26^{ns}	-0.28^{ns}	-0.23^{ns}	-0.43*	0.48*	0.45*	0.78**	-0.54**	-0.32^{ns}	-0.38*	0.33^{ns}	-0.07^{ns}	-0.71**	1.00			
IC	0.54**	-0.01^{ns}	-0.09^{ns}	-0.50**	-0.09^{ns}	0.40*	0.49*	0.49**	-0.36^{ns}	-0.59**	-0.60**	-0.36^{ns}	0.40*	-0.42*	0.27^{ns}	1.00		
Ik	0.68**	-0.03^{ns}	-0.35^{ns}	-0.58**	-0.28^{ns}	0.46*	0.77**	0.67**	-0.76**	-0.74**	-0.81**	-0.23^{ns}	0.35^{ns}	-0.81**	0.5**	0.85**	1.00	
Sev	0.78**	-0.08^{ns}	-0.35^{ns}	0.71**	-0.35^{ns}	0.56**	0.79**	0.72**	-0.75**	-0.74^{ns}	-0.84**	-0.19^{ns}	0.46*	-0.80**	0.46*	0.67**	0.94**	1.00

Var= variable Fib=fiber Moi=moisture Pro=Protein CHO= Carbohydrate Cal =Calorific value Tan= tannin Ger=germination Ins= weevil damage IC = mould incidence on cob IK= mould incidence on kernel Sev = mould severity

Table 20: Pearson correlation coefficients of response variables collected from collectors sample

Var	Fib	Moi	Pro	Fat	Ash	Fe	Zn	Ca	P	CHO	Cal	Phy	Tan	Ger	Ins	IK	Siv
Fib	1.00																
Moi	-0.43*	1.00															
Pro	-0.22^{ns}	0.37^{ns}	1.00														
Fat	-0.63**	0.60**	0.27^{ns}	1.00													
Ash	0.58**	-0.44*	-0.67**	-0.43*	1.00												
Fe	0.58**	-0.49**	-0.62**	-0.57**	0.69**	1.00											
Zn	0.61**	-0.49**	-0.31^{ns}	-0.54*	0.46*	0.71**	1.00										
Ca	0.72**	-0.65**	-0.59**	-0.79**	0.69**	0.77**	0.71**	1.00									
P	0.58**	-0.45*	-0.48*	-0.36^{ns}	0.49*	0.79**	0.71**	0.54*	1.00								
CHO	-0.69**	-0.45*	0.0.5^{ns}	-0.55*	-0.33^{ns}	-0.33^{ns}	-0.49*	-0.51*	-0.38*	1.00							
Cal	-0.93**	-0.35^{ns}	0.19^{ns}	-0.57**	-0.54**	-0.47*	-0.49*	-0.63**	-0.42*	0.64**	1.00						
Phy	-0.19^{ns}	0.26^{ns}	0.75**	0.16^{ns}	-0.46*	-0.55**	-0.22^{ns}	-0.38*	-0.51**	-0.17^{ns}	-0.10^{ns}	1.00					
Tan	-0.19^{ns}	0.25^{ns}	0.75**	0.17^{ns}	-0.47*	-0.57**	-0.23^{ns}	-0.39*	-0.52**	-0.16**	-0.11^{ns}	0.99**	1.00				
Ger	-0.53*	0.37^{ns}	0.72**	0.43*	-0.47*	-0.71**	-0.54*	-0.63**	-0.73**	0.13^{ns}	0.45*	0.64**	0.65**	1.00			
Ins	0.69**	-0.76**	-0.47*	-0.73**	0.62**	0.67**	0.74**	0.87**	0.51*	-0.63*	-0.55**	-0.34^{ns}	-0.33^{ns}	-0.51*	1.00		
Ik	0.59**	-0.49*	-0.68**	-0.39*	0.52**	0.79**	0.64**	0.66**	0.82**	-0.15^{ns}	-0.37^{ns}	-0.69**	-0.70**	-0.87**	0.57*	1.00	
Sev	0.43*	-0.70**	-0.16^{ns}	-0.59**	0.27^{ns}	0.24^{ns}	0.37^{ns}	0.58**	0.10^{ns}	-0.59**	-0.34^{ns}	0.05^{ns}	0.06^{ns}	-0.11^{ns}	0.71**	0.81**	1.00

Table 21: Pearson correlation coefficients of selected response variable collected at wholesalers

Var	Fib	Moi	Pro	Fat	Ash	Fe	Zn	Ca	P	CHO	Cal	Phy	Tan	Ger	Ins	IK	Siv
Fib	1.00																
Moi	-0.92**	1.00															
Pro	-0.65^{ns}	0.61^{ns}	1.00														
Fat	-0.72*	0.63^{ns}	0.86**	1.00													
Ash	0.77*	-0.89**	-0.74*	-0.62^{ns}	1.00												
Fe	0.53^{ns}	-0.67*	-0.74*	-0.76*	0.64^{ns}	1.00											
Zn	0.68*	-0.67*	-0.82**	-0.80**	0.58^{ns}	0.80**	1.00										
Ca	0.64^{ns}	-0.75*	-0.77**	-0.65*	0.72*	0.78**	0.80**	1.00									
P	0.72*	-0.79*	-0.83**	-0.76*	0.92**	0.72*	0.71*	0.64*	1.00								
CHO	-0.68*	-0.83**	0.49^{ns}	0.37^{ns}	-0.83**	-0.39^{ns}	-0.53^{ns}	-0.73**	-0.68*	1.00							
Cal	-0.80**	-0.81**	0.93*	0.78*	-0.87**	-0.74**	-0.85**	-0.86**	-0.89**	0.75**	1.00						
Phy	0.02^{ns}	-0.05^{ns}	0.51^{ns}	0.24^{ns}	-0.12^{ns}	-0.15^{ns}	-0.35^{ns}	-0.52^{ns}	-0.11^{ns}	0.18^{ns}	0.39^{ns}	1.00					
Tan	0.66*	-0.61^{ns}	-0.74*	-0.88**	0.69*	0.60^{ns}	0.68*	0.44^{ns}	0.88**	-0.47^{ns}	-0.79*	-0.08^{ns}	1.00				
Ger	-0.38^{ns}	0.20^{ns}	0.55^{ns}	0.62^{ns}	-0.17^{ns}	-0.30^{ns}	-0.68*	-0.26^{ns}	-0.44^{ns}	0.18^{ns}	0.51^{ns}	0.15^{ns}	-0.61^{ns}	1.00			
Ins	0.73*	-0.80**	-0.78*	-0.77*	0.77*	0.75*	0.90**	0.85**	0.82**	-0.78**	-0.91**	-0.34^{ns}	0.77*	-0.49^{ns}	1.00		
Ik	0.53^{ns}	-0.67*	-0.70*	-0.75*	0.66*	0.89**	0.84**	0.74**	0.77*	-0.53*	-0.77**	-0.24^{ns}	0.74*	-0.37^{ns}	0.90**	1.00	
Sev	0.75*	-0.78*	-0.91**	-0.89**	0.79*	0.89**	0.89**	0.86**	0.84**	-0.57*	-0.93**	-0.37^{ns}	0.77*	-0.41^{ns}	0.89**	0.89**	1.00

5. SUMMERY AND CONCLUSION

Maize is the largest and most productive crop in Ethiopia and it is preferred crop for the food security of the country households due to its lowest cost caloric source among all major cereals. Maize ranked first as important food and feed crop around Jimma zone. However, most of the farmers (67.9%) in the study area produce maize for household consumption and surplus product sold mostly at local market with lower price. Furthermore, harvested maize lost due to poor post-harvest management activities such as insect pests, storage fungi and rodent. Due to fear of risk loss in the store surplus product sold immediately after harvest when the price is low. Local assembler/ collectors were collect maize from farmers and sold for Jimma wholesalers. However, only less volume of maize were transport to Addis Ababa market the main reason for this was quality of maize grain such as discoloration and insect damage.

Around twelve post-harvest activities were practiced by farmers in Jimma zone (study sites). However, most of the activities are less effective to preserve harvested maize quality and resulted in large volume of post- harvest loss. Post-harvest loss mentioned by the respondents includes bad weather during harvest or by insect pests, storage fungi, rodents, wild animal, domestic animals and theft. Losses in storage were accelerated by late harvesting, high grain moisture content, poor storage facilities, rodents, storage insect pests and fungi. According to respondent farmers in the study area the highest estimated post-harvest loss occurred during storage period mainly because of insect pest, storage fungi and rodents damage.

In the study area basically three maize storage system (*gombisa*,modified and bag storage) were identified. However, the material used for construction of storage structures were vary depending on availability and financial capacity of the farmers; most of the farmers were use *gombisa* which constructed from bamboo(40.9%) or *Soyam* (26.4%) and the roof was covered with grass. Less number of farmers was used modified structures which mostly constructed from eucalyptus wood and the roof was covered either with grass or corrugated iron and; mostly it has window. Such type of storage structure common in Mana district (midland agro-ecology). Most of the farmers store maize cob after removing sheath in the *gombisa* on the other hand storing maize with sheath was common in Sokoru district which is the lowland part of the study area mainly to protect stored maize from storage insect pests' damage. However, traditional storage structures are less protective from external environmental condition and storage pests' further more poor management of stored maize resulted highestestimated loss during storage(17.75±9.07) as compared to other post-harvest management activities.

Both incidence and severity of mould was higher in highland part of the study area as a result of high grain moisture content and humidity in highland agro-ecology which might be conducive for mould infection. Also, both mould incidence and frequencywere increased along the storage duration in all studied value chain.

In current study totally seven fungi genera were identified. However, *Fusarium* spp. (100.0%), *Pencillium* spp. (68.5%) and *Aspergillus* spp. (43.0%) were important toxigenic fungi genera which were predominantly identified from sample collected from farmers, collectors and wholesalers storages around Jimma zone. Whereas, *Phoma* spp., *Geotrichum* spp., *Cloudosporium*spp. and*Drechslera* spp. was less frequently identified fungi genera however, *Drechslera* spp.were identified only from farmers and collectors sample.

The trend showed that *Fusarium* spp. was relatively decreased however; *Aspergillus andPencillium* spp. were relatively increased along the storage durationin all studied stages of maize value chain; this mainly associated with the declining of grain moisture content along the storage period favour the development of storage fungi such as *Aspergillus* and *Pencillium* spp.

The proximate composition result showed that moisture content of stored maize were decrease as the storage duration increase in all stages of studied maize value chain, except in farmers condition at the end of data collection it shows increments mainly due to rainy condition and traditional farmers storage structure *"gombisa"* not effective in protection of stored maize from external environment. Protein and fat content were significantly decreased along the storage duration.Furthermore, the lowest protein and fat percentage were recorded from maize sample collected from highland part of the study area in both farmers and collectors' storage condition mainly due to higher mould incidence and severity on maize sampled from highland agro-ecology of the study sites.

