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Development of Maize Post-harvest Loss Reduction Mechanism Owing to Mycotoxin-producing Fungi Contamination Along Agro-ecology and Supply Chain in Southwestern Ethiopia

Dissertation for the acquisition of the academic degree
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Chemeda Abedeta Garbaba (M.Sc.)

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Witzenhausen, den 20.12.2018 Chemeda Abedeta Garbaba

Dedications

To my dad, Abedeta Garbaba who passed away during course of my study. He will always be in my heart.

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Chemeda Abedeta Garbaba Witzenhausen, December 2018

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Chapter 3 **Garbaba, C.A**., Denboba, L.G., Mendesil, E., Ocho, F.L., Hensel, O., 2018. Actors' post-harvest maize handling practices and allied mycoflora epidemiology in southwestern Ethiopia: Potential for mycotoxin-producing fungi management. Journal of Applied Botany and Food Quality 91, 237 – 248. https://doi.org/10.5073/JABFQ.2018.091.032

Chapter 4 **Garbaba, C.A**., Denboba, L.G., Ocho, F.L., Hensel, O., 2017. Nutritional deterioration of stored *Zea mays* L. along supply chain in southwestern Ethiopia: Implication for unseen dietary hunger. Journal of Stored Products Research 70, 7-17. http://dx.doi.org/10.1016/j.jspr.2016.10.004

Chapter 5 **Garbaba, C.A.,** Diriba, S., Ocho, F.L., Hensel, O., 2018. Potential for mycotoxin-producing fungal growth in various agro-ecological settings and maize storage systems in southwestern Ethiopia. Journal of Stored Products Research 76, 22-29. https://doi.org/10.1016/j.jspr.2017.12.001

Chapter 6 **Garbaba, C.A.,** Stache, C., Román, F., Hensel. O., 2018. Development of a photovoltaic driven ventilation system to modified traditional Ethiopian *gombisa* for on-cobs-maize drying. CIGR Journal (accepted paper)

Also, parts of the research work have been also presented on different international conferences and listed below.

Garbaba, C.A., Hensel, O., 2018. Actors' post-harvest maize handling practices and allied mycoflora epidemiology in southwestern Ethiopia: Potential for mycotoxin-producing fungi management. Poster presented on Tropentag 2018 Conference in Ghent, Belgium, from 17 – 19 September 2018.

Garbaba, C.A., Denboba, L.G., Ocho, F.L., Hensel, O., 2018. Nutritional deterioration of stored *Zea mays* L. along supply chain in south-western Ethiopia: Implication for unseen dietary hunger. International DAAD Alumni Expert Seminar "Hidden Hunger"12-19 March 2017 in Giessen, Germany in combination with the 3rd International Congress Hidden Hunger, 20-22 March 2017 in Stuttgart, Germa*ny.*

Garbaba, C.A., Ocho, F.L., Hensel, O., 2016. Fungal pathogens associated with stored maize and nutritional quality losses along supply chain in southwestern Ethiopia: Implication for food security. “Solidarity in a competing world-fair use of resources”, Tropentag, 19-21 September 2016, Vienna, Austria. http://www.tropentag.de/2016/abstracts/links/Garbaba_RnZxk8X0.pdf, *Abstract*.

Garbaba, C.A., Denboba L.G., Ocho, F.L., Hensel, O., 2015. Mycoflora epidemiology in post-harvest maize (*Zea mays* L.) at producers, collectors and wholesalers levels in Jimma Zone, Southwest Ethiopia: Implication for Mycotoxins producing fungi management: First African symposium on Mycotoxicology. “Reducing mycotoxins in African food and feed”. 26-28 May 2015. Livingstone, Zambia. http://reloadglobe.net/cms/images/resources/Abedeta%20et%20al.%202015_Mycoflora%20epidemiology%20in%20post-harvest%20maize_abstract.pdf, *Abstract*.

Garbaba, C.A., Denboba, L.G., Guluma, G., Ocho, F.L., Lellia, M., Hensel, O., 2015. Assessment of post-harvest loss reduction in maize due to aflatoxin contamination along value chain in southwestern Ethiopia. http://reload-globe.net/cms/attachments/article/57/PLANT2030_Poster%20SP5.pdf. *Abstract*.

Abbreviations and acronyms

AAS	Atomic Absorption Spectrophotometer
ADB	African Development Bank
AEO	African Economic Outlook
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
APHLIS	The African Post-Harvest Losses Information System
ASAE	American Society of Agricultural Engineering
ATNESA	Animal Traction Network for Eastern and Southern Africa
BH	Bako Hybrid
BMBF	Federal Ministry of Education and Research
Ca	Calcium
CFD	Computational Fluid Dynamics
CFU	Colony-Forming Units
CHO	Carbohydrate
CSA	Central Statistical Agency
d.b.	Dry Base
DC	Direct Current
DON	Deoxynivalenol
EARO	Ethiopian Agricultural Research Organization
EATA	Ethiopian Agricultural Transformation Agency
EMA	Ethiopian Meteorological Agency
EPHI	Ethiopian Public health Institute
ESSP	Ethiopia Strategy Support Program
EU	European Union
FAO	Food and Agricultural Organizations
FAOSTAT	Food and Agricultural Organizations Statistical Database
FDA	Food and Drug Administration
Fe	Iron
FF	Fungal Frequency
GDP	Growth Domestic Product
GLM	Generalized Linear Model
GTP	Growth and Transformation Program

GTZ	Deutsche Gesellschaft FÜr Technische Zusammenarbeit
ha	Hectare
hg	Hectogram
HLPE	High Level Panel Experts
HSD	Honestly Significant Difference
IFPRI	International Food Policy Research Institute
IICA	Inter-American Institute of Cooperation on Agriculture
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
MAFAP	Monitoring African Food and Agricultural Policy
m.a.s.l	Meter Above Sea Level
m.c.	Moisture Content
MEF	Ministry of Environment and Forest
MI	Mould Incidence
MOFED	Ministry of Finance and Economic Development
OTA	Ochratoxin A
OECD	Organization for Economic Cooperation and Development
PA	Peasant Association
PBO	Plant Biosafety Office
PH	Post-Harvest
PHL	Post-Harvest Loss
PHM	Post-Harvest Management
PV	Photovoltaic
RELOAD	Reduction of Post-Harvest Losses and Value Additions in East African Food Value Chain.
RH	Relative Humidity
SD	Standard Deviation
SEM	Standard Error of Mean
SSA	Sub-Saharan Africa
USID	United State Agency for International Development
w.b.	Wet Base
ZEA	Zearalenone
Zn	Zink
ZOFED	Zonal Office of Finance and Economic Development

Kurzfassung

In vielen ländlichen Gebieten Äthiopiens ist Mais mit seinem hohen Kalorienwert das vorherrschende Grundnahrungsmittel und zudem für die Landwirte eine wichtige Einkommensquelle. Hohe Nachernteverluste sind jedoch ein landesweites Problem, allerdings gibt es hierzu kaum belastbare Daten, die die Ausarbeitung einer Reduzierungsstrategie erlauben würden. Insbesondere gilt das für die Verluste durch Pilzbefall und die daraus folgende Mykotoxinbelastung, wie dies häufig in den heißen und feuchten Klimabereichen im Südwesten Äthiopiens der Fall ist. Die vorliegende Arbeit hat das Ziel, neue wissenschaftliche Erkenntnisse über Pilzbefall und Mykotoxinbildung sowohl in unterschiedlichen Klimazonen, als auch bei den verschiedenen Lagersystemen zu erarbeiten, um gezielt die Nachernteverluste im Süd-Westen Äthiopiens verringern zu können.

Die in fünf Distrikten durchgeführte Untersuchung zeigte zehn verschiedene Arbeitsschritte, die bei den Landwirten selbst oder den Zwischen- und Großhändlern nach der Ernte noch erfolgen. Die Nachernteverluste bei Mais wurden auf 31% geschätzt, wobei der Verlustanteil während der Lagerung als besonders kritisch zu sehen ist. Der Rest-Wassergehalt der Maiskolben bei deren Einlagerung hatte einen entscheidenden Einfluss auf die Lagerfähigkeit. Beim Vergleich aller biologischen Schadursachen rangierte der Verlust durch Pilzpathogene an der Spitze. Die Häufigkeit der Schimmelpilzbildung sowohl an Maiskolben als auch an gerebbelten Maiskörnern nahm mit zunehmender Lagerdauer signifikant zu. Sieben Pilzgattungen wurden identifiziert, wobei *Fusarium, Penicillium und Aspergillus spp.* die vorherrschenden Pilze waren, die in allen entnommenen Proben entlang der Lieferkette vorkamen.

Die Nährstoffanalysen von eingelagertem Mais aus verschiedenen Lagersystemen zeigten, dass der Protein-, Fett-, Kohlehydrat- und Brennwert signifikant während der Lagerdauer abnahm. Der Faser-, Aschen- und Mineralstoffgehalt stieg jedoch während der Lagerzeiten signifikant an. Der Gehalt an Phytat und Tannin schwankte in Abhängigkeit der Lagerdauer und der Klimazone. Anhand langjähriger Wetterdaten sowie eigener Messungen auf dem Feld und in den Lagerhäusern wurde gezeigt, dass sowohl vor als auch nach der Ernte günstige Bedingungen für ein Pilzwachstum bestehen.

Entsprechend wurde eine Weiterentwicklung der traditionellen *Gombisa*-Lagersilos vorgeschlagen und diese erprobt. Durch einen zusätzlich installierten solar betriebenen Ventilator wurde die Grundbauart der äthiopischen *Gombisa* optimiert und ermöglichte so eine Belüftungstrocknung der Maiskolben. Die Lufttemperatur und die relative Luftfeuchte innerhalb des Silos wurden aufgezeichnet und der Energieverbrauch des Lüftungssystems gemessen. Es konnte nachgewiesen werden, dass die modifizierte *Gombisa*-Version sichere Lagerbedingungen innerhalb des Silos ermöglicht und die Schimmelbildung verhindert.

Die Ergebnisse haben gezeigt, dass dieses Lagersystem das Potential hat, die Nachernteverluste in tropischen Regionen zu verringern. Dennoch besteht weiterer Forschungsbedarf, um die Massen- und Qualitätsverluste von gelagerten Maiskolben in tropischen Regionen im Vergleich zu weiteren Lagersystemen zu bewerten.

1. General introduction

1.1 Background information

Ethiopia has been mentioned as the fastest growing country in Africa with a GDP of 8% in 2016 and 10.4% in 2015 (ADB, 2016) and anticipated to grow with the similar path during 2016/17 (AEO, 2016). Industrialization activity showed improvement in Ethiopia with a major problem of exporting issue and power (AEO, 2016). Agriculture considered as the leading sector for country's growth and transformation plan (GTP, 2010). The ultimate goal of the plan is to increase food crop production and productivity targeting food self-sufficient for the rapidly growing population. It is also aimed to supply better quality products for the industry and export market. In view of this, availability of market information for producers is essential and enables them to produce products in line with demand of the market (GTP, 2010).

Ethiopia has developed specific corridors of specialization for commercialization of the production system, including promotion of post-harvest (PH) technologies which play a key role in improving the supply chain and sustaining product quality (GTP, 2010). Post-harvest management determines food quality, safety and competitiveness in the market. It is generally accepted that food security can be improved by producing large amounts through more land cultivation, increasing productivity and reducing agricultural products losses. Hence, reducing post-harvest loss (PHL) of agricultural products is one of the key areas of innervations to augment food availability in the country (GTP, 2010; ADB, 2016).

According to OECD/FAO, (2016) report cereal crops are the dominant and primary source of energy for nearly one billion peoples in sub-Saharan Africa (SSA) countries. The report also disclosed that among cereal crops, maize is top staple food crop play major role in food security in the region. Furthermore, it is also projected that maize crop continue dominating the cereal market and about 40% of total consumption by 2025 (OECD/FAO, 2016). In Ethiopia, maize, *teff*, wheat, sorghum and barely occupy nearly 75% of the total area cultivated (IFPRI, 2011). Maize is the main staple food crop and one of the main sources of calories particularly in the major maize producing regions of Ethiopia. The crop ranks first in total production and yield per hectare (Abate et al., 2015).

The maize sector plays a key role in Ethiopia but PHL is one of the challenging and tremendously high in the country (Ashagari, 2000; Sori and Ayana, 2012; Befikadu, 2014).

There are several factors responsible for maize PHLs, among which fungal pathogens and insect pest damage are major biotic factors that leads grain losses in the store (Khosravi et al., 2007; Sori and Ayana, 2012). Likewise, a survey conducted in a southwestern part of Ethiopia on PH fungal diseases of maize revealed that mean grain damage caused by mould and weevil were 37.8 and 20.9%, respectively (Meshesha, 2013). The same author reported an incidence of mould on-cobs-maize at harvest 14.7% at mid altitudes, 19.8% in lowlands and 20.1% in highlands of the maize growing agro-ecology of Jimma zone. This preliminary survey result showed the extent of maize grain mould distribution and the importance to create awareness about mould contamination and fungal damage, with the possible health hazards on humans and animals upon consumption. Further research recommendation was forwarded to undertake focused research efforts with the possibility to develop appropriate management options; and ensure improved pre and PH handling of maize.

Pietrowski, (2012) stated that issue related mycotoxins particularly aflatoxin problem is very complex for a number of reasons. These include inadequate awareness to develop solutions and, lack of sufficient and efficient technologies for PH handling of the products. Also, effective management requires participation of all actors along the maize supply chain. Furthermore, there is a need to develop inexpensive technologies for quick drying and better storage system that minimize mycotoxins production particularly aflatoxin contamination in the store (Pietrowski, 2012). Keeping those research gaps in mind, the current study was initiated with the following research objectives.

1.2 Reserach objectives and general methodology

The overall objective was to create new scientific knowledge on minimizing PHLs in maize that occur due to contamination of mycotoxin-producing fungi under different crop growing agro-ecology and actors' storage systems in southwestern Ethiopia. In order to address the ultimate goal of the research, survey, field study and laboratory analyses have been conducted in Jimma zone, southwestern Ethiopia. Finally, based on the findings, a modified storage structure was developed and tested under field condition. The following specific objectives have been set to meet the overall objective of the research.

to:

1. document maize PH handling practices and; identification of allied mycoflora and their epidemiology during storage at different stages of supply chain in southwestern Ethiopia.
2. identify effects of storage systems and agro-ecological settings on nutritional status of maize along supply chain in southwestern, Ethiopia.
3. investigate role of agro-ecology and storage methods for mycotoxin-producing fungi growth potential on maize in southwestern Ethiopia.
4. develop and experimentally test the performance of photovoltaic module fitted ventilation system to modified Ethiopian *gombisa* for on-cobs-maize drying and storage.

1.3 Research questions

- What maize post-harvest activities practiced by different actors and associated fungal pathogens fauna especially mycotoxin-producing fungi that resulted in quantity and quality losses at different agro-ecology and storage systems in southwestern Ethiopia?
- Is there possibility to improve locally available storage structure as modified *gombisa* for on-cobs-maize drying and storage to minimize mould occurrence inside the store?