However, fiber and ash content were showed increment along the storage period. Similar trend were observed in same mineral content including Fe, Ca and Zn were increase along the storage period. Increments in mould and insect damage were observed along the storage period and selective feeing of storage pest mainly the organic matter which is high in endosperm part and low in pericarp of maize grain may resulted reduction of organic matter and increments in ash, fiber and mineral content of stored maize which are higher in pericarp of maize grain.

Significant effect of storage duration was observed on carbohydrate and calorific value of maize stored under all actors' storage condition. The highest carbohydrate and calorific value were recorded from farmers sample at loading stage and it was 69.5±0.4% and 353.8±2.8 Kcal after six month storage both declined to 66.5±0.4% and 325.5±2.8 Kcal, respectively. The trend shows that declining of both carbohydrate and calorific value along the storage duration under all actors' storage conditions as a result of significant increment of mould incidence and severity along the storage period under all actors' storages. The lowest carbohydrate and caloriecontent were recorded from highland agro-ecology under farmers and collectors storage conditionswhich resulted due to higher mould incidence and severity in highland agro-ecology as compared to lowland and midland agro-ecologies of the study areas. Carbohydrate and calorific value were negatively and significantly correlated with mould incidence, severity and weevil damage under storage condition of all actors of maize supply chain.

Generally, current study finding reviled that most of post-harvest management practices are not effective to preserve harvested maize quality and toxigenic fungal pathogens such as *Fusarium*, *Asperigillus* and *Pencillium* spp. were important in stored maize in the study areas under farmers', collectors' and wholesalers' storage conditions. The nutrient composition of stored maize especially protein, fat, carbohydrate and calorific value were declined along the storage duration as a result of damage caused by storage pests furthermore, those nutrients were low in highland parts of the study areas due to higher mould development on maize stored under highland agro-ecology in both farmers and collectors storage conditions.

6. RECOMMENDATION

Despite the government efforts to help farming communities through the provision of extension service in the study area , less attention have been given for post-harvest technologies and practices due to this and other related reasons large volume of maize is lost after harvest. However, reduction of on-farm post-harvest losses is directly increase smallholder income and improves food security. Therefore, post-harvest management practices such as; optimal harvesting time, drying techniques, maize shelling method and storage management techniques need to be improved and should be disseminated through the extension system.

Beating maize with stick will results in physical damage which makes it more vulnerable to pests and moulds growth; therefore useof maize shellers machines should be adopted to avoid such type of damage. There are a number of post-harvest technologies and many of these have great potential to reduce post-harvest losses but those technologies are not available for farmers. Therefore; the government, NGOs and other stakeholders should give attention to aware the farmers about those technologies and disseminate those technologies which can measurably improve the income of smallholder farmers through reduction of post-harvest loss of maize.

The storage structures used in study area are resulted in high levels of post-harvest losses so, there is a need to develop and disseminate appropriate technologies to reduce these losses. Increasing farmer awareness about effective on-farm storage techniques via training (through more interactive channels like practical training at FTCs), using public media such as radio and such awareness should be matched by convenient access to appropriate storage techniques like; metal silos, etc. Furthermore, additional research should be conducted to improve local on-farm storage structures. Generally, integrated approach of post-harvest loss reduction including evaluation of different maize varieties grown in the area to develop variety tolerate or resist insect pest damage and mould development.

Infection of maize grain by storage fungus results in discoloration, dry matter loss, chemical and nutritional changes and overall reduction of maize grain quality. Fungal pathogens are a major maize production challenge as well as it is a serious problem in maize trading system around Jimma zone. Currently, contamination of maize grain with fungal pathogens are regarded as one of the most serious safety problems in the tropical countries and throughout the world due to production of mycotoxin by most toxigenic fungi among which *Aspergillus*, *Pencilluim* and *Fusarium* are most important. Those three fungi genera were predominantly identified from maize stored under all actors of maize value chain which covered by current study. Therefore; farther investigation were needed regarding to determination and quantification of mycotoxins level associated with those fungi genera from maize stored under all actors of maize value chain and in different agro-ecologies of Jimma zone. Furthermore, attention should be given about increasing awareness of maize value chain actors regarding to cause and control method as well as health impact of toxigenic fungi.

The nutrient content of stored maize especially protein, fat, carbohydrate and calorific value were decreased as a result of storage pest damage.Therefore, attention should be given training farmers about the effect of storage pests on nutritional quality of stored maize and the training should be aligned with introduction of appropriate technologies which helps to preserve harvested maize quality.

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APPENDICES

Appendix A: List of tables

Appendix table 1: ANOVA for grain moisture content germination, weevil damage, incidence and severity of mould on maize collected from farmers' store

Response variables	Source	P-value	C v %
Grain moisture content	SD	<.0001	7.0
	AG	<.0001	
	AG*SD	0.0141	
Germination percentage	SD	<.0001	6.1
	AG	<.0001	
	AG*SD	0.0119	
Weevil damage	SD	<.0001	29
	AG	<.0001	
	SD*AG	0.3633	
Mould incidence in cob	SD	<.0001	21.8
	AG	<.0001	
	SD*AG	0.3453	
Mould incidence in kernel	SD	<.0001	20.9
	AG	<.0001	
	SD*AG	0.00136	
Mould severity	SD	<.0001	17.9
	AG	<.0001	
	SD*AG	0.3633	

Appendix table 2: ANOVA for grain moisture content germination, weevil damage, incidence and severity of mould on maize sampled from collectors' store

Response variables	Source	P-value	C v %
Grain moisture content	SD	<.0001	3.8
	AG	<.0001	
	AG*SD	0.6953	
Germination percentage	SD	<.0001	10.9
	AG	<.0001	

	AG*SD	0.2841	
Weevil damage	SD	<.0001	26.0
	AG	<.0001	
	SD*AG	0.0007	
Mould incidence in kernel	SD	<.0001	17.5
	AG	<.0001	
	SD*AG	0.0005	
Mould severity	SD	<.0001	17.7
	AG	<.0001	
	SD*AG	0.377	

Appendix table 3: ANOVA for grain moisture content germination, weevil damage, incidence and severity mould on maize kernel collected from whole seller's store

Response variables	**Source**	**P-value**	**Cv%**
Germination	SD	0.0012	8.8
Weevil damage	SD	0.0021	40.0
Incidence of mould on maize grain	SD	0.0017	13.3
Severity of mould on maize grain	SD	<.0001	11.6
Maize grain moisture content	SD	0.0202	2.9

Appendix table 4: Fungi colony color isolated from maize grain stored under farmers condition

Colony colour		Isolated fungi genera						
Front	**Reverse**	***Fusarium* spp.**	***Pencillium* spp**	***Aspergillus* spp.**	***Phoma* spp.**	***Geotrichum* Spp.**	***Cludosporium* spp.**	***Drechselera* spp.**
White	light salmon	137.5±43	-	-	-	-	-	-
deep pink	Salmon	13.3±7	-	-	-	-	-	-
Pink	salmon	85.7±18	-	-	-	-	-	-
Light pink	Hot pink	99.5±20	-	-	-	-	-	-
orange	dark orange	7.7±2.7	-	-	-	-	-	-
Light Salmon	Salmon	8.5±3.0	-	-	-	-	-	-
Pale Goldenrod	Dark goldenrod	11.5±4.5	-	-	-	-	-	-
Navajo white	Tan	91.7±31.7	-	-	-	-	-	-
Wheat	Burly wood	9.8±4.5	-	-	-	-	-	-
Salmon	brown	5±1.7	-	-	-	-	-	-
Rosy brown	Chocolate	46.5±23.4	-	-	-	-	-	-
Tomato red	Salmon	1.8±0.7	-	-	-	-	-	-
Violate red	pale violet red	1.8±1.8	-	-	-	-	-	-
Auatic 2	Saddle brown	1.7±1.8	-	-	-	-	-	-
Indian red	brown	11.2±1.1	-	-	-	-	-	-
Lemon chiffon	light salmon	13.8±5.6	-	-	-	-	-	-
Bisique 3	Tan	9.3±3.1	-	-	-	-	-	-
Sea green	Dark Orange	-	59.2±38.6	14.2±6.6	-	-	-	-
dark sea green	yellow	-	112.7±34	10.4±4.7	-	-	-	-
Dark olive green	green yellow	-	8.8±5.6	1.0±0.6	-	-	-	-
Khaki green	Dark goldenrod	-	4.2±2.4	6.3±3.4	-	-	-	-
Dark khaki green	Orange red	-	5.5±0.5	-	-	-	-	-
Olive drab	yellow Green	-	3.3±0.3	-	-	-	-	-
Medium sea green	light Goldenrod	-	2.0±1.2	-	-	-	-	-
Yellowish green	Peru brown	-	-	1.8±0.9	-	-	-	-
Yellow	orange	-	-	5±1.2	-	-	-	-
Golden yellow	Golden yellow	-	-	17±6.1	-	-	-	-
Black	yellow	-	-	42±17.2	-	-	-	-
Dark green	yellow	-	-	13±9.2	-	-	-	-
Dark olive green	Salmon pink	-	-	-	1.8±0.8	-	-	-
white (cottony)	cornsilk3	-	-	-	-	10.7±4.5	-	-
dark salty gray	Dim gray	-	-	-	-	-	10.7±4.5	-
Dark olive green	Salty gray	-	-	-	-	-	20.8±9.9	-
Burly wood	Saddle brown	-	-	-	-	-	-	3.3±1.0
Total no. of isolates		2513	1204	667	11	64	189	20
Total no. of samples		270	270	270	270	270	270	270

Appendix table 5: Fungi colony color isolated from maize stored under collectors condition