1.4 Thesis outline

Maize PHL resulted in both quantity and quality declines causing in reduction of available food for consumption and loss in income. Taking into account of food shortage and need of food aid in Ethiopia, it is pertinent for realization of PHL reduction mechanism of staple food crops. It is generally accepted that PHL reduction is cost effective and environmentally friendly to address food security both in quantity and quality. In spite necessitate for tumbling PHL, inadequate research work have been done so far that gears to reduce maize PHL along supply chain in southwestern Ethiopia. Furthermore, the region characterized by hot and humid climatic condition that support development of mycoflora on the stored products. Considering this general background, current thesis work was structured and described as eight chapters.

Chapter one describes general background of the study, presents both general and specific objectives and structure of the thesis. It presents brief information about economic growth of Ethiopia and agricultural key role for the system. It also introduce about importance of maize in SSA particularly in Ethiopia. Preliminary works on maize PHL focusing on fungal pathogens in the storage system in the country was presented. Chapter two provides current literature covering state-of-the-art for this research work. The first part presented review of maize importance, PH management and losses in global, continental and also in Ethiopia cases. The second part of the review deals with the role of mycotoxin-producing fungal pathogens in maize PHL and possibility of health effects on human and animals feed on contaminated product. Also, some of the mitigation strategies have been addressed. Lastly, different types of maize storage structures in Ethiopia including opportunities and limitations of the systems have been incorporated under this chapter.

Chapter three describes standard survey methods and procedures for maize PH handling practice documentation and associated fungi pathogen epidemiology along the maize supply chain in southwestern Ethiopia. It highlights maize PH handling practices by different actors, loss estimated and critical loss point. Generally, this chapter presents role of maize PH handling practices in reducing PHL. While, chapter four deals with maize quality loss that complement quantity loss described under chapter three. This chapter highlights the role of different storage methods on substantial quality losses of stored maize along supply chain.

Chapter five deals with the potential role of weather conditions on mycotoxin-producing fungal growth at different agro-ecology and storage methods along maize supply chain in southwestern Ethiopia. The methodology part describes different storage methods and testing procedures. The findings showed the potential role of temperature and relative humidity on mycotoxin-producing fungal occurrence under storage conditions. Finally, results provides under chapter three, four and five utilized as foundation for chapter six. Chapter six provides information for reduction of maize PHL due to mould development inside the store by developing modified *gombisa* and test the system that used photovoltaic module for maize drying and storage under field condition. The findings of developed and tested modified *gombisa* were presented. While, chapter seven draws important general discussion which includes chapters considered for current study. Implication of the current research for maize PHL reduction and future research direction also indicated in this chapter. Whereas, chapter eight provides summary for the research work both in English and Germany language (Fig. 1.1).

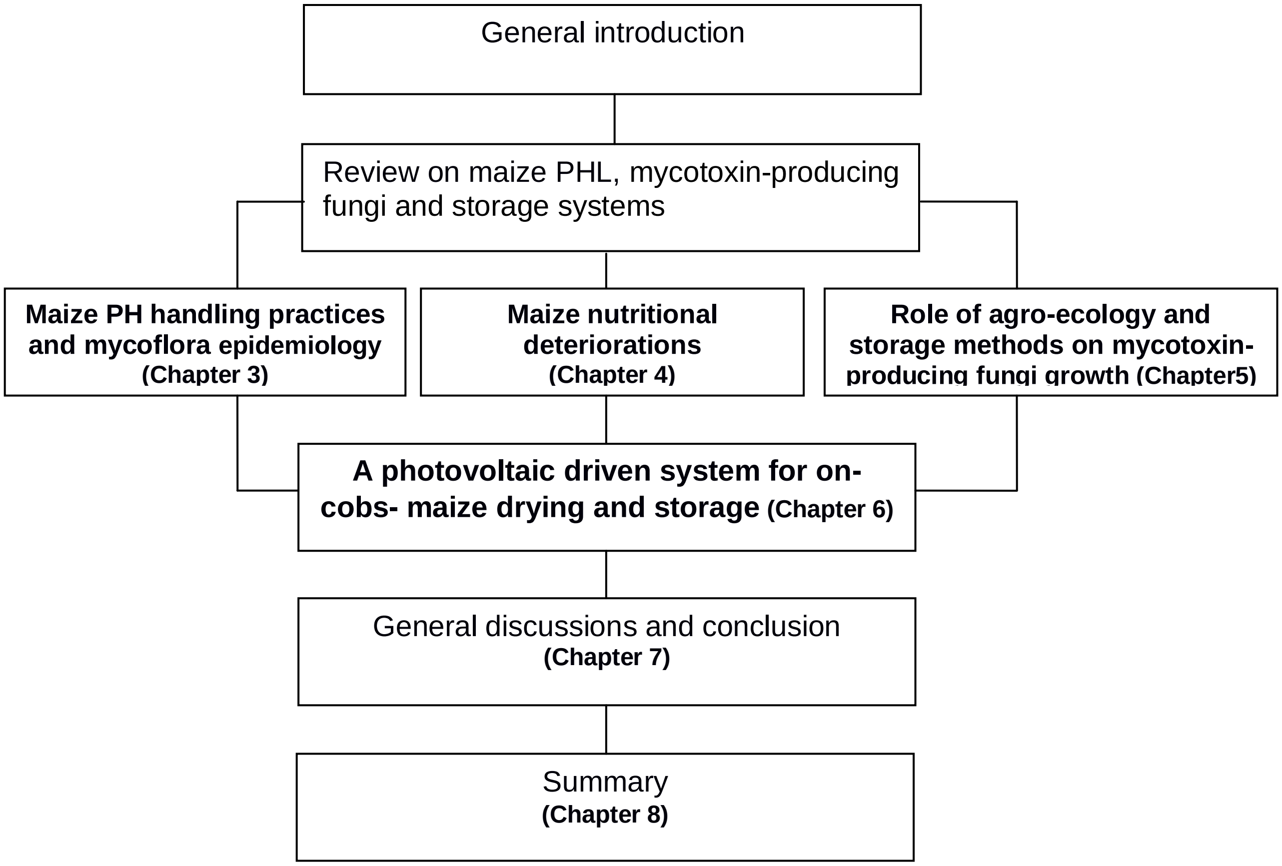

Figure 1.1 Schematic of the thesis

1.5 References

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2 State-of-the-art

2.1 Maize taxonomy, production and global importance

Maize or corn (*Zea mays* L.) botanically belongs to family *Graminae* (*Poaceae)* and commonly identified as the grass family. The genus *Zea* consists of four species of which *Z. mays* is economically important one. *Zea mays* contains chromosome number of 2n = 20 (Doebley, 1990; PBO, 1994; MEF, 2011). Maize is an annual crop growing up to 4 m tall with fiber type root system and its leaves are arranged in two opposing rows. Photo-synthetically, maize is grouped into C4 pathway which helps the crop for higher yield and biomass potential (Kellogg, 2013). The inherent nature of maize, which is predominantly cross-pollinated species, favors the crop to adapt for wide ranges of agro-ecological settings and morphological variability (Kogbe and Adediran, 2003).

Maize is among the top three food crops with wheat and rice dominantly used as food source globally (FAOSTAT, 2017). Maize is cultivated under wide range of agro-climatical conditions and soil types than any other crops (Shiferaw et al., 2011). The global area cultivated, yield and production for ten years (2007-2016) is indicated on figure 2.1. The trend depicted that there was an increment both in production (tonnes) and yield (hg/ha) of maize during 2007-2016. The percent shared by regions account for 52, 29.6, 11.1, 7.2 and 0.1 for Americans, Asia, Europe, Africa and Oceania, respectively (FAOSTAT, 2017). Also, FAOSTAT (2017) data showed that United State of America, China, Brazil, Argentina, Mexico, India, Indonesia, Ukraine, France and South Africans were among the top ten maize producers in decreasing order. Shiferaw et al. (2011) demonstrated that, maize is an important food security crop especially for Africans and Latin American. The authors also stated that, in SSA, especially in East and southern Africa, and West and Central Africa the crop account 73 and 64% as food source with respective order. Furthermore, the authors also indicated maize as one of the most staple food crop and source of income in the region. Maize is mainly produced by smallholder farmers in SSA dominantly for food (M'mboyi et al., 2010; Smale et al., 2011). Maize has the largest numbers of ways it can be utilized compared to other cereals and crucial for food security in SSA (M'mboyi et al., 2010).

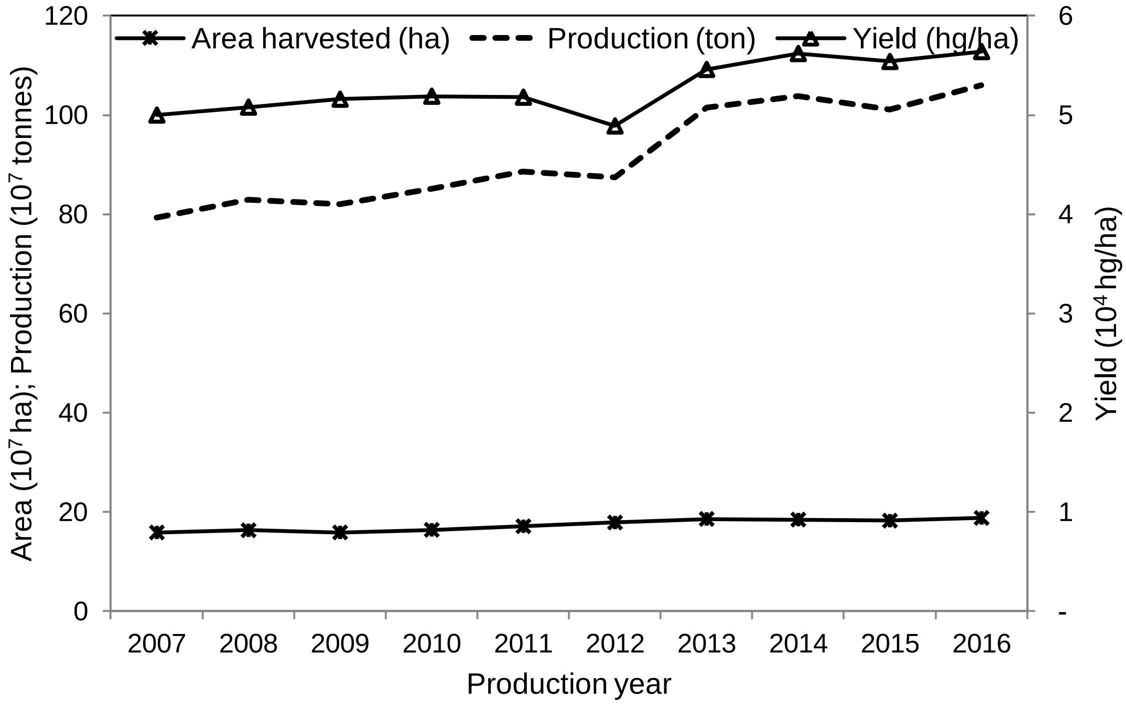

Figure 2.1 Global maize area harvested, production and yield for ten years (Compiled from FAOSTAT, 2017)

The consumption rate of maize and its processing vary greatly from place to place and region to region (Ranum et al., 2014). Maize dominantly contains starch and relatively less protein and fat compared to rice and wheat (Nuss and Tanumihardjo, 2010; Ranum et al., 2014). Nuss and Tanumihardjo (2010) stated that maize kernels constitutes starch, protein and micronutrients that are required for human health, as a result the crop become highly integrated into global agriculture, human diet and cultural traditions.

Sub-Saharan Africa, Southeast Asia and Latin Americans depend on maize as main staple food crop. On the other hand, different countries including USA, China, India and Brazil have been using maize as alternative source as bio-fuels ethanol production (HLPE, 2013). Ranum et al. (2014) stated that maize processing for ethanol productions generate very useful byproducts that can serve as feed for livestock. The authors further stated that in addition to human consumption and animal feed, maize is used to bi-produce corn oil, corn starch, corn syrups, alcoholic beverages and other industrial applications. Outstandingly, maize is one of the key and versatile crops used for different purpose and produced under wide range of agro-ecological settings.

2.2 Maize production and importance in Ethiopia

In Ethiopia, maize ranked on top both in total production and yield compared to any cereal crops produced in the country (IFPRI, 2012; Abate et al., 2015). The crop is predominantly produced under rain-feed condition and diverse range of agro-ecological settings throughout the country. As result, maize is the dominant crop grown by more than nine million households in Ethiopian (Abate et al., 2015). The authors also described the annual growth rate of households producing maize is 3.5% and greater than any of the cereals produced in the country. Maize is considered amongst the top commodities contributing to food security in Ethiopia due to its wide adaptability, high production, productivity and relatively cheap calories source compared to other cereals. As result, it has been included in the national food security strategy via intensive agriculture system (Demeke, 2012; Abate et al., 2015). FAOSTAT (2017) data for ten years on area cultivated, production and yield per hectare showed an increment trend of 8.4, 84.9 and 70.5%, respectively (Fig. 2.2). Abate et al. (2015) reported that maize production and productivity in Ethiopia has doubled its yield in less than two decades and second in SSA in yield/ha next to South Africa. According to the authors improved varieties, use of modern inputs via extension-linkages, wide range adaptability of the crop, low production risk, increment for consumption trend and market access are among the major factors that geared maize expansion and change productivity in the country.

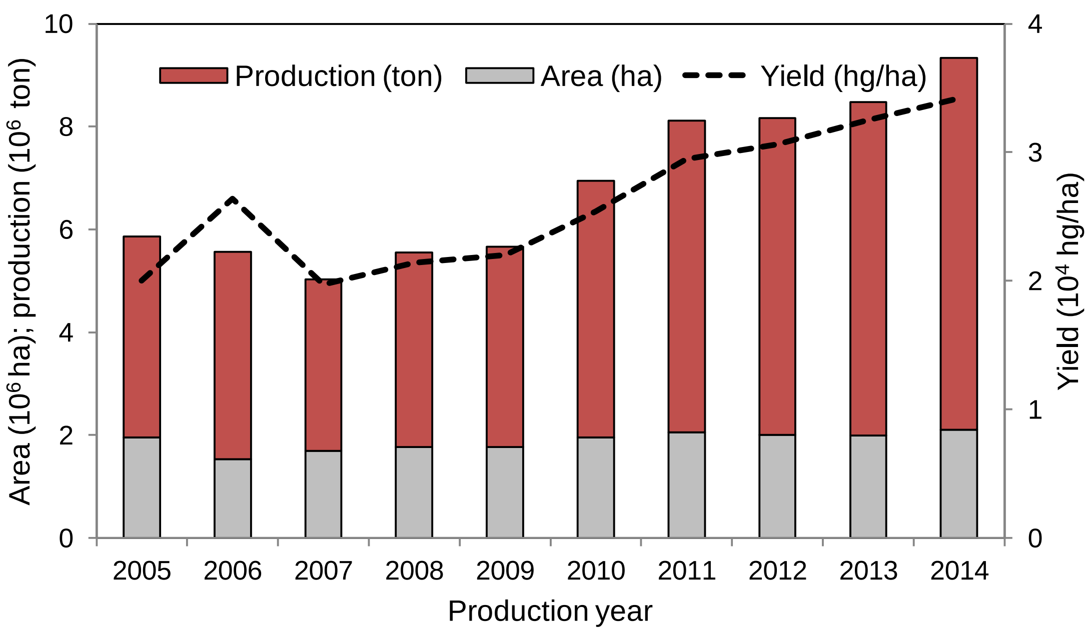

Figure 2.2 Maize area cultivated, production and yield for year 2005-2014 in Ethiopia (Compiled from FAOSTAT, 2017).

2.3 Maize post-harvest management and losses

2.3.1 Maize post-harvest handling practices

Maize, similar to other crops passes through PH chain of activities to reach consumer baskets. However, there are slight differences in maize PH handling practices between countries even within country. For instance, chain of activities includes harvesting, transportation of the harvest products, storage, processing, packing and marketing in Tanzania (Abass et al., 2014). On the other hand, chain of activities including on farm drying, harvesting, transportation, sorting, storage, transportation to market and selling for the consumers are among major activities performed in southwest of Ethiopia (detail information indicated on chapter 3 of this thesis). Rembold et al. (2011) also described maize PH chain of activities in SSA includes harvesting/field drying, transport to homestead, drying, shelling, winnowing, farm level storage, transportation to market and market level storage as major chain of activities. Furthermore, Kumar and Kalita (2017) also stated during crop move from producers to consumers, it passes through different chain of activities including harvesting, threshing, cleaning, drying, processing and transportation.

2.3.2 Maize post-harvest loss

Post-harvest losses (PHLs) can be defined as a quantifiable decrease of grains along PH chain of activities that resulted in quantitative, qualitative and economic losses or unsuitable for consumption (Hodges et al., 2011; Gitonga et al., 2013; Kumar and Kalita, 2017). Review by Kumar and Kalita (2017) indicated that PHLs in supply chain greatly vary among different crops, areas and economies of the country. For instance, in developing countries PHL is significant during PH chain of activities, while in developed countries occurs at the end of the chain. Maize is one of the dominant staple food crops but PHLs occurring along chain of activities are significant throughout the globe. For example, in Bangladesh it account 4.07% (Bala et al., 2010); in Ecuador 10-30%, Guatemala about 50%, panama (20%) and 15-25% for Peru (IICA, 2013).

In Africa, maize PHLs were estimated between 14 - 36% (Tefera, 2012). Losses in weight of the same commodity in eastern and southern Africa was projected at 17.5% (Rembold et al., 2011) and 41% - 80% in Ethiopia (Sori and Ayana, 2012). In Ghana, up to 15% weevil attack was reported for five weeks stored maize (Baidoo et al., 2010). In southwestern Ethiopia, maize PHL was estimated to 31% (indicated on chapter 3). However, globally there are a range of definitions exists for PHL by different entities around the globe which has great impacts on methodologies to be used for measurements and quantifications of the losses. As clearly summarized by HLPE (2014) "*Different definitions, metrics, measurement protocols and the lack of standards for data collection adapted to different countries and products make it difficult to compare studies, system and countries*". p.11.

2.4 Role of mycotoxin-producing fungi in maize post-harvest loss

2.4.1 Mycotoxin-producing fungi occurrence in maize under post-harvest conditions

Different fungal pathogen species belong to genera of *Aspergillus*, *Penicilliun* and *Fusarium* are known to produce mycotoxins before harvest or/and PH conditions and resulted in high maize PHL (Wagacha and Muthomi, 2008). In similar manner study from Ethiopia confirmed that *Fusarium, Penicillium* and *Aspergillus* spp. were the most significant and dominant mycotoxin-producing fungal pathogens occur in maize and resulted in PHL (Tesfaye and Abate, 2000). More specifically, research conducted in southwestern Ethiopia also showed those fungal genera were dominantly identified along maize supply chain under different storage methods, storage periods and agro-ecologies contributed for PHL (Befikadu, 2014; Garbaba et al., 2018). *Fusarium, Penicillium,* and *Aspergillus* were predominantly identified mycotoxin-producing fungal genera from traders samples collected from different agro-ecologies in Ugandan (Kaaya and Kyamuhangire, 2006). Up to 96, 63 and 32% infection levels of stored maize were made by *Fusarium, Aspergillus* and *Penicillium* spp. respectively from Cameron (Tagne et al., 2003). Several studies confirmed that those three fungal genera were the most ones across maize PH activities and cause losses (Kulkarni and Chavan, 2010; Mostafa and Kazem, 2011; Toffa et al., 2013; Bosah and Omorusi, 2014).

Mycotoxin-producing fungal pathogens growth and development can be affected by abiotic, biotic and handling practice both pre- and PH activities. Specially, environmental conditions like high temperature and relative humidity play key role for growth and development of mycotoxin-producing fungal pathogens inside the stored products that leads to high PHL. Additionally the target fungal genera are capable to produce secondary metabolites under these favorable environmental conditions (Shotwell et. al. 1975; Homdork et al, 2000; Lewis et al*.,* 2005; Popovski and Celar, 2013). It is generally accepted that, infection, growth and expansion of storage fungi mainly depends on the moisture content of the kernels during loading and subsequent activities. Furthermore, poor handling and storage practices, inappropriate transportation along chain of activities have great contribution for fungal growth and mycotoxins production.

2.4.2 Major mycotoxins produced in stored maize

Mycotoxins are secondary metabolites, toxic compounds commonly produced by *Aspergillus, Fusarium,* and *Penicillium* fungal genera and able to contaminate different agricultural crops both under field and PH conditions (Golob, 2007; Schmidt, 2013). Mycotoxin refers to a "poisonous substance produced by fungi" (Ashiq, 2015). *Fusarium*, *Aspergillus* and *Penicillium* are ~~also~~ the dominant fungal genera which infect PH maize and produce mycotoxins (Gonzalez et al., 1995; Nesci et al., 2003). Out of hundreds of mycotoxins, aflatoxins, Ochratoxin A (OTA), Fumonisins, Zearalenone (ZEA), Deoxynivalenol (DON), and Patulin are known as the most important concerning human and animal health and economic impact globally (Nesci et al., 2003). Major myctoxin-producing fungal species, mycotoxins produced and the health conditions they may cause are summarized in Table 2.1. In general, in addition to quantitative, qualitative and economic losses caused by mycotoxin-producing fungi; health implication of contaminated products on animals is also enormous.

Table 2.1 Major myctoxin-producing fungal species, mycotoxins produced and toxicology in animals fed on contaminated maize products.

Major mycotoxin-producing fungi	Mycotoxins produced	Health implications/ toxicology	Comment
A. flavuse, A. *parasiticus*	Aflatoxins	Hepatocellular carcinoma, liver lesions, stunted growth in children, depressed immune response, carcinogen	Can survive ensiling process
F. proliferatum, F. verticillioides	Fumonisins	Neural tube defects, esophageal cancer in humans, liver and kidney damage in domestic animals	Very stable, can survive cooking
F. culmorum	Zearalenone	Reproductive disorders, infertility, early pubertal changes, increased blood clotting time, increased susceptibility to disease	Very stable, can survive cooking
F. graminearum	Deoxynivalenol	Vomiting, fetal skeletal deformities, diarrhea, headache, gastroenteritis, increased mortality	Very stable, can survive cooking
P. verrucosum, A. ochraceus	Ochratoxin A	Kidney lesions, Balkan endemic nephropathy, urothelial tumors	-

(Source: Golob, 2007; Ashiq, 2015)

2.5 Mitigation strategies of mycotoxins

Broadly management of mycotoxins categorized as preventive and curative methods (Enyiukwu et al., 2014). On the other hand, Wagacha and Muthomi (2008) stated three possible intervention strategies for mycotoxins 1) Proper practices during production, harvesting, storage, transportation, marketing, processing and legislation to prevent exposure of the commodity to mycotoxins 2) Decontamination of the contaminated food and feed products 3) Surveillance, inspections and awareness creations to carry out good agronomic and PH practices to minimize the cause. Alternatively, Hell and Mutegi (2011) proposed four aflatoxin control and prevention strategies 1) Stopping infection processing through developing resistant varieties and control responsible fungal pathogens growth in the field using biological agents 2) Controlling environmental factors that facilitate growth and dispersal of fungal pathogens 3) Good agronomic practices during pre-harvest 4) PHM practices especially focusing on moisture content and temperature that aggravate production of Aflatoxin. Adeyeye, (2016) described that mycotoxins prevention and control in foods generally categorized in to three 1) Plant breeding (using resistant varieties) 2) Good agronomic and handling practices and 3) Detoxification/ decontamination to minimize mycotoxins contamination in agricultural commodities.

2.6 Maize storage structures in Ethiopia: Opportunities and limitations

Maize is the key cereal crops dominantly produced in the country and instrumental for the food security for millions of households (IFPRI, 2010). However, maize PHL is still the key limiting factors especially inadequate and insufficient access to cost-effective on-farm storage technologies that reduce quantity and quality loss (EATA, 2013). Traditional storage structures such as *gombisa, dibignit, gotera*, and sacks are the most commonly used for maize storage in Ethiopia (Tadesse and Basedow, 2004; Abebe and Bekele, 2006; IFPRI, 2010; Garbaba et al., 2017). However, those structures make maize susceptible to bio-deterioration especially owing to the hot and humid climate condition of southwestern Ethiopia. Furthermore, structures are not highly protective from external climatic conditions and resulted in fungal growth (IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014; Garbaba et al., 2018). It was clearly indicated that storing maize in these traditional structures resulted in quality and quantity loss. As a result research recommendation was forwarded the need for low-cost, climatically controlled storage structures that are simple to operate and accessible to the resource-poor farmers in the country (Garbaba et al., 2017; 18). In addition to lack of better on-farm storage technologies, insufficient skilled personnel within easy reach of smaller holder farmers is other limitations to reduce maize PHL in the country (EATA, 2013). EATA (2013) suggested intervention strategies as "*Research should be conducted on locally available on-farm storage technologies for modification and possible innovations that could significantly improve the cost effectiveness of on-farm storage and minimize maize PHL*". p.42. Evaluation of metallic silo performance for on-farm grain storage structure in three regions of Ethiopia implemented as participatory approach showed promising and effective in protection of storage insect pests with side benefits of avoiding use of chemicals, saving money and increase income (Ali et al., 2016). However, there was no information indicated about storage fungi (especially mycotoxin-producing fungi which need attention) during six month storage and experimental periods.

The-state-of-the-art revealed the global and national importance of maize as source of food, feed and fuels. Also, review of literature disclosed high maize PHL that affects food security in developing countries especially subsistence farmers in Ethiopia. On the other hand, loss assessment addressing along supply chain was not fully carried out in Ethiopia to figure out the extent of losses to develop intervention strategies. Similarly, Information on mycotoxin-producing fungi along supply chain was not adequately assessed. Furthermore, maize quantity and quality losses including chain of activities were not sufficiently assessed in southwestern, Ethiopia. Challenges of using traditional storage structures for both quantity and quality losses also not investigated. Consequently, current research work tried to address and seal those key research gaps as it indicated in detail under chapter three, four, five and six.

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3 Actors' post-harvest maize handling practices and allied mycoflora epidemiology in southwestern Ethiopia: Potential for mycotoxin-producing fungi management

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3.1 Abstract

Maize plays a key role in household food security in Ethiopia, but post-harvest loss is among the major challenge. This study was thus initiated to assess post-harvest practices and associated fungi pathogen epidemiology along the maize supply chain in southwestern Ethiopia. The study was conducted in five purposively selected districts and a three-stage sampling procedure was employed for the selection of the target groups. In total, 342 participants from different actors were interviewed using semi-structured questionnaire. Maize samples were collected every month from 63 randomly selected actors for mycological analysis during six months of storage periods. Survey results showed 10 post-harvest activities practiced by actors. Post-harvest loss has been estimated to be 31% and loss during storage was identified as a critical loss point. Comparing all biological agents, loss due to fungal pathogens in the store ranked on top. Moisture content at loading stage could not increase the shelf life of the commodity. Germination test showed a significant ($P < 0.01$) decrease as storage duration increased, while mould incidence on cobs and kernels significantly ($P < 0.05$) increased as storage duration increased, In total, seven fungal genera were isolated, characterized and identified, with *Fusarium, Penicillium* and *Aspergillus* being predominant. *Penicillium* and *Aspergillus* spp. showed positive increment with storage duration which needs priority attention for the control of those well-known mycotoxin-producing fungi. However, *Fusarium* spp., decline as storage duration increases. Most of the post-harvest practices are not effective in reducing post-harvest losses. Especially, farmers' traditional storage structures can be influenced by external climatic conditions and makes the grains liable to develop mould during the rainy season. This research, therefore, highlights the need to design/develop or modify existing storage technologies that reduce post-harvest loss due to mycotoxin-producing fungal pathogens. Furthermore, post-harvest drying to obtain optimum moisture content is also crucial to reduce losses.

Keywords: Mould, post-harvest management, post-harvest loss, storage fungi, stored maize

3.2 Introduction

Food security is a major challenge in sub-Saharan African countries. Whilst increasing production through crop intensification has been suggested, the reduction of post-harvest losses (PHLs) has received little attention. Globally, PHLs has been estimated at one-third of the produce but it could be higher in sub-Saharan Africa (FAO, 2011). The magnitude of PHLs due to deterioration of quality seems to be at a level similar to quantity losses. For instance, the caloric loss is estimated at 24% of all food produced (Lipinski et al., 2013). This suggests that PHL reduction can play a key role to improve food, nutritional security and household income. It is also considered as the easiest, and cheapest option for resource conservation (Yahia, 2008).

The food security and economic wellbeing of Ethiopia, in general, depends on agriculture. Maize is considered amongst the top commodities contributing to food security due to its wide adaptability, high production, productivity and relatively cheap calories compared to other cereals. As a result, it has been included in the national food security strategy via intensive agriculture system (Abate et al., 2015). Maize production and productivity in Ethiopia has doubled in less than two decades and is the second in sub-Saharan Africa in yield/ha (Abate et al., 2015). However, this boost in production and productivity threatens to be negated by high PHLs, further affecting food security. For instance in Africa, maize PHLs were estimated at 14% to 36% (Tefera, 2012). Losses in weight of the same commodity in eastern and southern Africa was estimated at 17.5% (Rembold et al., 2011) and 41% to 80% for maize stored for six months using farmers traditional storage in Ethiopia (Sori and Ayana, 2012). In Ghana, up to 15% weevil attack was reported for five weeks stored maize (Baidoo et al., 2010).

Maize PHLs occur along the whole activity chain including harvesting, drying, shelling, transport to store, storage, transport to market and processing for consumption (Rembold et al., 2011). As a result, different research recommended commodity handling system analysis as the rational step in identifying suitable tactics for reducing PHLs along the activity chain (LaGra, 1990; Bell et al., 1999; Kitinoja and Gorny, 1999; Kader, 2005). However, several authors have been reported maize PHL in Ethiopia in general and southwestern in particular without considering those chain of activities and analysis handling systems (Ashagari, 2000; Dubale et al., 2012; Sori and Ayana, 2012; Befikadu, 2014). Consequently, issues leading to high PHLs were not fully identified and characterized along the activity chain in order to reduce losses. Identifying local available post-harvest (PH) technologies and practices along the maize PH activity chain should be the first step in designing loss reduction strategies.