Colony color		Fungi genera						
Front	Reverse	*Fusarium spp.*	*Pencillium spp.*	*Aspergillus spp.*	*Phoma spp.*	*Geotrichum spp*	*Cloudosporium spp.*	*Drechselera spp.*
White	light salmon	63.8±14.0	-	-	-	-	-	-
Deep pink	Salmon	5.6±3.7	-	-	-	-	-	-
Pink	Salmon	11.5±2.9	-	-	-	-	-	-
Light pink	Hot pink	28.5±8.6	-	-	-	-	-	-
Orange	dark orange	0.8±0.4	-	-	-	-	-	-
Light Salmon	Salmon	2.2±0.9	-	-	-	-	-	-
Pale Goldenrod	Dark goldenrod	3.7±0.9	-	-	-	-	-	-
Navajo white	Tan	25.7±2.6	-	-	-	-	-	-
Wheat	Burly wood	0.3±0.3	-	-	-	-	-	-
Salmon	brown	0.7±0.4	-	-	-	-	-	-
Rosy brown	Chocolate	8.3±0.6	-	-	-	-	-	-
Tomato red	Salmon	-	-	-	-	-	-	-
Violate red	pale violet red	-	-	-	-	-	-	-
Auatic 2	Saddle brown	-	-	-	-	-	-	-
Indian red	brown	0.8±0.2	-	-	-	-	-	-
Lemon chiffon	light salmon	5.0±1.8	-	-	-	-	-	-
Bisique 3	Tan	0.8±0.1	-	-	-	-	-	-
Sea green	Dark Orange	-	16.5±6.2		-	-	-	-
Dark sea green	yellow	-	45.0±11.2	2.7±1.0	-	-	-	-
Dark olive green	green yellow	-	-	-	-	-	-	-
Khaki green	Dark goldenrod	-	-	6.8±2.1	-	-	-	-
Dark khaki green	Orange red	-	4.5±0.3	-	-	-	-	-
Olive drab	yellow Green	-	-	-	-	-	-	-
Medium sea green	light Goldenrod	-	1.2±0.1	-	-	-	-	-
Yellowish green	Peru brown	-	-	-	-	-	-	-
Yellow	orange	-	-	2.3±0.7	-	-	-	-
Golden yellow	Golden yellow	-	-	11.7±5.0	-	-	-	-
Black	yellow	-	-	1.5±0.1	-	-	-	-
Dark green	yellow	-	-	-	-	-	-	-
Dark olive green	Salmon pink	-	-	-	6.7±1.3	-	-	-
White (cottony)	cornsilk3	-	-	-	-	4.8±0.6	-	-
Dark salty gray	Dim gray	-	-	-	-	-	6.7±0.3	-
Dark olive green	Salty gray	-	-	-	-	-	-	-
Burly wood	Saddle brown	-	-	-	-	-	-	1.0±0.0
Total no. of isolates		947	401	150	40	29	42	6
Total no. of samples		90	90	90	90	90	90	90

Appendix table 6: Fungi colony color isolated from maize stored under wholesalers condition

Colony color		Fungi genera					
Front	**Reverse**	***Fusarium spp.***	***Pencillium spp.***	***Aspergillus spp.***	***Phoma spp.***	***Geotrichum spp.***	***Cloudosporium spp.***
White	Light salmon	14.0±3.0	-	-	-	-	-
Deep pink	Salmon	0.6±0.1	-	-	-	-	-
Pink	Salmon	1.8±0.4	-	-	-	-	-
Light pink	Hot pink	3.0±1.4	-	-	-	-	-
Orange	Dark orange	0.3±0.1	-	-	-	-	-
Light Salmon	Salmon	-	-	-	-	-	-
Pale Goldenrod	Dark goldenrod	-	-	-	-	-	-
Navajo white	Tan	0.8±0.1	-	-	-	-	-
Wheat	Burly wood	4.8±0.4	-	-	-	-	-
Salmon	Brown	0.3±0.1	-	-	-	-	-
Rosy brown	Chocolate	0.2±0.1	-	-	-	-	-
Tomato red	Salmon	-	-	-	-	-	-
Violate red	Pale violet red	-	-	-	-	-	-
Auatic 2	Saddle brown	-	-	-	-	-	-
Indian red	Brown	0.3±0.2	-	-	-	-	-
Lemon chiffon	Light salmon	0.8±0.3	-	-	-	-	-
Bisique 3	Tan	-	-	-	-	-	-
Sea green	Dark Orange	-	3.3±1.0	2.7±0.8	-	-	-
Dark sea green	Yellow	-	11.0±1.6	0.3±0.1	-	-	-
Dark olive green	Green yellow	-	-	-	-	-	-
Khaki green	Dark goldenrod	-	-	-	-	-	-
Dark khaki green	Orange red	-	-	-	-	-	-
Olive drab	Yellow Green	-	0.2±0.1	-	-	-	-
Medium sea g green	Light Goldenrod	-	-	-	-	-	-
Yellowish green	Peru brown	-	-	0.7±0.3	-	-	-
Yellow	Orange	-	-	0.3±0.1	-	-	-
Golden yellow	Golden yellow	-	-	2.7±1.0	-	-	-
Black	Yellow	-	-	2.5±0.4	-	-	-
Dark green	Yellow	-	-	-	-	-	-
Dark olive green	Salmon pink	-	-	-	-	-	-
White (cottony)	Cornsilk3	-	-	-	6.0±1.3	-	-
Dark salty gray	Dim gray	-	-	-	-	6.0±0.4	6.0±1.7
Dark olive green	Salty gray	-	-	-	-	-	-
Burly wood	Saddle brown	-	-	-	-	-	-
Total no. of isolates		163	103	55	5	21	9
Total no. of samples		27	27	27	27	27	27

Appendix table 7: Occurrence of fungi genera on maize grain stored under farmers storage in the study sites

Storage duration (Month)	Districts	Fungi genera																				
		Pencillium spp			***Asparagillus spp***			***Fusarium spp***			***Phoma spp***			***Geotrichum spp***			***Cloudosporium spp***			***Drechslera spp***		
		In (%)	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**	**In (%)**	**Fr (%)**	**Rd (%)**
1st	Sokoru	18.5	5.4	14.1	1.5	1.2	3.0	68.9	23.2	64.9	10.4	3.9	10.6	0.0	0.0	0.0	3.0	0.7	2.2	10.4	2.2	5.1
	O/Nada	8.9	3.7	7.7	3.7	1.5	2.5	77.0	31.3	72.1	5.9	2.5	6.2	0.1	0.7	1.7	10.4	3.0	5.8	8.1	2.2	4.5
	Mana	3.0	0.0	1.5	2.2	0.2	0.7	86.7	22.7	97.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	8.1	0.5	2.9	3.0	0.0	0.6	85.9	18.8	94.7	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.2	0.6	0.0	0.0	0.0
	Dedo	3.0	1.2	2.9	6.7	2.5	6.5	88.1	30.9	88.7	1.5	0.7	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Over all mean (%)		**8.3**	**2.2**	**5.8**	**3.4**	**1.1**	**2.7**	**81.3**	**25.4**	**83.6**	**3.6**	**1.4**	**3.8**	**0.0**	**0.1**	**0.3**	**2.8**	**0.8**	**1.7**	**3.7**	**0.9**	**1.9**
2nd	Sokoru	1.5	8.6	1.7	9.6	3.7	11.3	86.7	29.6	87.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	O/Nada	3.0	5.7	2.6	0.7	0.2	0.5	92.6	34.6	93.3	0.0	0.0	0.0	2.2	1.5	3.7	0.0	0.0	0.0	0.0	0.0	0.0
	Mana	0.0	0.4	0.0	2.2	1.2	4.2	94.1	29.4	84.3	0.0	0.0	0.0	0.0	0.0	0.0	9.2	4.0	11.5	0.0	0.0	0.0
	Kersa	0.0	0.8	0.3	2.5	1.7	5.4	92.4	26.2	87.9	0.0	0.0	0.0	0.0	0.0	0.0	5.1	2.2	6.6	0.0	0.0	0.0
	Dedo	9.6	1.7	12.2	2.9	0.7	2.0	49.6	25.7	78.0	0.0	0.0	0.0	0.0	1.0	2.1	2.7	1.7	4.6	0.1	0.5	1.1
Over all mean (%)		**2.8**	**3.4**	**3.4**	**3.6**	**1.5**	**4.7**	**83.1**	**29.1**	**86.1**	**0.0**	**0.0**	**0.0**	**0.4**	**0.5**	**1.2**	**3.4**	**1.6**	**4.5**	**0.0**	**0.1**	**0.2**
3rd	Sokoru	42.2	15.1	35.8	5.9	1.5	3.5	48.9	17.8	46.5	2.2	0.0	0.0	1.5	0.5	1.0	0.4	0.7	2.8	0.0	0.0	0.0
	O/Nada	20.7	9.4	19.3	3.7	1.5	3.5	70.4	28.9	75.4	2.2	0.0	0.0	0.7	1.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0
	Mana	31.9	15.3	32.9	11.9	9.6	9.8	55.5	25.2	55.7	0.7	1.0	1.9	0.0	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	22.9	7.9	19.6	2.9	0.5	1.6	68.2	28.4	72.3	2.2	1.7	4.3	2.2	0.7	2.3	0.0	0.0	0.0	0.0	0.0	0.0
	Dedo	32.6	14.1	24.9	8.2	0.2	0.7	58.5	34.8	72.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	2.3	0.0	0.0	0.0
Over all mean (%)		**30.1**	**12.4**	**26.5**	**6.5**	**2.7**	**3.8**	**60.3**	**27.0**	**64.4**	**1.5**	**0.5**	**1.2**	**0.9**	**0.5**	**1.1**	**0.2**	**0.3**	**1.0**	**0.0**	**0.0**	**0.0**
4th	Sokoru	32.6	36.3	23.2	5.2	3.7	2.4	57.8	82.9	57.6	0.0	0.0	0.0	0.0	0.0	0.0	4.4	12.6	5.7	0.0	0.0	0.0
	O/Nada	23.7	35.6	23.2	7.4	8.1	2.4	49.6	60.7	57.6	0.0	0.0	0.0	10.4	17.0	11.7	9.6	11.9	5.7	0.0	0.0	0.0
	Mana	42.2	62.2	49.6	8.9	12.6	11.9	43.7	37.0	25.8	1.5	2.2	1.7	0.0	0.0	0.0	2.2	11.1	7.2	1.5	5.9	3.7
	Kersa	20.0	11.1	10.1	5.9	5.9	5.2	72.6	88.2	84.0	0.7	0.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	Dedo	23.2	25.2	16.1	21.0	25.9	17.0	49.1	64.4	44.4	0.8	0.0	0.0	2.8	8.9	5.7	2.8	8.2	2.2	0.1	0.7	0.5
Over all mean (%)		**28.3**	**34.1**	**24.4**	**9.7**	**11.2**	**7.8**	**54.6**	**66.6**	**53.9**	**0.6**	**0.6**	**0.5**	**2.6**	**5.2**	**1.1**	**3.8**	**8.8**	**4.2**	**0.3**	**1.3**	**0.8**
5th	Sokoru	14.1	13.3	8.2	20.0	20.7	13.4	56.3	46.7	67.5	2.6	5.2	4.2	0.7	0.0	0.0	8.9	11.1	6.6	0.0	0.0	0.0
	O/Nada	17.1	17.1	21.2	6.7	10.4	2.1	63.0	79.2	76.2	0.0	0.0	0.0	4.5	3.7	0.6	7.4	12.6	10.5	0.0	0.0	0.0
	Mana	14.8	24.4	13.7	11.1	17.0	9.1	74.1	95.6	63.4	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	23.7	31.1	14.6	1.5	2.2	11.3	73.3	94.1	74.1	0.0	0.0	0.0	1.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dedo	36.3	45.2	35.7	12.6	13.3	10.5	49.6	47.4	50.9	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.7	4.4	2.9
Over all mean (%)		**21.2**	**26.2**	**18.7**	**10.4**	**12.7**	**9.3**	**63.3**	**72.6**	**66.4**	**0.5**	**1.0**	**0.8**	**1.3**	**1.2**	**0.8**	**3.3**	**4.7**	**3.4**	**0.1**	**0.9**	**0.6**
6th	Sokoru	28.2	33.4	21.4	8.2	20.7	15.3	60.7	74.8	63.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	O/Nada	10.4	11.1	7.1	1.5	4.4	3.8	80.7	90.4	78.5	0.0	0.0	0.0	2.2	6.7	6.3	4.5	7.4	4.3	0.0	0.0	0.0
	Mana	38.5	48.2	34.5	23.7	32.6	18.0	35.5	62.2	25.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	38.5	34.8	37.5	17.8	18.5	21.2	37.8	48.9	36.9	0.0	0.0	0.0	1.5	2.9	1.1	0.0	2.2	2.2	0.7	2.2	2.1
	Dedo	32.6	54.1	30.1	17.1	11.8	23.8	49.6	61.5	43.9	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Over all mean (%)		**29.6**	**36.3**	**26.1**	**13.7**	**17.6**	**16.4**	**52.9**	**67.6**	**49.6**	**0.0**	**0.0**	**0.0**	**0.7**	**1.9**	**1.5**	**1.0**	**1.9**	**1.3**	**0.1**	**0.4**	**0.4**