An efficient PHL reduction strategy for maize basically depends on the ecological conditions of storage which includes, physical, chemical and biological characteristics of the maize grain; the storage period and type; and functional characteristics of the facility (Golob et al., 2002 ; IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014). Despite the realization of the importance of storage, the potential impact of destructive storage pests (especially fungus) that cause quantity, nutritional and financial losses has not been well researched (Fourar-belaifa et al., 2011). Furthermore, maize PHL by fungal pathogens is not only of economic importance but is also a public health concern due to the possible production of mycotoxins (Golob, 2009). *Aspergillus, Fusarium* and *Penicillium* spp. are the top three mycotoxins producing fungi in food and feed in the tropics and sub-tropics along production chains. Generally, contaminated kernels by consuming those mycotoxins, particularly aflatoxin, resulted in illness, death, immunological suppression, liver cancers and nutritional interference (Rundbergeta et al., 2002; Jonathan et al., 2004; Stumpf et al., 2013 and Kiarie et al., 2016).

Study findings reported that on-farm storage practices and structures in southwestern Ethiopia, such as *gombisa,* can make maize susceptible to different types of damage, including storage pests and mould development (IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014). Furthermore, research findings reported maize PHL based on point data taken once or twice, and sample collection for loss assessment without considering the full storage duration until the product was depleted. At the same time, previous researches only focused at the farmer level without considering other actors along the maize supply chain that play a key role in maize transactions. In addition to farmers, collectors (small traders) and wholesalers play key role in maize transaction in Jimma Zone. Therefore, the current research project was designed to assess maize post-harvest handling practices and the fungal pathogens dynamic associated with maize stored by producers, collectors, and wholesalers in selected districts of the Jimma zone in southwestern Ethiopia.

3.3 Materials and methods

3.3.1 Study site

The study was conducted in Jimma Zone, which is situated in southwest Ethiopia at 7°15´ and 8°56´ N latitude and 36°00´ and 38°38´ E longitude. The elevation of Jimma Zone ranges from 800 to 3360 m.a.s.l. The agro-ecological setting includes highlands (15%), midlands (67%) and lowlands (18%) (CSA, 2009; ZOFED, 2013). For the current study, five districts namely Dedo from the highlands, Kersa, Omonada and Mana from the midlands; and Sokoru from the lowlands agro-ecology were purposely selected based on their high maize production potential and varied agro-ecological conditions (Fig.3. 1).

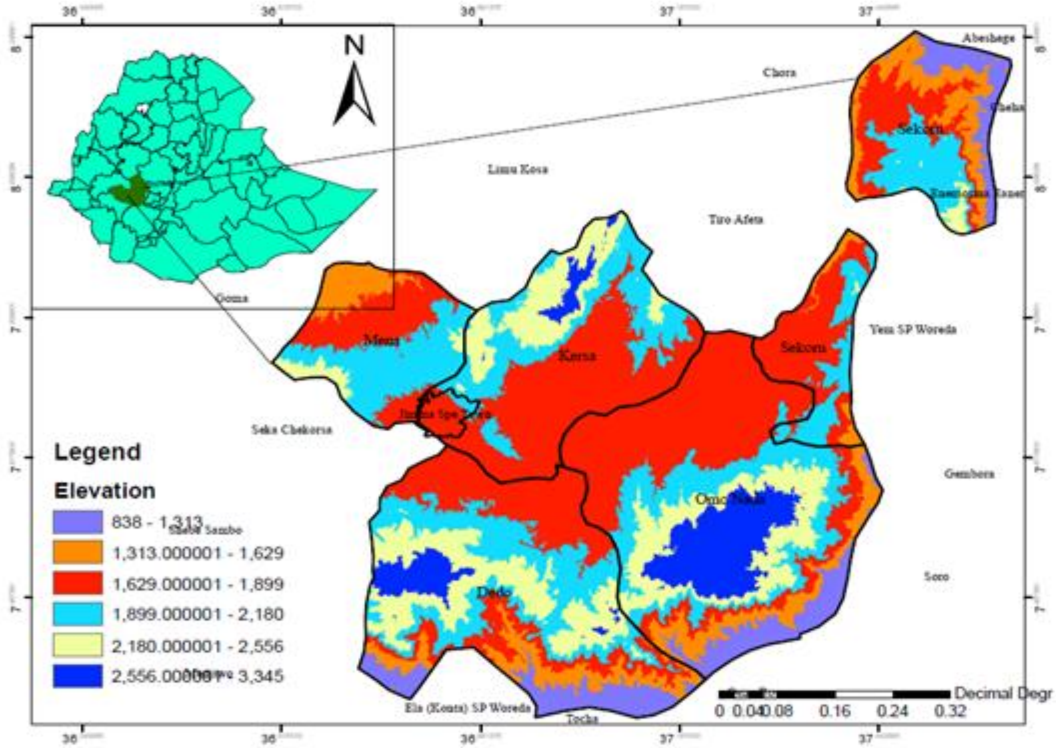

Figure 3.1 Study area map with different agro-ecology of the study districts of Jimma Zone, Southwestern Ethiopia.

3.3.2 Participant selection

A three-stage sampling procedure was used to select participants. Jimma Zone was purposively selected from the southwest part of the country due to its high maize producing potential and it's not previously well investigated regarding storage technology and associated issues. Five districts ranking among top maize producers and representing variable agro-ecology from the aforementioned zone were selected purposely based on secondary data from Jimma Zonal Agricultural Office. After discussion with Agricultural Office experts and extension agents from each district, three *kebeles* (the lowest administrative region, Peasant Associations, PAs) were selected based on agro-ecological settings and the potential for maize production. Considering the total population of each PA, sample size (the number of participants) were selected from the households was determined using sampling formula with a 95% confidence level (Yamane, 1967 as cited by Ajay and Micah, 2014) as indicated below.

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

Where n is the sample size; e is the level of precision at 5% and N is the total number of maize producing household in selected PA. After determination of sample size, a list of all household was collected from each PA and respondents were selected randomly using Minitab randomization software. Similarly, a number of collectors from each district and wholesalers from Jimma town were randomly selected and used for data collection. For triangulation and validation of the information collected, key informants from farmers, developmental agents, experts at districts and Zonal level were also interviewed. Collectors and wholesalers also included in order to acquire the desired depth of information and a total of 342 participants were involved in the study.

3.3.3 Data collection techniques

The study was conducted from January 2014 to June 2015. Both quantitative and qualitative data were collected from secondary and primary sources in the selected districts and communities. Secondary data were collected from the archives of various organizations. Semi-structured questionnaires covering socio-economic, demographic data, maize post-harvest handling practices and associated issues were collected during field surveys via village meetings, key informants, and individual interviews. House to house interviews were carried out with the help of developmental agents from each PA. Semi-structured questionnaires were prepared accordingly for each participant (farmers, key informants, traders and experts) to generate reliable data. Pre-test interviews were conducted before actual data collection at each study site and amendments were made before the final interview.

From each PA, three farmers were randomly selected from those growing the dominant BH-660 maize variety and storing their maize in a local storage structure, called *gombisa,* of uniform structure. In total, 45 farmers were included for the mycological study of the maize samples collection. Similarly, three local collectors from each district (15 in total) and three wholesalers from Jimma town were also included in the fungal pathogens assessment of maize kernels sample. Disease assessment and sample collection started at harvest and loading stage (farmers) then continued with monthly intervals up to six months, at which time most of the participants' stored product depleted from all actors store.

3.3.4 Experimental designs

A 3 × 6 factorial design was used for the determination of the germination test, mould incidence on-cobs- and maize kernels stored in the farmers' traditional storage structures. Three agro-ecological levels (highland, midland, and lowland) and six-month storage duration with monthly interval data collection were used at the farmer level. Three farmers from highland and lowland agro-ecological setting were used as replicates. But, average of the three districts used as replication for midland agro-ecology since maize dominantly produced in this agro-ecology. All factors including storage structures, maize variety, and management practices were kept uniform to minimize experimental error. Similarly, for the collectors 3 × 6 factorial design was used that included the three agro-ecological levels of the respective districts and six-month storage duration with a monthly interval for the determination of germination test and mould incidence of maize kernels. For all collectors, the same maize variety, open-weave sacks and management practices used were uniforms. In a similar manner, three collectors from each district were used as replicates. For the wholesalers, three actors were included in the study with six level of storage duration. A completely randomized design was used for determination of germination test and mould incidence on kernels as samples were collected from Jimma town alone for wholesaler storage conditions.

3.3.5 Germination test and moisture content

The germination test was undertaken by randomly selecting 150 maize kernels from each sample lot. The test was done in triplicate: 50 kernels per replication. Maize kernels were sown in 9 cm Petri-dishes lined with filter paper (Whatman No.1), moistened with distilled water and then placed on a clean laboratory bench at room temperature (25°C) for 7 days. The germinated seeds were visually examined for the appearance of radical and/or plumule and the germination percentage was computed following developed method (Ogendo et al., 2004).

Germination (%) = $\frac{a}{b}$X100

Where *a* stands for a number of germinated kernels, and *b* stands for the total number of plated kernels.

The moisture content of the sample maize was determined using a digitally calibrated moisture tester (Wile[55] TR serial number 554601 by Farm comp Agro-electronics, France) on the spot (Farhan et al., 2013).

3.3.6 Mycological analysis

Six cobs from each farmer's store were brought for laboratory analysis. Similarly, two kilograms of maize kernels from every trader's store were sampled by deep probing at three layers of each sack, then mixed together and brought for mycological analysis under laboratory conditions.

3.3.6.1 Mould incidence on-cobs-maize

Sixty cobs were picked from a different level of each farm storage structure (top, centre, and bottom) and fed through PVC pipe fitted at the middle and bottom of the *gombisa* which allowed removal of sample cobs from the store. Twenty cobs sampled from each layer were used as replication (Atukwase et al., 2012). A visual inspection and scrutiny for kernel infections on each cob was made to record mould in order to calculate the incidence following (Meer et al., 2013).

Mould incidence (MI) on-cobs-maize = $\frac{a}{b}$X100

Where *a* stands for a number of infected cobs while *b* stands for a total number of cobs assessed.

3.3.6.2 Mould incidence on kernels

A blotter test was used to determine mould incidence on maize kernels and the test was carried out following developed procedures (Fandohan et al., 2003; Hajihasani et al., 2012).

Mould incidence on kernel (%) = $\frac{a}{b}$X100

Where *a* stands for infected kernels, while *b* total number of kernels plated.

3.3.6.3 Isolation and identification of fungal genera

Fungal pathogens on the maize kernels were grown, isolated and identified to the genus level on a monthly basis until the six month of storage period following standard techniques and procedures (Magnoli et al., 2003; Deacon, 2006; Hocking, 2006; Narayanasamy, 2006; Pitt and Hocking, 2009; Atukwase et al., 2012). The isolated fungal genera frequency of occurrence and relative density were calculated (Mostafa and Kazem, 2011; Meer et al., 2013).

Fungal frequency (FF) = $\frac{nf}{nt} X\ 100$

Where *nf* number of particular fungal genera and *nt* a total number of samples/kernels.

Relative density (RD) = $\frac{ng}{tg}$ X 100

Where *ng* stands for a number of the specific isolated genus, while *tg* for a total number of the fungal genus.

3.3.7 Data analysis

Statistical Package for Social Sciences (SPSS) version 20.0 software was used for descriptive analysis of data (socioeconomics, maize PHM practices, frequency of occurrence and relative density of fungal genera recorded). Whereas germination tests, mould incidence on kernels and on-cobs-maize were analyzed using SAS software version 9.0 after checking ANOVA assumptions. Analysis of Variance was carried out using general linear model (GLM). Wherever significant difference was observed, means separation was carried out using Tukey's Honestly Significant Difference (HSD) test at the 5% probably level.

3.4 Results

3.4.1 Socio-economic characteristics

Most of the respondent farmers and traders were between 30 and 59 years old. But, about 78% of the experts participating were less than 30 years old. The majority of the respondent farmers and traders had primary education. More than 50% of the farmers had up to two decades' experience in maize production but only a few traders more than that. However, none of the participant experts had more than five years' experience in maize post-harvest management. Most of the socio-economic characteristics didn't show significant differences ($P > 0.05$) between surveyed agro-ecological settings (Table 3.1).

Survey results showed a majority of the participants (74%) had a family size of 5-10 and 58% of the farmers had less than five workforce in the household. On average, most of the participant farmers (68.4%) produced maize on less than 1 ha of land. Similarly, most of the farmers (51.3%) allotted up to 50% of their land for maize, while 34.7% of the farmers allocated up 75% out of their total land, the rest allotted one-quarter of their land for maize production. In the study areas, participant farmers mainly produce maize for household consumption (67.9%) while 32.1% of the producers used it both for consumption and for sell (as an income source). Most of the collectors collected maize from nearby PAs in their district. About 50% of collectors sold their maize to individual consumers. Wholesalers also sold to both local traders and consumers (33.3%) and Addis Ababa traders (50%). Low quality of maize especially discoloration and irregularity of maize supply was the major trading problem mentioned by both collectors and wholesalers.

Table 3.1 Scio-economics characteristics of the participants

Actor	Scio-economics characteristics	Agro-ecology lowland	midland	highland	mean	Statistical test χ^2- value	P- value
Farmer	Sex (%)					0.278	0.870^{ns}
	• Male	95.5	94.6	92.7	94.3		
	• Female	4.5	5.4	7.3	5.7		
	Educational level					3.921	0.687^{ns}
	• None	4.5	20.8	17.1	14.1		
	• Basic	18.2	15.4	14.6	16.1		
	• 1 to 6	59.1	46.2	53.7	53.0		
	• 7 and above	18.2	17.7	14.6	16.8		
	Age (years)					12.896	0.012*
	• Less than 30	9.1	5.4	24.4	13.0		
	• 30 to 59	81.8	86.9	70.7	79.8		
	• More than 60	9.1	7.7	7.3	8.0		
	Experience (years)					7.834	0.098^{ns}
	• Less than 10	22.7	7.7	17.1	15.83		
	• 10 to 20	31.8	24.6	29.3	28.57		
	• More than 20	45.5	67.7	53.7	55.63		
Traders	Sex					2.974	0.245^{ns}
	• Male	100.0	100.0	83.3			
	• Female	0.0	0.0	16.7			
	Educational level					8.922	0.063^{ns}
	• 1- 6	33.3	60.0	0.0	31.1		
	• 7- 10	50.0	30.0	33.3	37.8		
	• 11- 12	16.7	10.0	66.7	31.1		
	Age (years)					7.145	0.128^{ns}
	• less than 30	0.0	50.0	16.7	22.2		
	• 30 to 59	66.7	50.0	66.7	61.1		
	• 60 and above	33.3	0	16.7	16.7		
	Experience (years)					7.559	0.109^{ns}
	• Less than 10	16.7	70.0	83.3	56.7		
	• 10 to 20	66.7	30.0	16.7	37.8		
	• More than 20	16.7	0.0	0.0	5.6		
Experts	Sex					0.297	0.862^{ns}
	• Male	90.0	87.5	80.0	85.8		
	• Female	10.0	12.5	20.0	14.2		
	Age (years)					2.385	0.304^{ns}
	• less than 30	70.0	62.5	100.0	77.50		
	• 30 to 59	30.0	37.5	0.0	22.50		
	Experience (years)					1.179	0.555^{ns}
	• Less than 3	20.0	12.5	0.0	10.8		
	• 3 and 4	80.0	87.5	100.0	89.2		

Statistically significant at *P < 0.05; ns= not significant.