RD= relative density, Fr=frequency and In =incidence

Appendix table 8: Occurrence of fungi genera on maize grain stored under collectors storage in the study sites

Storage duration (Month)	Districts	Fungi genera																				
		Pencillium spp			*Asparagillus spp*			*Fusarium spp*			*Phoma spp*			*Geotrichum spp*			*Cloudosporium spp*			*Drechslera spp*		
		In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)	In (%)	Fr (%)	Rd (%)
1st	Sokoru	5.2	4.5	7.1	0.0	3.4	0.2	85.0	88.1	92.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	O/Nada	5.5	4.5	6.9	4.4	2.2	1.9	74.3	88.9	91.2	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mana	29.2	20.0	21.7	4.4	0.0	0.0	47.8	79.3	78.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	0.0	0.9	6.6	0.0	0.0	0.0	75.8	62.4	93.4	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dedo	10.6	4.5	0.0	5.9	3.4	0.0	66.5	88.1	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Over all mean (%)		**10.1**	**6.9**	**8.5**	**3.0**	**1.8**	**0.4**	**69.9**	**81.4**	**91.1**	**0.0**	**0.0**	**0.0**	**0.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2nd	Sokoru	8.5	3.2	8.4	0.0	0.0	0.0	86.7	38.6	91.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	O/Nada	6.7	11.1	7.0	3.8	0.0	2.1	91.1	100.0	90.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mana	35.6	8.9	33.0	4.4	2.2	0.0	60.0	88.9	67.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	0.0	38.5	0.0	0.0	0.0	0.0	91.1	61.5	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dedo	11.1	0.9	0.0	6.7	0.0	0.0	84.4	62.4	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Over all mean (%)		**12.4**	**12.5**	**9.7**	**3.0**	**0.4**	**0.4**	**82.7**	**70.3**	**83.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
3rd	Sokoru	26.7	1.0	16.7	15.6	0.0	14.7	51.1	62.3	49.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0
	O/Nada	20.0	37.8	20.9	20.0	7.4	4.8	40.0	66.7	25.0	0.0	0.0	0.0	15.6	0.0	17.6	4.4	6.7	0.0	0.0	0.0	0.0
	Mana	46.7	26.7	45.5	13.3	2.2	15.1	33.3	33.3	39.5	0.0	0.0	0.0	2.2	24.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Kersa	15.6	53.3	10.0	6.7	6.7	0.0	77.8	53.3	66.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dedo	8.9	0.0	11.1	15.6	0.0	18.7	57.8	33.3	56.4	0.0	0.0	0.0	15.6	0.0	13.3	0.0	0.0	0.0	0.0	0.0	0.0

Over all mean (%)		**23.6**	**23.8**	**20.8**	**14.2**	**3.3**	**10.6**	**52.0**	**49.8**	**47.5**	**0.0**	**0.0**	**0.0**	**6.7**	**4.9**	**6.2**	**0.9**	**1.3**	**1.5**	**0.0**	**0.0**	**0.0**
4th	Sokoru	42.2	17.8	45.3	6.7	8.9	3.2	40.0	60.0	36.5	0.0	0.0	0.0	0.0	15.6	0.0	0.0	0.0	15.0	0.0	0.0	0.0
	O/Nada	53.3	48.9	52.6	4.4	4.4	0.0	35.6	42.2	14.0	0.0	0.0	0.0	4.4	0.0	0.0	11.1	15.6	0.0	0.0	0.0	4.4
	Mana	57.8	48.9	37.8	8.9	0.0	5.0	31.1	8.9	50.2	0.0	0.0	0.0	0.0	0.0	0.0	4.4	4.4	0.0	2.2	4.4	7.0
	Kersa	17.8	71.1	30.0	0.0	6.7	2.1	82.2	40.0	63.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	8.9	0.0
	Dedo	22.2	22.2	29.1	17.8	0.0	17.5	55.6	82.2	33.5	0.0	0.0	0.0	4.4	0.0	11.1	0.0	0.0	4.4	0.0	0.0	4.2
Over all mean (%)		**38.7**	**41.8**	**39.0**	**7.6**	**4.0**	**5.5**	**48.9**	**46.7**	**39.6**	**0.0**	**0.0**	**0.0**	**1.8**	**3.1**	**2.2**	**3.1**	**4.0**	**3.9**	**0.9**	**2.7**	**3.1**
5th	Sokoru	2.2	2.2	2.1	4.4	8.9	8.2	93.3	97.8	89.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	O/Nada	28.9	53.3	36.7	13.3	6.7	5.0	53.3	51.1	33.8	0.0	0.0	0.0	4.4	31.1	24.6	0.0	0.0	0.0	0.0	0.0	0.0
	Mana	6.7	15.6	13.7	22.2	22.2	19.2	51.1	46.7	48.4	0.0	0.0	0.0	6.7	8.9	8.3	0.0	11.1	10.4	0.0	0.0	0.0
	Kersa	17.8	26.7	18.2	11.1	11.1	10.8	57.8	77.8	66.8	0.0	0.0	0.0	2.2	0.0	0.0	11.1	6.7	4.2	0.0	0.0	0.0
	Dedo	40.0	26.7	35.3	44.4	11.1	43.0	15.6	77.8	21.7	0.0	0.0	0.0	0.0	0.0	0.0	8.9	6.7	0.0	0.0	0.0	0.0
Over all mean (%)		**19.1**	**24.9**	**21.2**	**19.1**	**12.0**	**17.3**	**54.2**	**70.2**	**52.1**	**0.0**	**0.0**	**0.0**	**2.7**	**8.0**	**6.6**	**4.0**	**4.9**	**2.9**	**0.0**	**0.0**	**0.0**
6th	Sokoru	68.9	82.2	68.5	0.0	2.2	1.9	31.1	35.6	29.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	O/Nada	13.3	13.3	14.2	2.2	2.2	2.0	82.2	86.7	83.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mana	48.9	57.8	48.2	2.2	2.2	1.9	46.7	57.8	48.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	2.2	1.9
	Kersa	53.3	64.4	50.7	24.4	31.1	22.2	22.2	40.0	27.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dedo	46.7	73.3	30.6	35.6	33.3	16.7	15.6	22.2	19.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Over all mean (%)		**46.2**	**58.2**	**42.4**	**12.9**	**14.2**	**15.8**	**39.6**	**48.4**	**41.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.4**	**0.4**	**0.4**

RD= relative density, Fr=frequency and In =incidence

Appendix table 9:ANOVA for nutrient and anti-nutrient composition of maize grain collected from farmers' storage

Response Variable	Source	P-value	C v%
Moisture	SD	<.0001	5.6
	AG	<.0001	
	SD*AG	0.0038	
Ash	SD	0.0032	20.2
	AG	0.0225	
	SD*AG	0.9678	
Protein	SD	0.0013	12.1
	AG	0.1376	
	SD*AG	0.8031	
Fat	SD	0.0002	7.6
	AG	0.0003	
	SD*AG	0.1367	
Fiber	SD	<.0001	9.7
	AG	0.56	
	SD*AG	2.16	
CHO	SD	<.0001	3.3
	AG	0.0032	
	SD*AG	0.2516	
Calorific value	SD	<.0001	3.1
	AG	0.0032	
	SD*AG	0.3426	
Fe	SD	<.0001	12.6
	AG	0.9223	
	SD*AG	0.0143	
Zn	SD	<.0001	16.2
	AG	0.0012	
	SD*AG	0.1322	
Ca	SD	<.0001	9.2

	AG	0.0066	
	SD*AG	<.0001	
P	SD	<.0001	18.7
	AG	0.0848	
	SD*AG	0.0027	
Phytate	SD	0.007	15.1
	AG	<.0001	
	SD*AG	0.1842	
Tannin	SD	<.0001	13.7
	AG	0.0049	
	SD*AG	<.0001	

Appendix table 10: ANOVA for nutrient and anti-nutrient composition of maize grain sampled from collectors' storage

Response Variable	Source	P-value	C v%
Moisture	SD	<.0001	5.3
	AG	0.1215	
	SD*AG	0.9614	
Ash	SD	<.0001	19.4
	AG	0.4698	
	SD*AG	0.1177	
Protein	SD	<.0001	5.4
	AG	<.0001	
	SD*AG	0.0112	
Fat	SD	<.0001	4.6
	AG	0.0003	
	SD*AG	0.1499	
Fiber	SD	0.0005	6.8
	AG	0.2261	
	SD*AG	0.9570	
CHO	SD	0.0029	2.2

	AG	0.0001	
	SD*AG	0.1094	
Calorific value	SD	<.0.0146	2.7
	AG	0.4946	
	SD*AG	0.9509	
Fe	SD	<.0001	13.9
	AG	0.0030	
	SD*AG	0.0246	
Zn	SD	<.0001	11.6
	AG	0.0006	
	SD*AG	0.5250	
Ca	SD	<.0001	9.6
	AG	0.0626	
	SD*AG	0.0060	
P	SD	<.0001	16.6
	AG	<.0001	
	SD*AG	0.0444	
Phytate	SD	<.0001	9.9
	AG	<.0001	
	SD*AG	0.0179	
Tannin	SD	<.0001	5.6
	AG	<.0001	
	SD*AG	0.0102	