3.4.2 Maize post-harvest practices

In the current study, 10 post-harvest handling practices have been identified at producer level but harvesting, transportation, drying, storage and shelling are amongst the key activities carried out by producers. Some of handling practices to maintain PH quality also carried out by traders too.

3.4.2.1 Harvesting

Maize harvesting in the study area started in September and lasted until end December. Farmers used visual observation, crop calendar method, shelling and observing kernel dryness; and checking seed hardness with the proportion of 61.1%, 28.8%, 8.8%, and 2.1%, respectively to determine the dryness of the crop for harvesting. However, none of the respondent farmers used the moisture testing method to harvest maize for safe storage. The moisture content w.b. (%) at harvest and loading stage ranged between 0.16 - 0.28 which is far more than the optimum moisture content recommended for long term storage (Fig. 3.2).

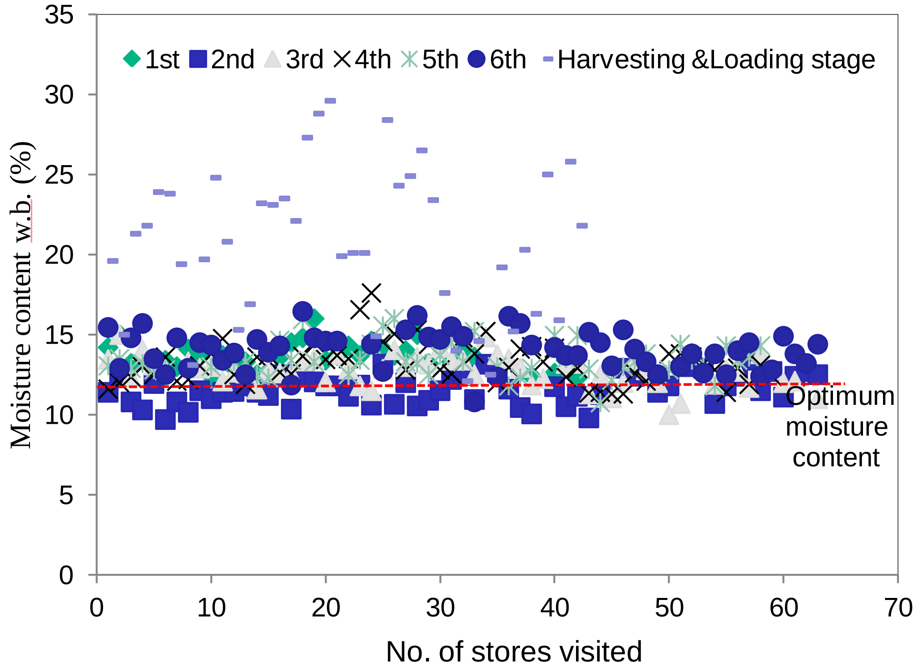

Figure 3.2 The moisture content of maize measured with monthly interval from loading stage to six month of storage periods.

3.4.2.2 Drying

The majority of the farmers (75.1%) practiced on-farm drying with the cobs still attached to the stalk (Fig. 3.3), creating favorable conditions for fungal infection. The drying process was usually done by heaping up or spreading out the on-cobs-maize on bare ground for a couple of days which inadvertently creates favorable conditions for a mycotoxin-producing fungal contamination.

3.4.2.3 Transportation

About 55.0% of the respondent used animals as transportation means, while the remaining 45.0% used human labor (Fig. 3.3). However, spillage loss of the harvested product was high during transportation.

3.4.2.4 Storage

The most common maize storage structure used by farmers across all agro-ecological settings was *gombisa* to store on-cobs-maize dominantly without sheaths. *Gombisa* is the type of circular granary and is made by interweaving locally available materials; mostly bamboo split by local artisans. The roof is covered with natural grass or thatch. In rare cases, the corrugated sheet is used. The most critical problem observed in *gombisa* was not climatically controlled structure, resulting in high moisture leakage during the rainy season and the common formation of mould on stored maize. The survey result also showed, constructed *gombisa* can be used for about 10 years. The farmers can use the same structure every year which serves as an inoculum source to enhance damage by insect pests and stored fungal pathogens.

About 94.8% of farmers stored their new maize separate from old maize (if available) while, 5.2% of the farmers mixed it with the old maize. Participant farmers stored maize separately from other cereals to prevent from insect damage (73.6%), to avoid difficulty during storage management (11.9%) and to control mould problems (8.3%). The remaining farmers mixed maize with other cereals such as sorghum or *teff.* Maize was stored in different forms by farmers. De-husked cob was most common (75.6%), both as cob and shelled kernels (21.2%) and sheath kernels alone (2.6%). Maize cobs were stored on average for six months in the *gombisa* then shelled and stored inside the house with sacks for a few months as it depleted mostly at six months.

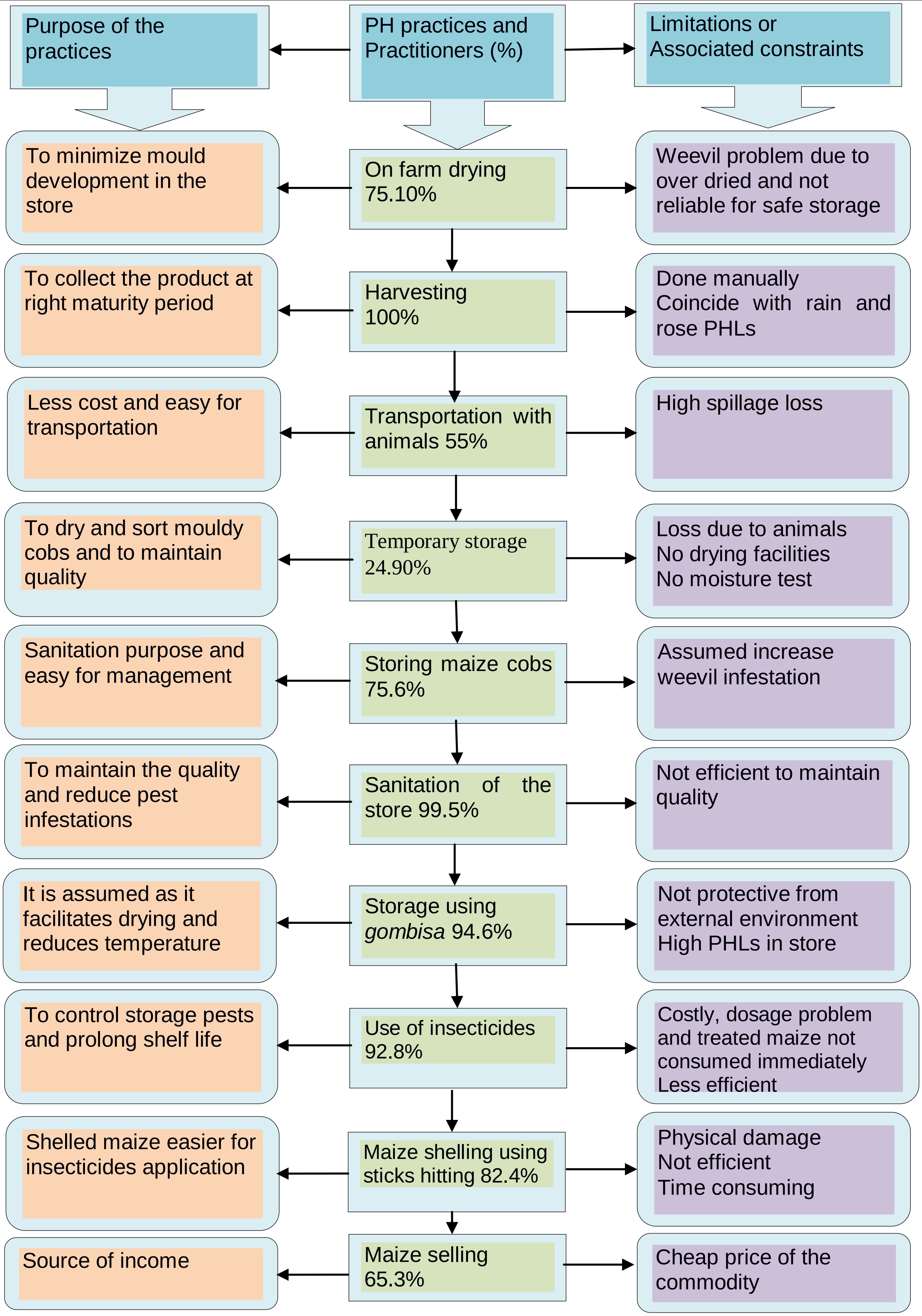

Figure 3.3 Flow chart for maize PH activity chain, its function, and associated constraints

Both collectors and wholesalers stored shelled maize with sacks inside a house like structure made up of wood from different trees and roofed by a corrugated iron sheet. In most cases, the inside and outside wall were sealed by mud (81.5%) or cement (18.8%) and the floor was either cemented (56.3%), mud (25%) or mud covered with plastic (18.8%). Only 18.8% of the participant maize collectors store had windows and most of the stores had no ventilation system. However, half of the wholesalers' stores possessed windows and a ventilation system. In general, the storage structure from both collectors and wholesalers were not protected from insects, fungal pathogens, and other pests which resulted in high PHLs. In addition, sanitation was the main problem observed in stores belonging to traders.

3.4.2.5 Shelling

Farmers in the study area shelled maize kernels from cobs manually. Farmers were hitting cob by stick inside the sack, finger palm shelling and hitting cob inside the house which physically damaged and made the kernels prone to fungal damage.

3.4.3 Post-harvest loss estimation and causes

Actors estimated 31% of maize PHL along the activity chain including harvesting, drying, shelling, storage, selling and consumption (Fig. 3.4) out of this, 14% happened during storage. The proportion of PHLs due to biological agents is the most significant factor which starts as the crop reaches physiological maturity. Respondent estimated that the highest proportion of PHL (18%) was due to mould development followed by insect pest, rodents, wild animals and domestic animals in decreasing order.

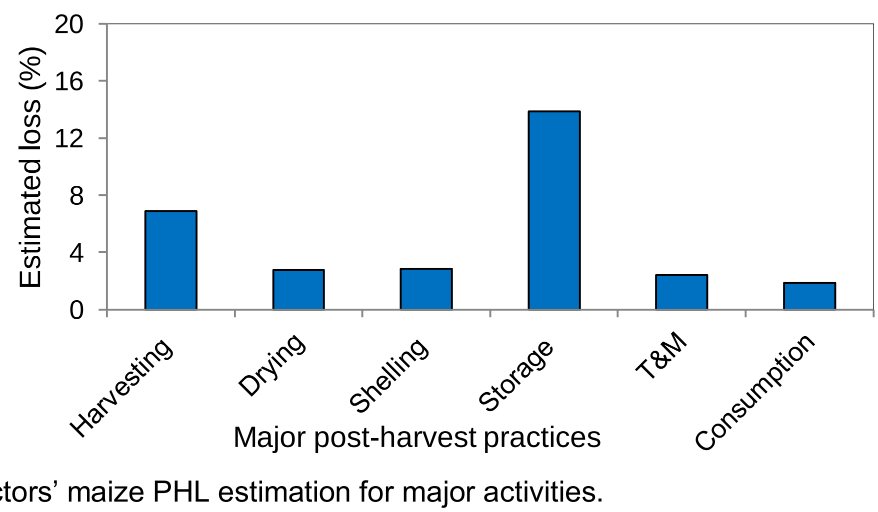

Figure 3.4 Actors' maize PHL estimation for major activities.
T& M= Transportation and marketing activity

3.4.4 Germination test

A significant (P = 0.01) difference was observed due to the interaction of storage duration and variation in agro-ecology which affected germination percent of maize stored in farmers' storage systems (Table 3.2). Similarly, a very highly significant (P < 0.0001) effect on the germination percentage of maize kernels stored under collector condition was also observed without interaction between storage duration and agro-ecological variations (Fig. 3.5). Maize kernels stored under wholesaler stores were significantly (P = 0.0012) affected by storage duration (Table 3.2).

Table 3.2 Mean separation for germination (%) test of stored maize kernels under farm and wholesaler conditions

		Storage duration (months)						
Actors	AE	1	2	3	4	5	6	P-value
Farmer	Lowland	93.1±1.7^{a}	82.2±1.7^{b-d}	83.3±1.7^{bc}	78.5±1.7^{c-f}	77.1±1.7^{c-f}	71.2±1.7^{fg}	0.01
	Midland	86.9±1.7^{b}	86.2±1.7 ^{b}	83.5±1.7^{bc}	80.7±1.7^{cd}	79.2±1.7^{cd}	72.6±1.7^{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}	
Whole-saler	-	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

Values are mean ± SE of triplicate samples. Means followed by the same letter among columns and/or rows are not significantly different from each other at P < 0.05 for the farmer and along row for the wholesalers. AE = Agro-ecology

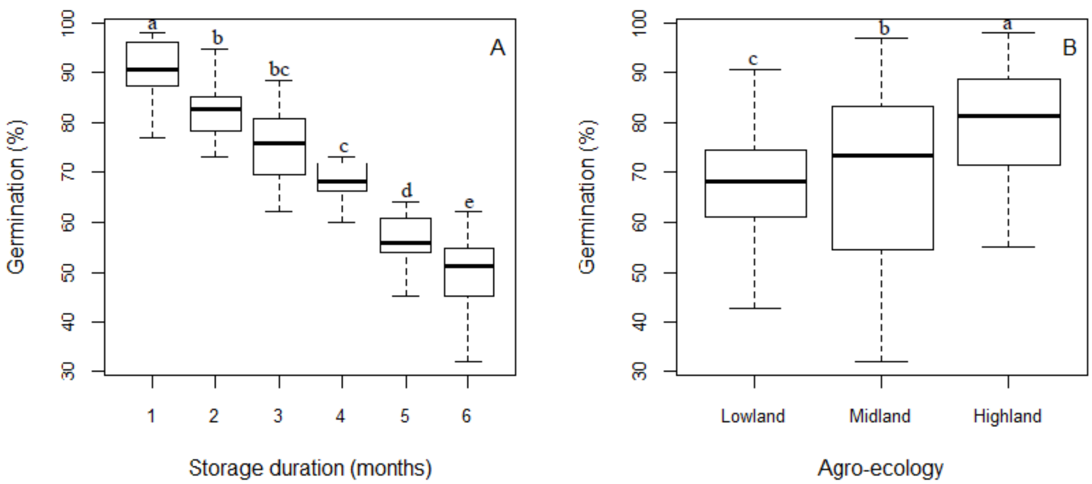

Figure 3.5 Box plots for germination test of maize stored in collector stores A) varying storage duration and B) different agro-ecology.
P < 0.0001 for both storage duration and agro-ecology. Box plots with the same letter(s) for each figure do not significantly different from each other at P < 0.05. Error bars are range values.

3.4.5 Mycological analysis

3.4.5.1 Mould incidence

Both storage duration and variation in agro-ecology exhibited highly significant (P < 0.0001) effects on the MI of on-cobs-maize stored under farm conditions (Fig. 3.6). Significant interaction between agro-ecology and differences in storage duration were observed in MI of maize kernels sampled from both farmer and collector stores (Table 3.3 and Fig. 3.7), respectively. For wholesaler storage systems, the MI on kernels differs significantly (P = 0.0017) with storage duration (Fig. 3.8).

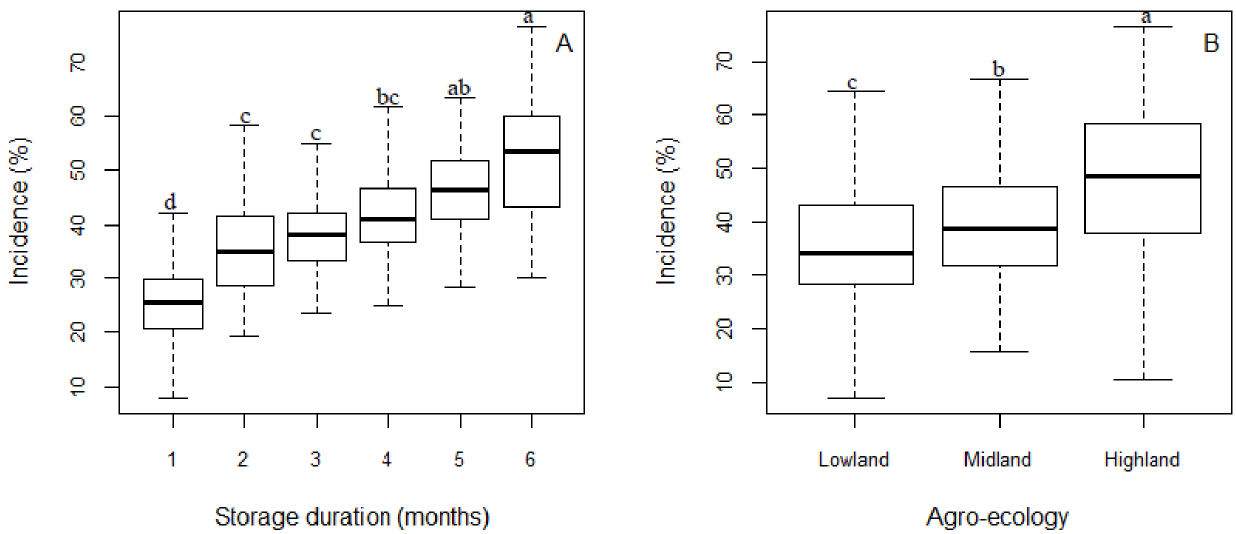

Figure 3.6 Box plots for mould incidence of on-cobs-maize stored under farm conditions A) storage duration B) agro-ecology.
P < 0.0001 for both storage duration and change in agro-ecology. Box plots with the same letter(s) for each figure do not significantly different from each other at P < 0.05. Error bars are range values

Table 3.3 Mean separation for mould incidence (%) of maize kernels stored under farm condition

	Storage duration (months)						
Agro-ecology	1	2	3	4	5	6	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±2.7b-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±1.6cd	61.6±1.6b	
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±2.7bc	78.9±2.7a	

Values are mean ±SE of triplicate samples. Means with the same letter(s) are no significantly different from each other along the columns and/or rows at P < 0.05.

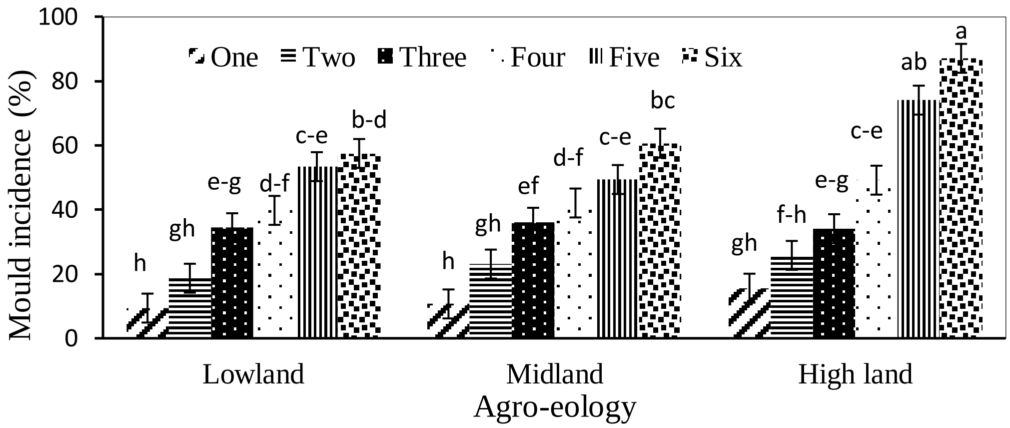

Figure 3.7 Mould incidence of stored maize kernels in collector store-house for six months. P-value = 0.005; Values are mean ± SE of triplicate samples. Means with the same letter(s) do not differ significantly from one another at P < 0.05, both for storage duration and agro-ecology.

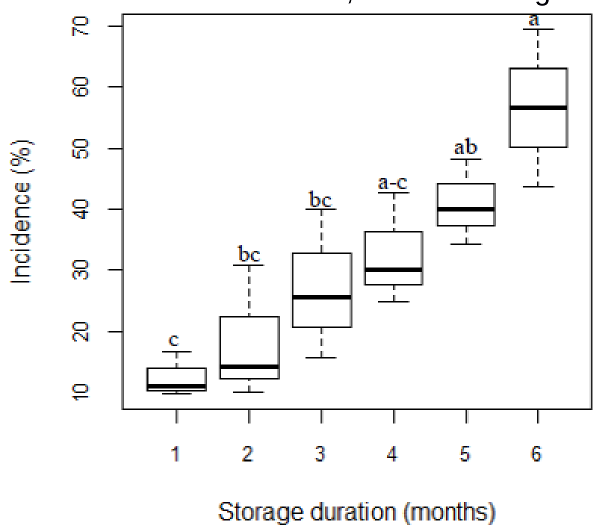

Figure 3.8 Box plots for mould incidence on maize kernels collected from wholesaler warehouse.
P-value = 0.0017. Box plots with the same letter(s) are do not significantly different from each other at P < 0.05. Error bars are range values.

3.4.5.2 Fungal genera

A total of seven fungi genera were isolated, characterized and identified in maize kernels from each actor's store, except for wholesalers; where six fungi genera were recovered. Genus *Fusarium* was the most common fungi based on the frequency of occurrence and relative density followed by *Penicillium* and *Aspergillus* throughout the study period (Table 3.4). In the current study, *Fusarium* had the highest frequency of occurrence and relative density during the first two months of storage then slightly decreased as storage duration increased. Comparison of the first month's data with the last month's exhibited a negative increment for *Fusarium* but a positive one for both *Penicillium* and *Aspergillus* (Tables 3.5-7).

Table 3.4 Frequency of occurrence and relative density of fungal genera associated to maize under different actors' store

Actors	Fungi genera (%)													
	Penicillium		*Aspergillus*		*Fusarium*		*Phoma*		*Geotrichum*		*Cloudosporium*		*Drechslera*	
	Fr	Rd	Fr	Rd	Fr	Rd	Fr	Rd	Fr	Rd	Fr	Rd	Fr	Rd
Farmer	19.1	17.48	7.80	7.45	48.05	67.33	0.58	1.05	1.57	1.0	3.02	2.68	0.60	0.65
Collector	28.02	23.60	5.95	8.33	61.13	59.18	0.00	0.00	2.67	2.5	1.70	1.38	0.52	0.58
Wholesaler	35.70	20.22	31.02	16.68	36.38	44.95	11.12	1.85	0.00	2.4	6.67	2.53	0.00	0.00

Rd= relative density, Fr =frequency of occurrence

Table 3.5 Frequency of occurrence and relative density of major fungal genera associated to stored maize under farmers condition

Fungal genera	Parameters	Storage duration (months) 1	2	3	4	5	6	Mean	SD	Increment (%)*
Penicillium	Frequency	2.20	3.40	12.40	34.10	26.20	36.30	19.10	15.15	93.94
	Relative density	5.80	3.40	26.50	24.40	18.70	26.10	17.48	10.39	77.78
Aspergillus	Frequency	1.10	1.50	2.70	11.20	12.70	17.60	7.80	6.96	93.75
	Relative density	2.70	4.70	3.80	7.80	9.30	16.40	7.45	5.04	83.54
Fusarium	Frequency	67.40	29.10	27.00	66.60	72.60	36.60	48.05	23.00	-84.15
	Relative density	83.60	86.10	64.40	53.90	66.40	49.60	67.33	14.97	-68.55

Where , SD = Standard deviation, * = % increment calculated by subtracting last month data from first-month data, then divided the value by last month data and multiply by 100 for each fungal genera frequency of occurrence and relative density.

Table 3.6 Frequency of occurrence and relative density of major fungal genera associated to stored maize under collector condition

Fungal genera	Parameters	Storage duration (months) 1	2	3	4	5	6	Mean	SD	Increment (%)*
Penicillium	Frequency	6.90	12.50	23.80	41.80	24.90	58.20	28.02	17.39	88.14
	Relative density	8.50	9.70	20.80	39.00	21.20	42.40	23.60	13.07	79.95
Aspergillus	Frequency	1.80	0.40	3.30	4.00	12.00	14.20	5.95	5.22	87.32
	Relative density	0.40	0.40	10.60	5.50	17.30	15.80	8.33	6.77	97.47
Fusarium	Frequency	81.40	70.30	49.80	46.70	70.20	48.40	61.13	13.39	-68.18
	Relative density	91.10	83.20	47.50	39.60	52.10	41.60	59.18	20.31	-118.99

Table 3.7 Frequency occurrence and relative density of major fungal genera associated to stored maize under wholesaler condition

Fungal genera	Parameters	Storage duration (months) 1	2	3	4	5	6	Mean	SD	Increment (%)*
Penicillium	Frequency	28.80	32.00	2.10	68.90	48.90	35.60	36.05	22.21	19.10
	Relative density	9.20	9.00	1.88	44.40	34.40	24.30	20.53	16.65	62.14
Aspergillus	Frequency	1.60	6.70	44.40	66.70	17.80	48.90	31.02	26.09	96.73
	Relative density	5.60	11.30	8.90	27.80	16.60	29.90	16.68	10.11	81.27
Fusarium	Frequency	60.90	60.90	8.10	12.11	57.80	30.60	38.40	24.73	-99.02
	Relative density	78.00	72.50	24.40	9.08	49.00	45.80	46.46	26.70	-70.31

Where: SD = Standard deviation, * = % increment calculated by subtracting last month data from first-month data, then divided the value by last month data and multiply by 100 for each fungal genera frequency of occurrence and relative density.

3.5 Discussion

The present study identified 10 post-harvest handling activities in the maize PH supply chain (Fig. 3.3). Generally, the moisture content at harvest and loading stage was not optimum to increase the shelf life of the stored product; it actually favored the development of mould in the store. High kernel moisture levels of above 12% increase the chances of fungal growth in the store (Dubale et al., 2012). It was also suggested that for either mechanical or manual harvesting, the maize grain must be dried to safe moisture levels (FAO, 2011). Furthermore, most farmers in the study area did not use post-harvest drying but wait until the crop dries on the field. Unfortunately, this mostly coincides with rainfall which will also facilitate mould development when the maize is stored. Delayed harvesting causes maize ear rot and *Fusarium* spp. which are the principal pathogenic fungi responsible for causing this rotting of maize ears (Alakonya et al., 2008; Pitt and Kocking, 2009). The report also indicated, *Aspergillus* spp. also often encountered on maize kernels that were allowed to dry in the field before harvesting (Owolade et al., 2005). Producers commonly used domestic animals, both for transportation of harvested maize to stores and to market; loss due to spillage was also common problem observed while using domestic animals (Fig. 3.3). Pack animals especially donkey and mules are used for transportation of goods in most parts of Africa and Ethiopia (Fernando and Starkey, 2004; Tolera and Abebe, 2007).

G*ombisa* is the most dominant traditional storage structure used to store maize in cob form. Studies conducted in various areas of Ethiopia showed that most of the farmers across the country used *gotera, gombisa* and sacks to store maize (Tadesse and Basedow, 2004; Dubale et al., 2012). Traditional granaries (cribs), usually made up of locally available materials such as timber, bamboo, etc are used in humid countries both for drying and for the storage of maize (Nukenine, 2010). Life span of newly constructed *gombisa* can be used for up to ten years for the same purpose in the study area. Hell et al. (2000) reported most storage structures for maize in Benin were used for up to 5 years. This accelerated the risk of contamination with the increasing age of the storage structure. Maize storage with sheath was only common in lowland maize producing districts and farmers in the study area assumed it reduced weevil damage. A study conducted at Bako research centre, in western Ethiopia, showed good sheath cover is considered as protecting the ear from insect and fungi damage (Demissie et al., 2008). In general, the traditional storage structure, *gombisa* provides less protection from pests and not effective in protecting the stored products from external climatic conditions (like rainfall and high temperatures) which facilitate the development of fungi in the store (Narayanasamy, 2006). On an average, after six months of storage, shelling is another main activity that is carried out to store the remaining kernels in the sack. However, shelling is totally carried out manually using stick hitting. This action causes physical damage or breakage, splitting or cracking of kernels which make them prone to fungal damage by other pests resulting in high PHL (Tadesse and Basedow, 2004; Kaaya and Kyamuhangire, 2006; IFPRI, 2010; USID, 2011). It has been reported that physical damage during shelling favors *Fusarium* infections and using mechanical shelling can reduce fumonisin levels by 57% - 65% in maize (Fandohan et al., 2003).

Current survey results revealed that maize PHL estimated at 31%. In Ethiopia, the major maize production challenge for farmers is high PHL, ranging from 15 to 30% (IFPRI, 2010) and up to 19% (Ashagari, 2000). In sub-Saharan Africa, about 37% of losses occur during storage and handling (Lipinski et al., 2013). It was also stated that poor PH management results in large amounts of maize loss after harvest (Kaaya et al., 2006). Declining of germination percentage along the storage duration was observed for all actors' storage systems; mainly due to the increment of mould which resulted in kernels quality loss too. Therefore, the current study shows that high fungi damage resulted in reduction of maize kernel germination. This result is in accordance with Befikadu, (2014) who reported that germination reduction of maize grain stored for six months in traditional farmers' storage was 98% to 68.5% under intermediate and 97.5% to 70.17% in lowland agro-ecology. Decrease in the germination percentage of stored maize to 28% after 180 days of storage at 35^{o}C with 14% moisture content has been reported (Tabatabaei and Naghibalghora, 2013). Somda et al. (2008) and Govender et al. (2008) also reported that fungal infection caused a reduction in germination rates of maize kernels.

For the all of the storage systems studied, the trend in mould development rose along with the storage duration and agro-ecology. Both mould incidence on-cobs-maize and kernels were more significant in the highland agro-ecology of the area studied and were also related to an increase of storage duration coincided with the region's next rainy season. This may be because of higher relative humidity that favors fungal growth in less protected traditional storage structures. Insufficient drying and humid conditions favor the development of fungi in tropics (Suleiman et al., 2013). Groot, (2004) also stated that humidity is crucial for the development of fungi; even at low temperatures, 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 a higher moisture content of 19.0%. Furthermore, damage caused by weevils can allow fungi to enter more easily and at the same time serve as an agent transferring fungi spores from infected to healthy grain (Kankolongo et al., 2009; Suleiman et al., 2013). Moreover, even if maize can be harvested during the dry season, the rainy season that follows will facilitate mould development in traditional storage structures which are not climatically controlled and allow entry of moisture from outside.