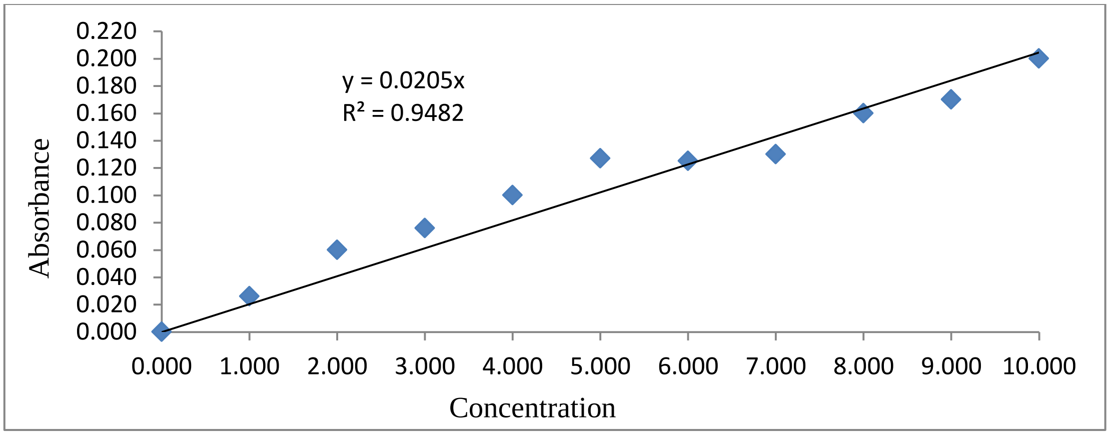
Appendix table11: ANOVA for nutrient and anti-nutrient composition of maize collected from wholesalers store

Response Variable	source	P-value	Cv%
Fiber	SD	0.0452	5.5
Moisture	SD	0.0046	3.1
Protein	SD	0.00014	4.3
Fat	SD	0.0225	2.9
Ash	SD	0.0058	9.7
CHO	SD	0.0227	1.9
Calorific value	SD	<.0001	0.5
Fe	SD	0.0098	12.9
Zn	SD	0.0076	13.8
Ca	SD	0.0037	17.4
P	SD	0.004	8.8
Phytate	SD	0.0906	13
Tannin	SD	0.0514	14

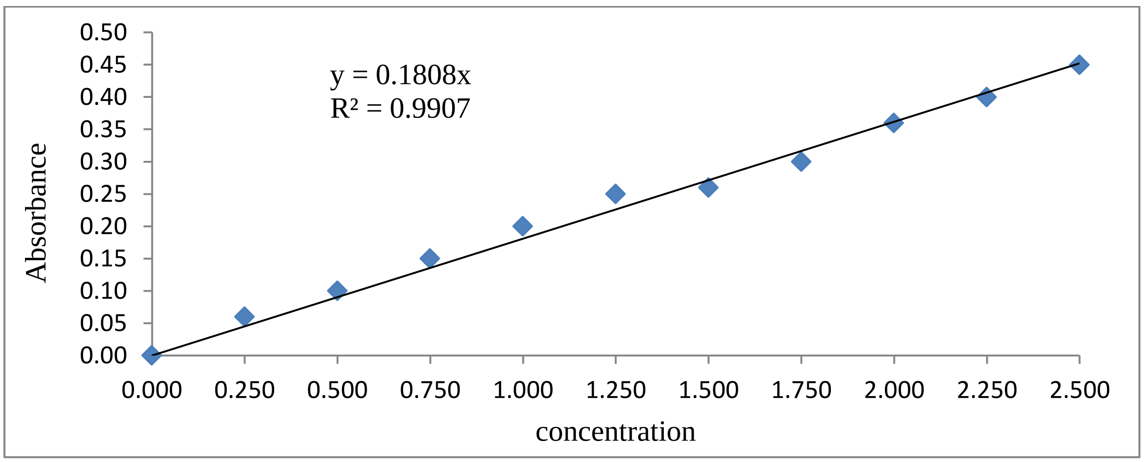
Appendix table 12: Number of respondents

District	PA's	Farmers	DA/expert	Key informants	Traders	Total
Dedo	Mole	19	2	9	2	65
	Ofole	9	0	5		
	Warokolobo	13	0	8		
Kersa	Bala Wajo	13	1	8	2	65
	Bulbuli	10	2	7		
	Gelo	14	0	8		
Mana	Bilida	15	1	7	3	66
	Kenteri	10	2	8		
	Somodo	5	3	10		
Omonada	Burka-Asandabo	16	2	0	2	86
	Gudeta –Bula	27	2	9		
	Nada –Chala	21	0	7		
Sokoru	Abelti	5	2	0	6	50
	Andode	5	2	0		
	Walmera	17	6	7		
Jimma	Jimma	0	0	0	10	10
Total		199	25	93	25	342

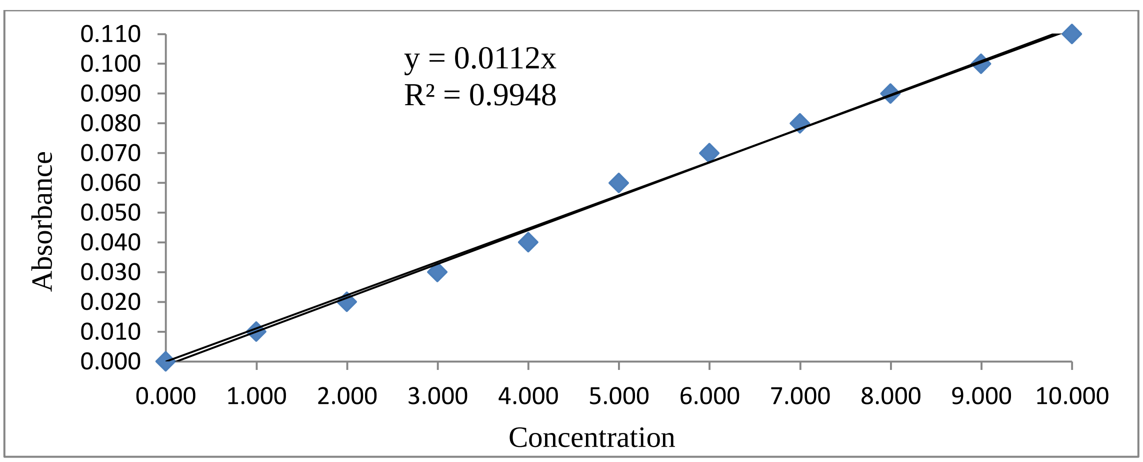
Appendix B: List of figure



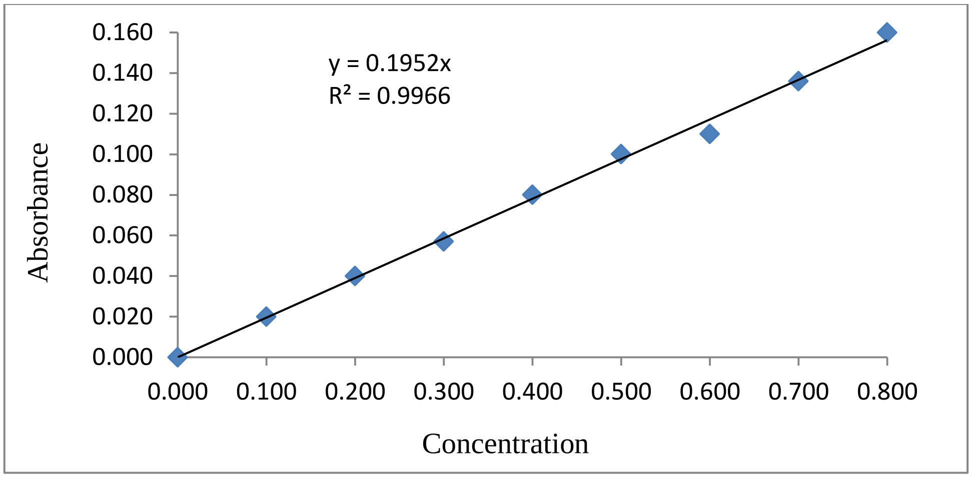
Appendix figure 1: Iron standard curve



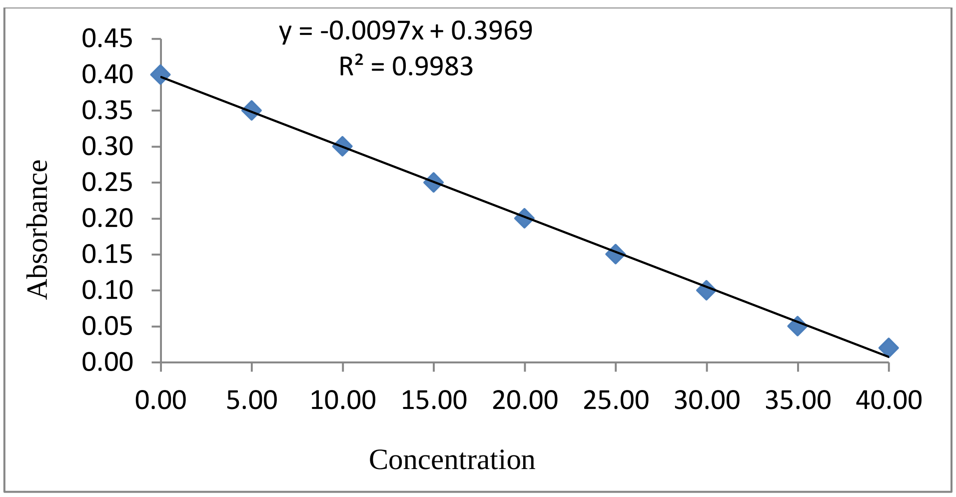
Appendix figure 2: Zinc standard curve



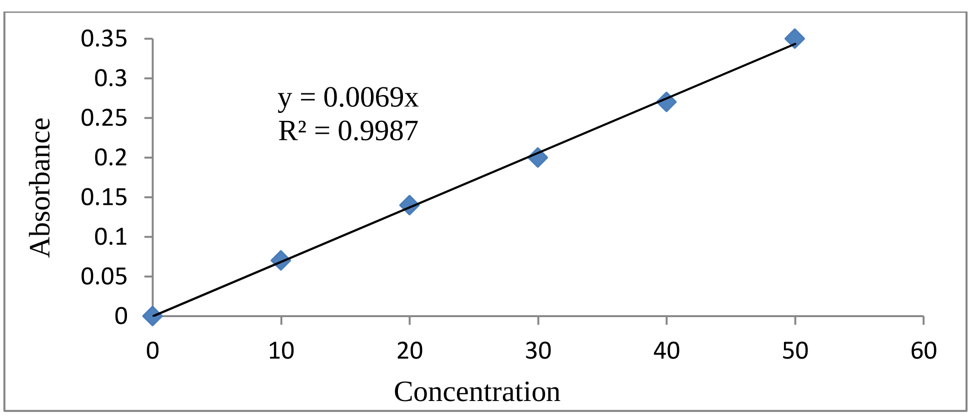
Appendix figure 3: Calcium standard curve