The present findings show that there were seven fungal genera associated with stored maize but *Fusarium, Penicillium* and *Aspergillus* were the most dominant ones. Tesfaye and Abate, (2000) also reported that *Fusarium, Penicillium* and *Aspergillus* spp. were the most significant toxigenic fungal pathogens in Ethiopian maize. *Fusarium* was the most common of the above three. In a study conducted in the Jimma zone, *Fusarium, Penicillium* and *Aspergillus* spp. were identified from farmers' storage systems; in both *gombisa* and in sacks (Befikadu, 2014). However, this study confirmed that these fungi genera did not only dominant at producer level but also at collector and wholesaler conditions in the maize supply chain, including different agro-ecologies, storage periods and types. Kaaya et al. (2006) reported that predominantly *Fusarium, Penicillium,* and *Aspergillus* were identified from traders samples collected from different Ugandan agro-ecologies. However, a report from Cameron showed that the infection levels of stored maize were: *Aspergillus* (up to 96%), *Penicillium* (up to 63%) and lastly by *Fusarium* (up to 32%) (Tagne et al., 2003). Similarly, several studies have reported that these three fungi genera were the most significant in stored maize (Kulkarni and Chavan, 2010; Mostafa and Kazem, 2011; Toffa et al., 2013; Bosah and Omorusi, 2014). However, most studies did not cover the whole commodity supply chain but focused on the producer level.

The findings showed that as the storage duration increased, the occurrence of most toxinogenic fungi, *Aspergillus* spp. and *Penicillium* spp. increased along the maize supply chain. *Aspergillus* species (particularly *Aspergillus flavous* and *A. parasticus*) are the major aflatoxin producing fungi species in food and feed in the tropics and sub-tropics along production chains (Kiarie et al., 2016), but are particularly significant in the storage phase (Jonathan et al., 2004). Depending on dose and duration of the exposure, aflatoxin can cause acute illness and death, immunological suppression, liver cancers and nutritional interference (Jonathan et al., 2004). Several species of *Penicillium* are able to produce mycotoxins in the storage phase (Rundbergeta et al., 2002). Types of *Fusarium* are also among the main fungal diseases that contribute to a loss in quality and the contamination of maize kernels with mycotoxins (Stumpf et al., 2013).

3.6 Conclusions

Different post-harvest activities were practiced by farmers in study sites. However, many of the activities didn't seem effective at preserving harvested maize and resulted in tremendous PHLs. Losses during storage were particularly significant and identified as a critical intervention point. Storage structures in use in the study area do not protect well from external environmental conditions and pest problems. In the current study, seven fungi genera were identified, but *Fusarium, Penicillium* and *Aspergillus* were the predominant fungi occurring in all the maize sampled along the supply chain. At the same time, these were the top three fungi able to produce mycotoxins and cause health hazards both for humans and animals that feed on it. However, the trend showed *Fusarium* spp. slightly decreased over time but *Aspergillus and Penicillium* spp. increased rapidly with storage duration throughout the maize supply chain. Mould incidence both on-cobs-maize and kernels increased with storage duration for all storage situations studied.

The results clearly depicted high maize PHLs along the supply chain. Therefore, post-harvest management practices such as selecting the optimal harvesting time, drying techniques, maize shelling method and storage technologies should be improved and disseminated throughout the extension system to end users. In particular, the nature of *gombisa* used in the study area resulted in high levels of PHL and needs to be improved to reduce loss. In addition to quantity loss, there is a need to investigate quality loss that occurs along the supply chain. Also, current research findings thus highlight the need for further evaluation of storage structures in different agro-ecology by considering key climatic factors that favor mycotoxin-producing fungi and a possible modification or redesigning of appropriate storage structures. As the most dominant fungal pathogens isolated are able to produce secondary metabolites, further investigation is required to understand the multiple mycotoxin profiles along the maize supply chain using different types of storage structures.

3.7 Acknowledgement

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4 Nutritional deterioration of stored *Zea mays* L. along supply chain in south-western Ethiopia: Implication for unseen dietary hunger

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4.1 Abstract

Maize is an important food security crop in Ethiopia particularly for subsistence farmers. However, post-harvest loss is the main bottle-neck in southwestern part of the country, region characterized by hot and humid climatic conditions. Previous loss assessment and management studies have focused mainly on quantity losses. This study was therefore designed to assess nutritional quality losses of stored maize along the supply chain in Jimma Zone, southwestern Ethiopia. Three districts representing potential maize producers and different agro-ecological regimes for maize production were selected for analyses. Sample collection started at harvest and continued for six months at two-month intervals from 21 selected actors along the supply chain. The experiment was conducted for two seasons, and a total of 72 samples were collected during each season. Both nutritional and anti-nutritional analyses were carried out following the international standards of the Association of Official Analytical Chemists. Data were analysed using SAS software (version 9.2) using a general linear model (GLM). The result revealed that moisture content significantly decreases ($P < 0.05$) as storage duration increases under different actors and agro-ecological conditions. But, showed increment during the final months under farmers' storage conditions. In addition, moisture content at the loading stage was not optimal for safe storage. Crude protein, crude fat, carbohydrate, and calorific value content significantly decreased ($P < 0.05$) as the storage duration increased, but fibre, ash, and major mineral (Ca, Zn, and Fe) content increased significantly over the storage period. Phytate and tannin content varied with storage duration and agro-ecological setting. Storing maize under traditional conditions along the supply chain resulted in substantial quality losses. This has great implications for nutrition insecurity and unrecognized undernourishment in the society. Additionally, substantial increases in fibre content above the optimum have important effects on nutrient absorption. There is thus a need to develop and disseminate appropriate storage technologies that minimize quality loss in maize stores.

Keywords*:* Agro-ecology, quality loss, nutrition, storage duration, stored maize

4.2 Introduction

Cereal crops are a major agricultural product in Ethiopia and constitute the largest share of domestic food production (EATA, 2013). Of the major cereals produced in the country, maize ranks highest, since it has doubled in both production and productivity within two decades (Demeke, 2012; Abate et al., 2015). In 2010/11, maize accounted 28.07% (4.986 million tonnes) of the total cereal production, as against 22.30% (3.960 million tonnes) for sorghum and 19.61% (3.483 million tonnes) for *teff* which ranked second and third, respectively (Demeke, 2012). Maize consumption’s share has increased from 14% in the 1960s to 29% in the 2000s’ in Ethiopia, mainly at the expense of *teff*, and at the same time the unit cost of calories from maize is far lower than from all other major cereals produced in the country (Demeke, 2012).

Maize is exposed to high losses during production, but even more significant losses can occur during the post-harvest stage (Golob et al., 2002; Dubale et al., 2012; Tefera, 2012; Befikadu, 2014). Grain preservation is difficult for producers, but post-harvest grain storage is an equally important aspect of food security in developing countries (IFPRI, 2010; Sori and Ayana, 2012). Grain storage is an important issue since most cereals, including maize, are produced on a seasonal basis (Golob et al., 2002). Seasonal production leads to fluctuations in supply and demand at different stages along the maize supply chain. Storage helps to overcome fluctuations in market supply. As an important post-harvest activity, storage must take into account the bio-deterioration factors that cause quality reduction and consequent nutritional and financial losses (Fourar-belaifa et al., 2011).

Nutritional quality losses during storage are caused by poor post-harvest handling and the natural respiration of grain (Golob et al., 2002), and by damage caused by bio-deterioration (Rehman, 2006; Reed et al., 2007; Farhan et al., 2013; Paraginski, et al., 2013). Efficient post-harvest management and quality maintenance of maize depends on the ecological conditions of storage, the storage period, the type of storage structure, and the physical, chemical, and biological characteristics of the grain (Golob et al., 2002; IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014). Research recommendations also stress the need for nutritional loss assessment of stored products, including maize, and study of the factors that render grain unsuitable for human consumption (Reed et al., 2007; Fourar-belaifa et al., 2011). Furthermore, inappropriate storage and handling of stored grain may lead to the development of fungi, which can result in unacceptable levels of mycotoxin contamination in the tropics (Rashad et al., 2013).

In Ethiopia, maize is usually stored as cobs in traditional storage facilities such as *dibignit, gotera*, and *gombisa* (Tadesse, 2004; Abebe and Bekele, 2006; IFPRI, 2010). On-farm storage structures such as *gombisa* make maize susceptible to bio-deterioration in the southwestern part of the country owing to the hot and humid climate, and these structures are not highly protective in general (IFPRI, 2010; Dubale et al., 2012; Befikadu, 2014). Furthermore, small traders (collectors) and wholesalers use sacks to store shelled maize, and these are not airtight enough to preserve the quality and extend the shelf life of the commodity. Despite the importance of maize storage for food security (availability and nutritional quality), the potential impact of traditional storage structures on stored maize quality has not been well investigated, and there is limited information on the extent of nutritional deterioration during the storage period in southwestern Ethiopia. Furthermore, previous research focused only on the farmers, without considering the other actors along the maize supply chain who play key a role in maize transactions. The current study was therefore designed to investigate the nutritional and anti-nutritional content of stored maize in different agro-ecological settings involving farmers, collectors, and wholesalers in Jimma Zone, southwestern Ethiopia.

4.3 Materials and Methods

4.3.1 Study site description

The study was conducted in Jimma Zone, which is situated southwest of Addis Ababa, the capital city of Ethiopia. Geographically, it lies between 7°15′ and 8°56′ N latitude and 36°00′ and 38°38′ E longitude. The elevation of the zone ranges from 800 to 3360 m above sea level (m.a.s.l.), and it experiences an average annual rainfall of 1600 mm. The temperature of Jimma Zone varies between a maximum of 25 to 30°C and a minimum of 7 to 12°C. The agro-ecological setting includes highlands (15%), midlands (67%), and lowlands (18%) (CSA, 2009; Zonal Finance and Economic Development Office of Jimma (ZoFED), 2013). In the present study, three districts were purposely selected based on their high maize production potential and their different maize-producing agro-ecologies: Dedo from the highlands, Omo-nada from the midlands, and Sokoru from the lowlands of Jimma Zone (Table 4.1).

Table 4.1 Description of study districts and town

Districts/ Town	Annual RF (mm)	Temperature range (^oC)	Altitude (m.a.s.l)	Co-ordinates	
				Latitude (N)	Longitude (E)
Dedo	1920	13 - 22	2500 - 3360	07°13′- 07°39′	36°43′ - 37°12′
Omo-nada	1880	16 - 27	1500 -2500	07°17′- 07°38′	37°00′ - 37°28′
Sekoru	1467	15- 32	1000 - 1500	07°45′ - 8°47′	37°20′ - 37°25′
Jimma town	1600	14 - 30	1780	07°41′	36°50′

4.3.2 Sampling procedure and sample collection

Jimma Zone was selected from the southwestern part of Ethiopia specifically for its high maize-producing potential and because nutritional quality losses in maize have been little studied in the region. Three districts were selected that were known to have high maize production and that represented different agro-ecological conditions, according to secondary data from the zonal agricultural office. After discussion with experts and extension agents at each district's agricultural office, three farmers were selected randomly for the current study. These farmers produce the BH-660 variety, dominantly produced in the area and store their maize cobs in *gombisa.* The extensive ventilation of the structure causes moisture leakage into the stored maize cobs from all sides during rainy seasons. High moisture leakage results in mould development and insect pest damage. All maize producers in the area store their maize in *gombisa*.

Three local traders from each district were selected randomly in order to collect samples for nutritional analyses. To include all actors along the supply chain in Jimma Zone, three wholesalers from Jimma town were also included as they are also participants in maize transactions in the study area. Similar storage structures and the same BH-660 maize variety were used by all traders in the study.

Sample collection was started at the harvesting and loading stage from the farmers' stores and continued every two months for a total six months of storage, as most stored product was depleted by then. From the farmers' stores, twelve cobs were picked from different locations in each *gombisa* (top, centre, and bottom) through a PVC pipe fitted at the middle and bottom of the storage structure that allowed removal of sample cobs; the outside of the PVC pipe was covered with a plastic sheet. Four cobs were removed from each layer, mixed together, shelled on the spot, and maintained in plastic bags for moisture analyses under laboratory conditions. Similarly, 2 kg of grain from the stores of each of the traders (collectors and wholesalers) were sampled through a deep probe into three parts of open-weave sacks and mixed together. The samples were brought to the Post-Harvest Management Department Laboratory of Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM), for moisture content analyses and for sample preparation for nutritional and anti-nutritional analyses. The experiment was carried out during the two production seasons of 2013/14 and 2014/15, starting from the end of December until June in each case. Samples collected daily were coded for analyses. In total, 72 samples were collected per season.

4.3.3 Experimental design

A 3 × 4 factorial design was used for the determination of the nutritional composition of maize kernels stored in the farmers' traditional storage structures. Three agro-ecological levels (highland, midland, and lowland) and four storage duration levels (at harvest, and at two, four, and six months) were used at the farmer level. Three farmers from each agro-ecological setting were used as replicates. Factors such as storage structure, maize variety, and all management practices were kept uniform to overcome bias. For the collectors, a 3 × 3 factorial design was used that included the three agro-ecological levels (highland, midland, and lowland) of the respective districts and three storage duration levels (two, four, and six months). For all collectors, the same maize variety and the same open-weave sacks were used uniformly. As with the farmers, three collectors from each district were used as replicates. For the wholesalers, three actors were included in the study with three level of storage duration. A completely randomized design was used and the samples were collected from Jimma town alone, as there was no wholesaler at the district level. Both collectors and wholesalers store their maize in non-airtight sacks that can hold 100 kg.

4.3.4 Nutritional and anti-nutritional analyses

The nutritional components of all the stored maize samples, including proximate composition, minerals, carbohydrate (CHO), calorific value, and anti-nutritional content, were determined on a dry-weight basis. And, grain moisture content (m.c.) was measured on w.b. (%). All proximate composition analyses of the grain followed the Association of Official Analytical Chemists

(AOAC, 2005) methods for total ash (923.03), crude protein (979.09), crude fat (2003.06), and crude fibre (922.16). Major minerals including calcium, zinc, and iron were analysed with a flame Atomic Absorption Spectrophotometer (AAS) (Autosampler AA 6800, Japan) per AOAC method 985.35, and phosphorus content was measured per AOAC method 965.17 (AOAC, 2005). Condensed tannin and phytate levels were also determined following established methods (Maxson and Rooney, 1972; Vaintraub and Lapteva, 1988). The nutritional and anti-nutritional analyses were carried out at the accredited laboratory of the Ethiopian Public Health Institute (EPHI) in Addis Ababa, Ethiopia. All sample analyses were carried out in triplicate.