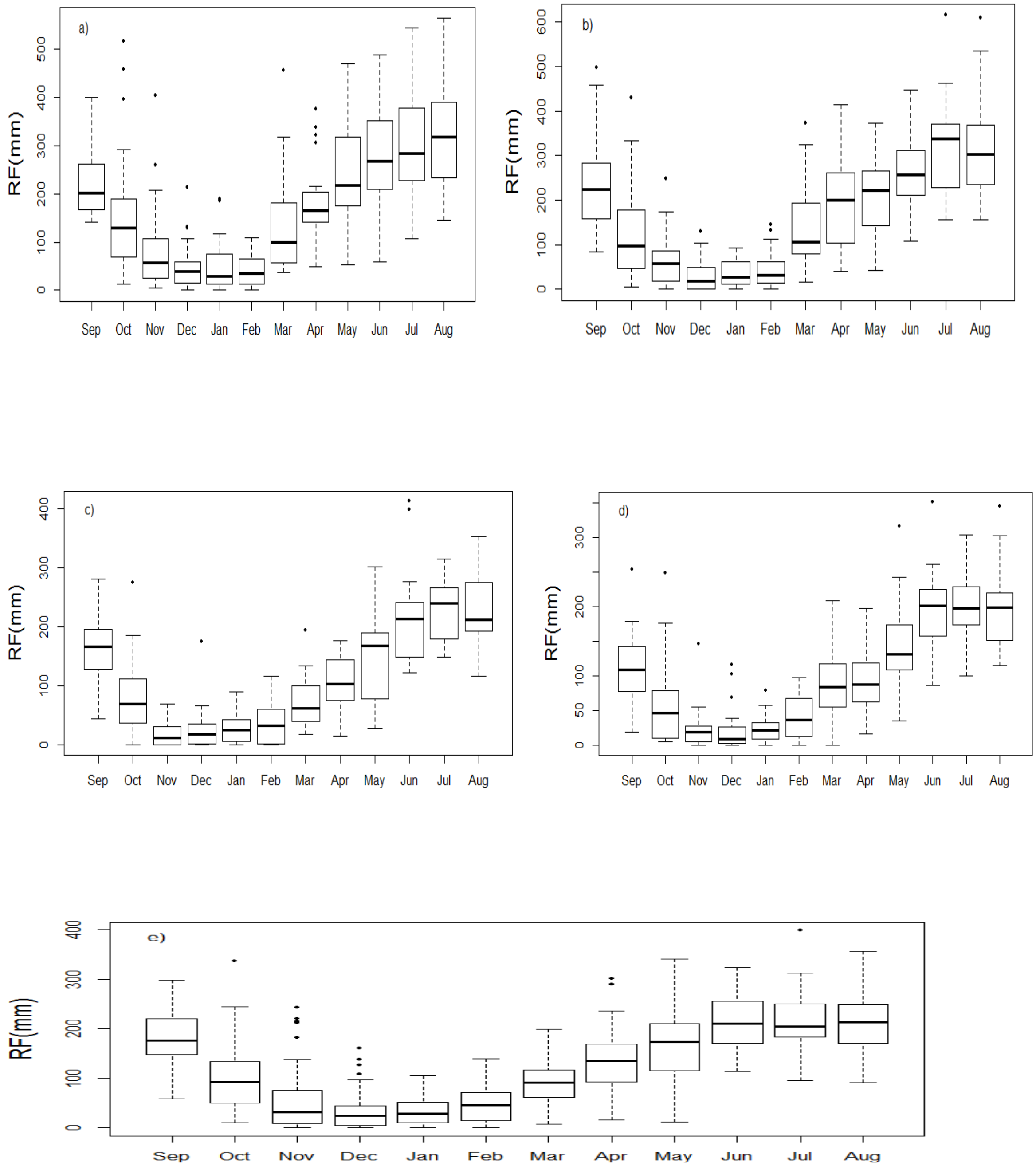
Appendix figure 4: Phosphorus standard curve



Appendix figure 5:Phaytate standard curve



Appendix figure 6: Tannin standard curve

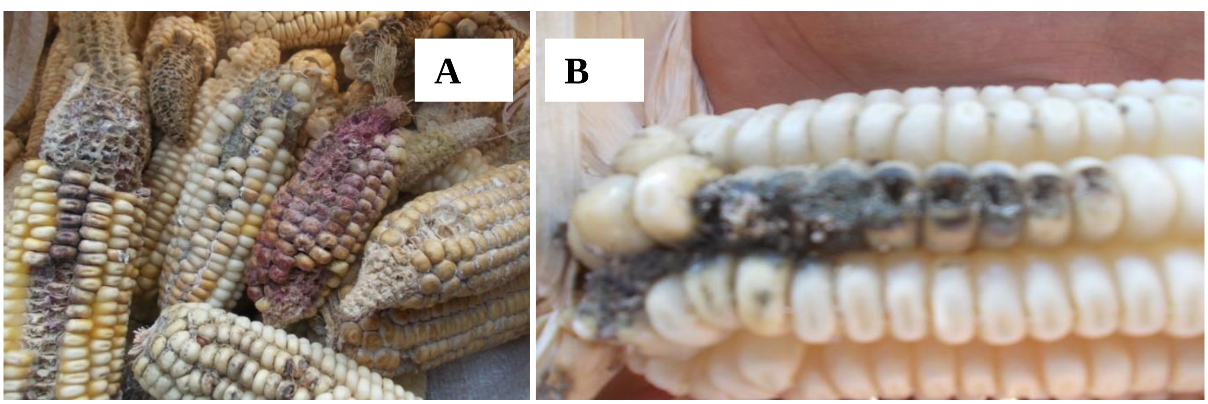


Appendix figure 7: Rain fall trend for different study districts A) Mana B) Dedo C) Sokoru D) Omonada E) Kersa

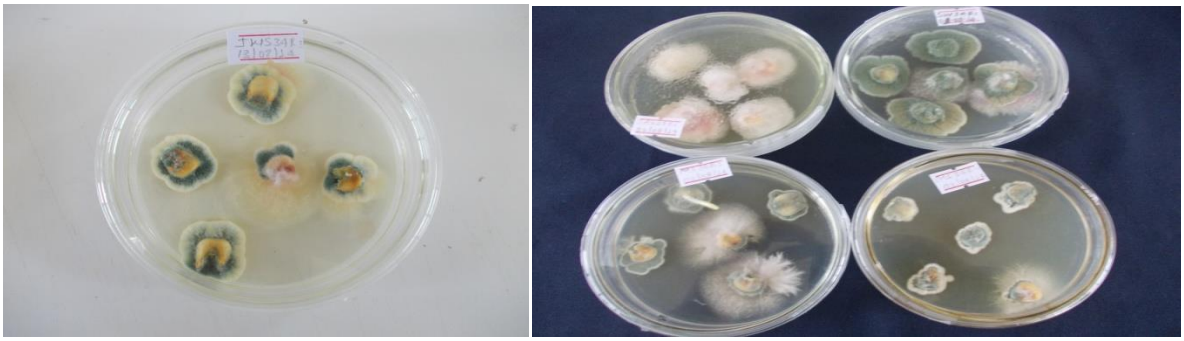
NB. Average thirty years data (1982 to 2012)

Appendix figure 8: Sorting out mouldy and undamaged cobs

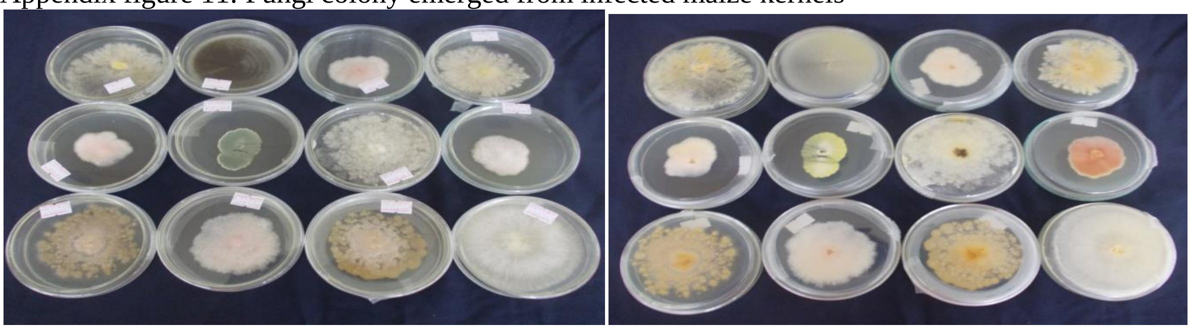
Appendix figure 9: Maize shelling method used by farmers in the study site



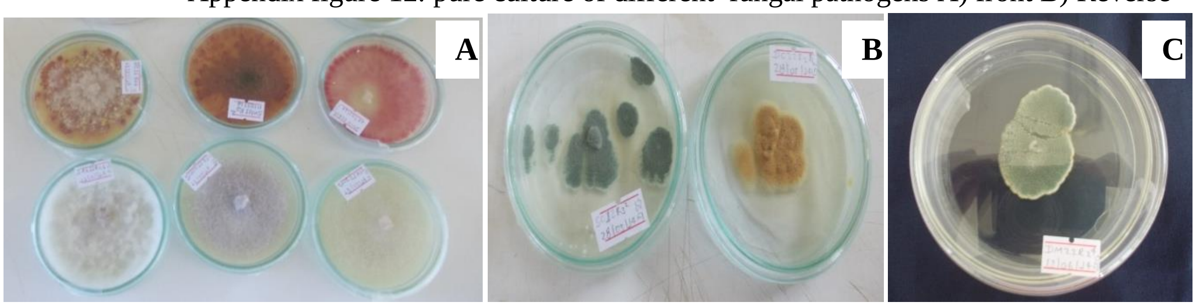
Appendix figure 10: Mouldy maize A) sorted out before storage and B) Sampled from storage



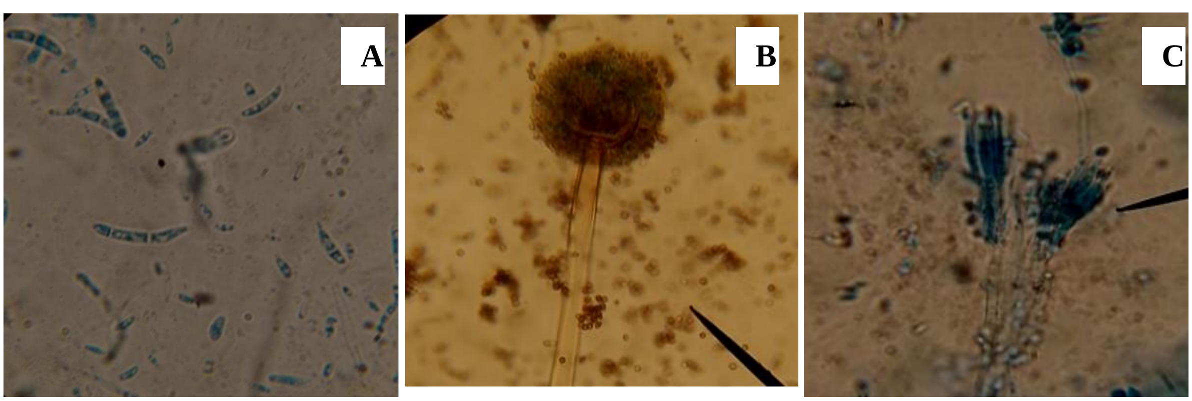
Appendix figure 11: Fungi colony emerged from infected maize kernels



Appendix figure 12: pure culture of different fungal pathogens A) front B) Reverse



Appendix figure 13: Most frequently identified fungi pure culture A) *Fusarium* Spp. B) *Aspergillus* spp. and C) *Pencillium* spp.



Appendix figure 14: Morphological structure of pre-dominant fungi A) *Fusarium* Spp. B) *Aspergillus* spp. and C) *Pencillium* spp.

Appendix C:Questionnaires

Date:____________________

Note to the Interviewer

This questionnaire is prepared to get feedback on Farmers' postharvest practices of maize in selected districts of Jimma. Please introduce yourself and the objectives of the study to the interviewee very politely. Complete the questionnaire by circling the letter of the choice and filling in the open ended questions very patiently. One question may have more than one answer. Please don't forget to thank the interviewee after completing the interview. I would appreciate for all the cooperation made.

Part I: Harvesting Practices, Storage Technology and Associated Constraints of PostharvestPractice of Maize in Jimma Zone, Ethiopia (Questionnaire to producers)

Name: Respondent:__________________ Interviewer:________________ Code________
Name of district_____________________ Peasant association (PA) ___________________
PA zone_________________*Gare* _______________Agro-ecological zone _____________
Altitude __________________ Longitude _____________________ Latitude ______________

I. General back ground

No.	**Character**	**Response**	**Character**	**Response**
1	Sex & Age	_____ _____	School	
2	Family size		Infrastructure (road)	
3	Education		Water source	
4	Religion		Electricity	
5	Number of working force in the family		Telephone	
6	Hospital/health center		Detail contact address	

Part II. Maize production and management

1. How long have you been producing maize? Make circle for best answer.
   a)< 10 years **b)**≥10 - <20 Years **c)**≥20 - <30 Years **d)**≥30 - <40 Years **e)**≥40 years
2. What is the primary objective of producing maize?
   a) House hold consumption **b)** For income **c)** a & b
   d) Other (specify)____

3. How much of your time (including all your families) do you spend on activities related to production and/or selling of maize? In man per day

   - Total maize farm area in has ________________

Activities	Days	Activities	Days
Land preparation		Transporting and storing	
Sawing		Shelling	
Weeding		Selling	
Protecting from wild animals		Insect pest control	
Protecting from domestic animals		Mould management	
Harvesting		Rodent management	
Draying			

4. Which maize variety do you grow, express in proportion
   a) BH660 _______%, **b)** BH540 ______________%; **c)** Shone _______________ %
   d) Other ____

5. From where you get improved variety of maize?
   a) Agricultural office **b)** Research Institutes **c)** Universities **d)** NGOs
   e) Model farmers **f)** Cooperative **g)** Unions
   h) Others, specify ____
6. To whom do you sell maize?
   a) Cooperatives **b)** Processors **c)** Whole sellers **d)** Retailers **e)** Individual consumers
   f) Institutional customers **g)** collectors **h)** other (specify) ___________________________
7. Do you sell to the same buyer each year? Tick X under your choice
   a) Yes ____________ **b)** No _________________ **c)** It depend on ______________________

8. If your answer is **yes** to question number **7,** why?
   a) I have written contract with the buyer **b)** I am going to get benefit from the profit of the buyer **c)** Business relationship with the buyer **d)** I have no other option
e) Other, specify ____

9. How important is maize to your overall income? Circle the answer below.
   a) Less than 15% **b)** 16 to 30% **c)** 31to 45% **d)** 46 to 60% **e)** 61 to75% **f)** More than 75%

10. Do you have any sources of income in your household other than maize commodity? Circle the choice **a)** Other agriculture commodity **b)** Off-farm activities **c)** none
11. Out of the total land you have, how much covered with maize last harvest, Circle the choice.
a) Less than 25% **b)** 26 to 50% **c)** 51 to 75% **d)** More than 75%
12. How do you harvest maize?

a) Manual harvesting of the cob with stalk and allow drying
b) Manually harvesting of died cob only
c) Mechanized harvesting
d) Other method (specify)____

---

13. How do you judge that maize is ready for harvesting?
a) Visual observation **b)** Shelling and checking for seed hardness
c) Count months based on sawing date **d)** Using local knowledge, like ______________
e) Other means (specify)____
13. Time of harvesting maize after attaining physiological maturity or start of green consumption? **a)** one week **b)** two week **c)** three week **d)** four week and more
14. Do you face problem of rain during harvest? Circle your answer **a)** Yes **b)** No

15. If the answer for question no. 14 is **yes** how long? Circle the best choice

a) one week before harvest **b)** two week before harvest
c) three week before harvest **d)** More than one month

16. What happen if the rain starts before harvesting dried maize cob or during harvesting? Explain
____
____
17. What method do you use for transporting the harvested maize to drying site/or storage site?
a) Carrying on human shoulders **b)** Back of animals **c)** Wheel barrows
d) Animal drawn carts **e)** other means (specify) ____________________________

18. How do you shell the harvested maize cobs? **a)** Beating the cobs with sticks inside sacks **b)** Finger-palm shelling **c)** Using mechanical shelters**d)** Beating the cobs with sticks inside the house **e)** Other method (specify)______________________________________
19. Do you dry maize after harvest by spreading it on drying floor?
a) Yes **b)** No.
20. If your response to question No. **20** is **yes,** is the drying surface bare ground
a) Yes **b)** No. **c)** Specify ____
21. If your response to question No. **20** is **No**, what is the finishing material used for drying surface?____
____
22. Do you use the same place for drying year after year? A) Yes ________ B) No ________

23. If you do not use drying surface, how and where do you dry the cob?
____
____

24. How long would it take, at an average, to dry the cobs to your satisfaction before taking it in to storage containers? Express in days**.**

____
____

25. How do you decide that the cobs are dry enough to be stored?

26. Farmers/owner's allocation of their harvested maize product for home consumption

a) <u><</u>25% **b)** From 26 to 50% **c)** From 51to 75% **d)**<u>></u>76% **e)** No allocation to home consumption

27. How you evaluate the support from governmental organization in terms of providing various services such as: farm practice and storage technology trainings, etc? Circle your choice.

a) It is excellent **b)** it is very good **c)** it is fair **d)** unsatisfactory e) no service at all

28. Evaluate the **Q 28** for Nongovernmental Organizations (NGOs). Circle your choice.

a) It is excellent **b)** it is very good **c)** it is fair **d)** unsatisfactory e) no service at all

29. What do you suggest the government or non-governmental agents should do in order to minimize postharvest loss and grain quality deterioration problems in your area?

____
____
____

Part III: Storage Technology

1. When maize fully dried in your area to be harvested?
   a) Mid September to mid October **b)** Mid October to mid November **c)** Mid November to mid December **d)** Mid of December to mid of January **e)** I don't know or remember the exact month

2. When harvested maize can be stored? Directly after harvest_____ Pre-storage_____ or ____

3. Why do you do pre-store?____

4. Where do you pre-store? Put X on appropriate space: Field_____ In the house______________ other, specify ____

5. For how long do you pre-store? ____

6. Where is your storage structure located?
a) Field **b)** In the house **c)** courtyard **d)** home garden
e) Both inside house and home garden **f)** other**,** specify ____________________________

7. What construction material can you use?
a) Wood (name of the plant) _______________________________________**b)** Clay **c)** Metal **d)** If any other specify____

8. For how many seasons can be used if it is newly constructed store? _______________

9. Do you store maize in the same store every season?
If**No**, why?____________________________ ____

If **Yes ,** why? ____

10. Do you store other products in the store with maize? **No**_____ **Yes**,
If **YES**, List the products?____
If **NO**, why ____

11. How long you can store your maize with cobs in store?
a) Up to one month **b)** two month **c)** three month **d)** four month **e)** five month **d)** six month **f)** more than six month
12. How long you can store your maize as shelled grains?
a) Up to one month **b)** two month **c)** three month **d)** four month **e)** five month **d)** six month **f)** more than six month

13. What type of maize storage container do you use? If you stored as cobs
a) *Gotera* /*Gombissa* **b)** *Dibignit* **c)** Sacks **e)** others, specify
____
____

14. What type of maize storage container do you use? If you stored as shelled maize or grains
a) *Gotera* /*Gombissa* **b)** *Dibignit* **c**) Sacks **e)** others, specify ___________________
15. Do you mix previous harvest with the new one during storage? **a)** Yes **b)** No
16. Do you clean your storage containers and the surrounding before storing newly harvested grain? **a)** Yes **b)** No.

If **Yes**, how and why? ____
____

If **No**, why?
____
____

17. Do you fumigate your storage container before taking new grains in?
a) Yes **b)** No.

18. If response to question No. **16** is **yes**, what do you use for fumigating store?
a) Smoking firewood **b)** Smoking pepper
c) Smoking plant leaves (specify leaf type) **d)** Others (specify)
____
____

19. Do you aerate your stored grain? **a)** Yes **b)** No

20. If the answer for question **No**. **18** is **No** why?
____
____

21. If your response to question **No**. **18** is **yes**, how and how often do you do it?

____

____

22. How do you inspect the stored maize to check for any sign of deterioration so that you could take measures on time?

____

____

23. How frequent do you inspect the stored grain? **a)** Every weeks **b)** Every two weeks **c)** Every three weeks **d)** Every month **e)** Every two months **f)** More than two months

24. What corrective measures do you take in response to your storage inspection if you find sign of disease (mould development)? **a)** Pesticides **b)** Plant material
c) Other traditional method (Specify)____

25. Describe briefly how you apply your treatment to the grain.
____

____

26. If you find other signs of deterioration different from fungal or disease attacks what measure do you take? Eg:- insect damage, rodent

____

____

27. How much of your maize grain do you think you lose because of problems associated with post- harvest practices start from harvest to final consumption/selling?

1. Mould (%)_____________ 2. Insect (%)______________ 3. Rodent (%)___________
4. Wild animals (%) _____________ 5. Domestic animals __________________________
6. Others, specify in percentage? ____

Part: IV. Storage technology constraints

1. Do you have storage problems? **a)**Yes **b)** No
2. Which storage problem is the most important?
List with them in decreasing order

____

____

3. What do you think the cause for mould development in the stored grain? Explain

____

____

4. When most of the time mould problem observed?
a) Starting at field condition _____________ b) Beginning of storage period ______________
c) After a few months (indicate in months) ___________ d) At the end of storage_________

5. What did you do to solve this problem? List them_________________________________

____

6. Does the maize grain germinate in storage? **a)** Yes **b)** No
7. If you treated the storehouse before storage, what methods did you use?
   a) Ash b) Sand c) Insecticides (specify)
   d) Smoke (specify)____________e) Manure (specify)________ f) Other (specify)________

i. ____

ii. ____

iii. ____

8. How did you store your maize?

a) As maize grain (shelled) _____ **b)** De-husked _____ **c)** With the husk ____ **d)** Others__

i. ____

ii. ____

iii. ____

9. Why do you store your maize with cobs?

a) Insect problem **b)** Saving because once shelled it may used extensively **c)** other ____

10. How much of your maize sold for different expense

a) 0-25% **b)** 26-50% **c)** 51-75 % **d)**>75% of the product

11. Express maize loss in % starting from harvesting to the final step.

a) During harvesting ____________ **b)** Drying _________________ **c)** Shelling ____________

d) Storage ____________________ **e)** Selling _________________ **f)** Consumption ________

12) Do you think producing maize if profitable **a)** Yes _____________ **b)** No _____________

If yes, why ____

If no, why ____

13. Did you use pesticides during storage? **If yes**, mention the name and its purpose

i. ____

ii. ____

iv. ____

14. From where you get the pesticides?

a) Ministry of agriculture office b) private shops c) NGOs d) others _______________

15. Did you take any other precautions? **If yes**, list

i. ____

ii. ____

iii. ____

16. For what purpose do you use maize grain damage by **insect pests?**

i. ____

ii. ____

iii. ____

iv. ____

17. If your maize grain damaged **by rodents**, for what purpose do you use?

i. ____

ii. ____

iii. ____

iv. ____

18. For what purpose do you use maize grain damage by **mould?**

i. ____

ii. ____

iii. ____

iv ____

19. Do you think consuming **mouldy maize grain** has impact on human or animal health?

a) Yes **b)** No

If yes, what it can cause? Explain

____

____

20. Do you feel any discomfort or illness when you consume mouldy maize?

a) Yes **b)** No

21. Have you get training from Governmental and/or NGOs about maize mould and its control methods? Yes------------- No-------------- If yes, mention what control measure you took

____

22. What type of effect caused by the attack of mould on maize?

a) Quality losses **b)** Yield losses **c)** Reduction of prices **d)** Both quality and yield loss

23. Mention advantages and disadvantages of different storage structures used in your locality

No.	PHM practices	Advantage	Disadvantage
1.	______________	______________	______________
2.	______________	______________	______________
3.	______________	______________	______________
4.	______________	______________	______________
5.	______________	______________	______________
6.	______________	______________	______________

Date ___________________

Questionnaire for experts and development agents

Part I: Harvesting Practices, Storage Technology and Associated Constraints of PostharvestPractice of Maize in the study site.

Name _____________________________ Sex: __________ Age _____________________
PA/town_____________________ Profession __________________ Code______________

How long you have been working as Developmental Agent in an area? **a)** For < 2 years **b)** From 2 to 3 years **c)** From 3.1 to 5 years **d)**> 5 years

1. List maize variety produced in your PA's in proportion (percentage).

No.	Variety	Amount in percentage
i.	______________________	____________________________
ii.	______________________	____________________________
iii.	______________________	____________________________
iv.	______________________	____________________________
v	______________________	____________________________

2. Total number of house hold of PA's in proportion who producing maize by variety

____

____

____

3. List advantages and disadvantages of maize variety which produced in your PA's

No. **<u>Maize variety Advantages Disadvantages</u>**

1.	_______________	______________	__________
2.	_______________	______________	__________
3.	_______________	______________	__________
4.	_______________	______________	__________
5.	_______________	______________	__________
6.	_______________	______________	__________
7.	_______________	______________	__________

4. Which type of storage structures commonly used in your PA's? Express in proportion (percentage)

<u>No. Storage structures ProportionReason</u>

1.	_______________	______________	__________
2.	_______________	______________	__________

3. ________________ ______________ __________
4. ________________ ______________ __________
5. ________________ ______________ __________

5. List the materials used for construction of storage structures?

____

6. Did the farmers get training how to construct improved storage structures?
a) Yes b) No

7. If the answer for question **no. 6 is yes** by whom the training given?
a) District agricultural office **b)** NGO's **c)** a & b **d)** other (specify)____________
8. What are the major problems related with storage structures? List

____

9. Mention the major potential for maize production and productivity in your PA's?

____

10. What are the major constraints for maize production and productivity in your PA'S? Mention each constraint in percentage.

____

11. List the major storage technology (storage management activities) applied for maize in your PA. eg:- cleaning the store before storage of new maize; fumigation of store; etc

____

12. List the advantage and disadvantage of each storage technology listed above in Q. No. **11**

____

13. How much of maize grain do you think can lose associated with postharvest practices start from harvest to final consumption/selling?
a) Mould (%)___________ b) Insect (%)_________________c) Rodent (%)_____________
d)Poor postharvest management __________% e) Poor harvesting ________________%
f) Transportation ______________% g) consumption_____________________________%
14. What is the source information about mould in maize?

a) Personal observation**b)** Maize producing farmer**c)** From extension agents**d)**From agricultural office**e)**From research centers**f)**Training g) From media**h)**Other source (NGOs).

15. Did you train mould management?Yes------------- No--------------

I) If Yes, What type of teaching methods you use? **a)** Lecture type**b)**Practical or demonstration type**c)**Integration of the two**d)**Others methods

II) At what frequency? **a)** Once in month **b)**Quarterly **c)** Once in six month **d)** Once in a year

Date ___________________

Questionnaires for maize collectors and wholesalers

PART I: Harvesting Practices, Storage Technology and Associated Constraints of Post-harvest Practice of Maize in the study site

Name ____________________________ **Age** _______ **Sex** ________ **Education** ___________ **Town** ________________**Code**___________________

1**.** For how many years you have been involved in maize trading? ______________

2. From where do you collect maize? _______________________________________

3. Which variety of maize does you buy or sale? _____________________________

4. To whom you can sale maize? ____

5. Mention major problems in maize trading in your area? Including availability, quality, training systems and others ____

6. Is there a problem of mould formation in your store? **a)** Yes **b)** No

7. If yes, how is the incidence of maize mould in store? **a)** Increased **b)** Reduced **c)** Constant **d)** I don't observe/know the incidence

8. If the answer for question no. 6 is yes what do you think the major cause for this?_______

9. Do you have the problem related with storage structure? **a)** Yes **b)** No

10. Materials used for structures construction

i) Floor a) Cemented b) Soil c) Soil covered with plastic d) Cemented & covered with plastics

e) bamboo/wood f) others __________________________

ii) Roof a) ceiling b) not ceiling

iii) Wall a) Mud b) cemented c) other ________________________

11. Storage structure with window a) Yes b) No

12. Ventilation system with except window and door a) Yes b) No

13. Frequency of cleaning the whole store

a) Once per month b) Every two month c) Every six month d) Once per year e) other

14. Where do you store your maize a) Inside house b) Outside house c) Both d) other __

15.Doyouhave\any\ideatoimprove?

i) Maize production at farm level ____

ii)Maize quality improvement ____

iii) Trading ____

iv) Storage structures ____

16. List the major storage technology (storage management activities) applied for maize

Eg:- cleaning the store before storage of new maize; fumigation of store; etc _______

17. List the advantage and disadvantage of each storage technology listed above in Q. No. 12

Date ________________

Questionnaire to key stalk holders for post-harvest

1. Rank commonly produced maize varieties in your area (Put number 1 for most commonly used and 9 for less used)

Ser no.	**Maize variety**	**Rank**	**Remark**
1	BH660		
2	BH540		
3	Shone		
4	J30		
5	Local		
6			

2. Rank maize varieties susceptible for mould development (Put number 1 for most and 9 for less used)

Ser no.	**Maize variety**	**Rank**	**Remark**
1	BH660		
2	BH540		
3	Shone		
4	J30		
5	Local		
6			
7			

3. Rank maize varieties susceptible for insect pest (Put number 1 for most and 9 for less used)

Ser no.	**Maize variety**	**Rank**	**Remark**
1	BH660		
2	BH540		
3	Shone		
4	J30		
5	Local		
6			
7			

5. Rank the major maize production activities and postharvest handling your time spend compared to other activities (Put number 1 for most time spent and 9 for less)

Ser no.	**Activities**	**Rank**	**Remark**
1	Land preparation		
2	Sawing		
3	Weeding		
4	Protecting from animals (wild and domestic animals) before harvest		
5	Harvesting		
6	Drying		
7	Storing		

8	Shelling		
9	Selling		
10	Protecting from insect damage		
11	Protecting from mould formation		
12	Protecting from rodents		
13	Other, specify (		

6. Rank the major factors lead for mould development in stored maize (Put number 1 for most commonly used and 9 for less used)

Ser no.	**Factors**	**Rank**	**Remark**
1	Rain during harvest		
2	Varietal difference		
3	Less protected storage structures		
4	Long storage period		
5	Prolonged pre- storage of maize		
6	Keeping both mouldy and normal cobs together		
7	Un-proper drying		
8			

7. Rank the major postharvest Management of insect pest in stored maize (Put number 1 for most commonly used and 9 for less used)

Ser no.	**Activities**	**Rank**	**Remark**
1	Synthetic insecticides		
2	Use new storage structure		
3	Botanicals		
4	Sanitation of storage condition		
5			

8. If rank synthetic insecticides mention used to control insect pest

Ser no.	**Chemical used**	**Rank**	**Remark**
1	Malathion		
2	DDT		
3	Actalic		
4			
5			

9. Rank for what purpose you use mould maize grains (Put number 1 for most commonly used and 9 for less used)

Ser no.	**Activities**	**Rank**	**Remark**
1	Home consumption (human)		
2	Animal feed		
3	Income source		
4	For local drink		
5	Other		
6			

9. Rank how can you judge that maize ready for harvesting (Put number 1 for most commonly used and 9 for less)

Ser no.	Activities	Rank	Remark
1	Visual observation		
2	Shelling and checking for seed hardness		
3	Count months based on sawing date		
4	Using local knowledge like		
5	Other, specify		
6			

10. Rank type of maize storage structures you use (Put number 1 for most commonly used and 9 for less used)

Ser no.	Activities	Rank	Major advantage
1	*Gotera* /*Gombesa*		
2	*Dibignit*		
3	Sacks		
4	Pot made from clay		
5			

11. Rank maize postharvest loss at different stage staring from harvesting to consumption (Put number 1 for most and 11 for less used)

Ser no.	Activities	Rank	Major advantage
1	Pre - harvest drying		
2	Harvesting		
3	Post-harvest drying		
4	Shelling		
5	Storage		
6	Packing		
7	Loading and unloading		
8	Transportation		
9	Selling		
10	Processing for consumption		
11	Wastage on plate		