4.3.5 Data processing and analysis

Analyses of proximate composition, minerals, carbohydrate, calorific value, and anti-nutritional factors were done for two production seasons (2013/14 and 2014/15). Means of the values from the two production seasons were used for the analyses (Farhan et al., 2013), which were carried out using SAS version 9.2 after checking the analysis of variance (ANOVA) assumptions. ANOVAs were carried out using a general linear model (GLM). Wherever significant differences were observed, the means were separated using Tukey's Honestly Significant Difference (HSD) test at the 5% probability level. Finally, R software used to draw the graphs and figures.

4.4 Results

4.4.1 Nutritional analyses

4.4.1.1 Moisture content and proximate composition

Moisture content: The m.c. of stored maize under the farm storage conditions showed highly significant ($P = 0.0003$) differences with interaction effects of storage duration and changes in agro-ecology. The highest (24.90%) and lowest (13.00%) means were recorded from the highland and lowland agro-ecologies (Table 4.2), respectively. Moisture content at the loading stage was not optimum to preserve the shelf life of the product. Likewise, the m.c. of maize stored in collector and wholesaler storage was significantly affected by storage duration (Table 4.3 and 4).

Protein: The protein content of stored maize was significantly affected by storage duration under farm storage conditions (Table 4.2), but no significant differences were observed across the different agro-ecologies at the producer level. By contrast, significant (P = 0.01) interaction effects of storage duration and agro-ecological conditions were observed in the protein content of maize kernels stored under collector conditions (Table 4.3). In a similar manner, the protein content of maize kernels sampled from wholesaler stores was significantly (P = 0.001) affected by storage duration (Table 4.4). As the storage duration increases, protein content significantly decreases under all actor storage conditions along the maize supply chain.

Fibre: The fibre content showed a highly significant increase as storage duration increased under farm storage conditions. At harvest, it was 4.2 ± 0.3%, but it increased to 8.5 ± 0.3% after six months of storage (Table 4.2). Similar results were obtained in samples taken from collectors and wholesalers (Table 4.3 and 4).

Table 4.2 Moisture, protein and fibre content of stored maize kernels under farm condition

		Storage duration (months)				
Quality Traits (%)	Agro-ecology	0	2	4	6	P-Value
Moisture	Lowland	19.2 ± 0.5^{bc}	$16.4 \pm 0.5^{c-e}$	13.0 ± 0.5^{f}	$15.6 \pm 0.5^{d-f}$	0.0003
	Midland	20.6 ± 0.5^{b}	$16.8 \pm 0.5^{c-d}$	13.4 ± 0.5^{f}	$15.2 \pm 0.5^{d-f}$	
	Highland	24.9 ± 0.5^{a}	$18.0 \pm 0.5^{b-d}$	$13.9 \pm 0.5^{e-f}$	$16.9 \pm 0.5^{c-d}$	
Protein	-	9.1 ± 0.3^{a}	8.6 ± 0.3^{ab}	7.7 ± 0.3^{bc}	7.2 ± 0.3^{c}	0.001
Fibre	-	4.2 ± 0.3^{d}	5.4 ± 0.3^{c}	7.2 ± 0.3^{b}	8.5 ± 0.3^{a}	<0.0001

Means with the same letter(s) are no significantly different from each other at P < 0.05 along the storage duration and agro-ecology for moisture; along the row for protein and fat content. Values are mean ± SEM

Fat: The fat content of stored maize was significantly affected by storage duration (P = 0.0002) and agro-ecological conditions (P = 0.0003) under farm storage conditions. It was 4.5 ± 0.1% at harvest but declined to 3.8 ± 0.1% after six months of storage. Comparing the three agro-ecologies, the highest fat content was recorded in lowland samples (4.5 ± 0.1%), followed by midland (4.3 ± 0.1%) and highland (3.9 ± 0.1%) (Fig. 4.1). Changes in storage duration (P < 0.0001) and agro-ecological conditions (P < 0.0003) showed similarly significant differences among the collectors. The highest fat content was recorded from first-round data (5.0 ± 0.1%) but by the end of data collection, it had declined to 4.2 ± 0.1%. A box plot trend for the fat content of stored maize from the collectors is shown in figure 2. Likewise, the fat content of maize kernels stored under wholesaler storage conditions was significantly (P = 0.02) affected by storage duration (Table 4.4). Under all storage conditions, the fat content significantly decreased as the storage duration increased.

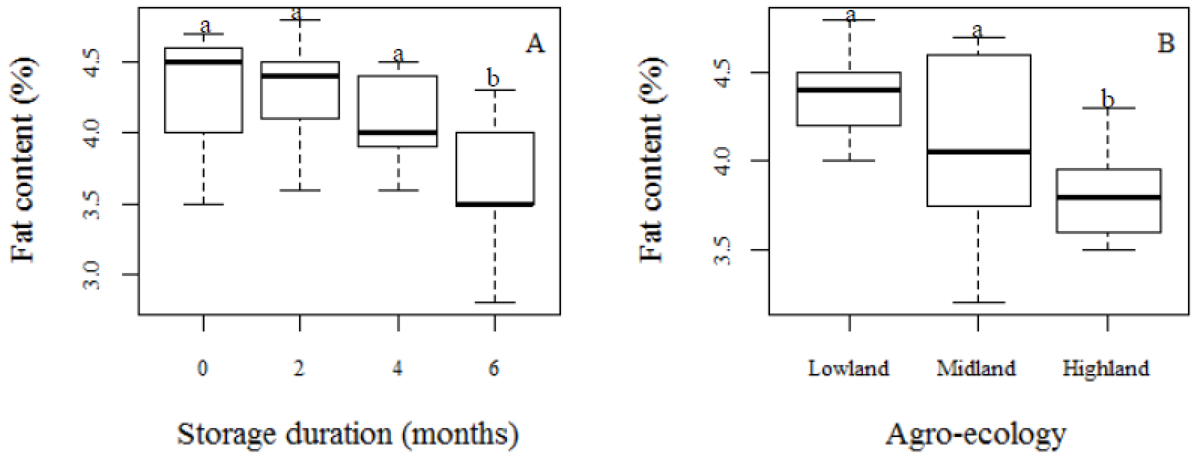


Figure 4.1 Box plots for fat content trend of maize kernels collected from farmers store A) across storage duration (P = 0.0002) B) under different agro-ecology (P = 0.0003).
Box plots with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are the range values.

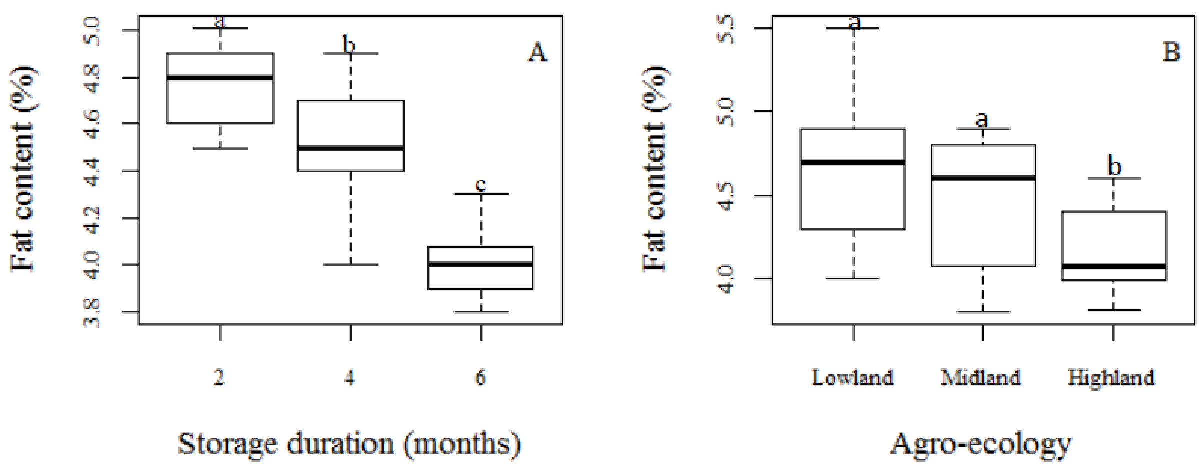


Figure 4.2 Box plots of fat content of maize kernels collected from collectors store A) storage duration (P < 0.0001) B) Under different agro-ecology (P < 0.0003).
Box plots with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are the range values.

Ash: The ash content of stored maize was significantly affected by storage duration (P = 0.003) and agro-ecology (P = 0.02) under farm storage conditions (Fig. 3A and B). Likewise, maize kernels' ash content from collectors was highly and significantly (P < 0.0001) affected by storage duration (Table 3), and similar results were recorded from wholesalers (Table 4.4).

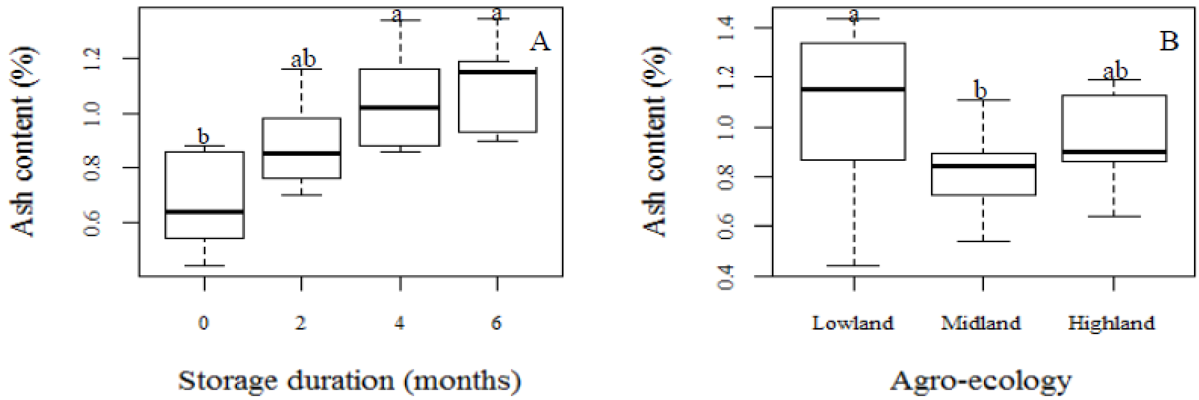


Figure 4.3 Box plots for ash content trend of maize kernels collected from farmers store A) across storage duration (P = 0.003) B) under different agro-ecology (P = 0.02).
Box plots with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are range values.

Table 4.3 Proximate composition of maize kernels sampled from collector store

		Storage duration (months)			
Quality traits (%)	Agro-ecology	2	4	6	P-value
Moisture	-	16.1 ± 0.2^{a}	14.5 ± 0.2^{b}	14.0 ± 0.2^{b}	<0.0001
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}	
Fibre	-	4.4 ± 0.5^{b}	6.7 ± 0.5^{a}	8.4 ± 0.5^{a}	0.0005
Ash	-	0.7 ± 0.1^{b}	0.9 ± 0.1^{b}	1.1 ± 0.1^{a}	<0.0001

Means with the same letter(s) are no significantly different from each other at P < 0.05 along the storage duration for moisture, fibre and ash; and both along storage duration and agro-ecology for protein. Values are mean ± SEM.

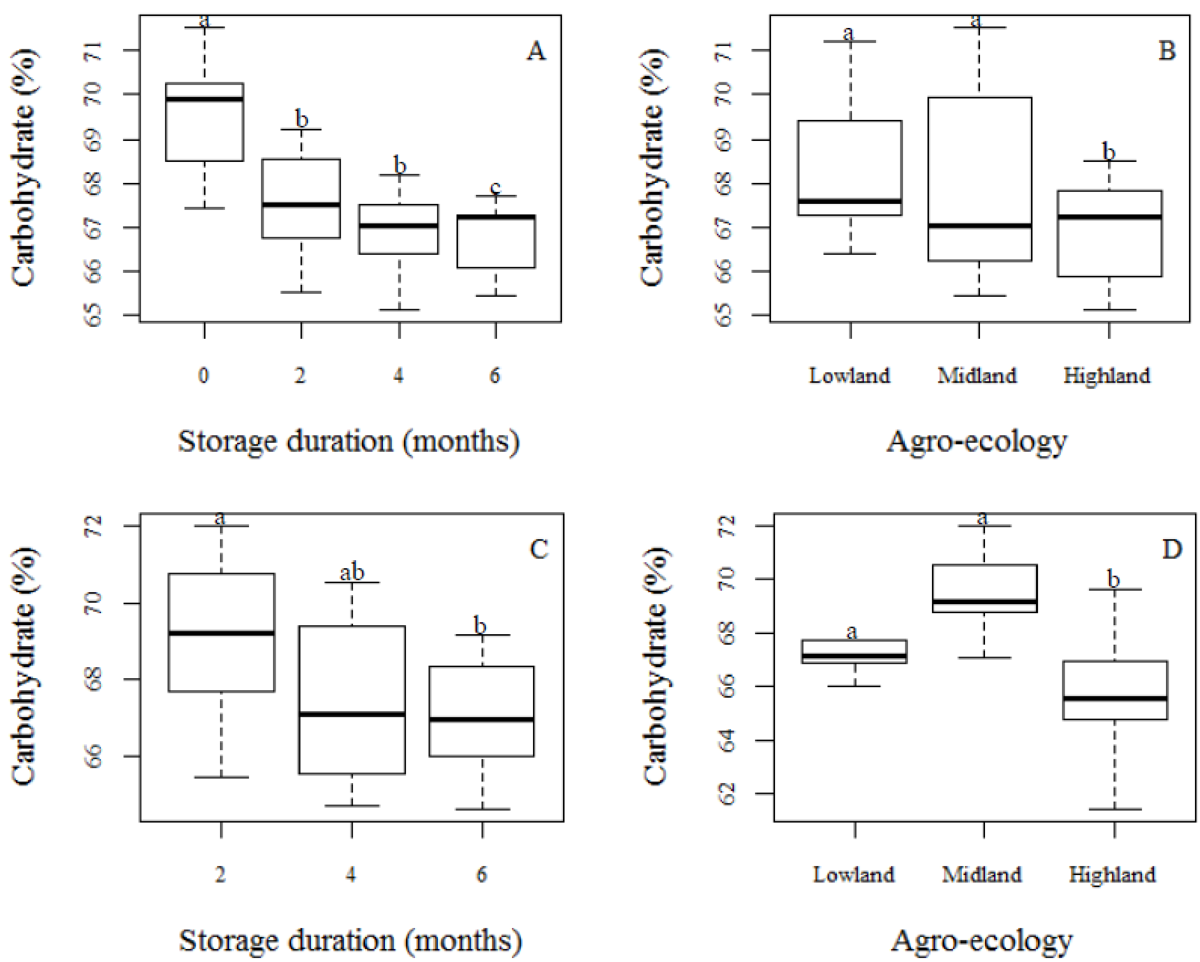
4.4.1.2 Carbohydrate content

The CHO content of maize stored under farmer and collector conditions was highly and significantly affected by both storage duration and differences in agro-ecology (Fig. 4.4A-D). The CHO content of maize kernels from wholesalers was also significantly affected by storage duration (Fig. 4.4E). The mean CHO content of maize showed decrement as storage duration increased under farmer conditions (Fig. 4.4A). A similar decreasing trend was observed for maize stored under collector (Fig. 4.4D) and wholesaler (Fig. 4.4E) conditions.

Table 4.4 Proximate composition of stored maize under wholesaler condition

	Storage duration (months)			
Quality traits (%)	2	4	6	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
Fibre	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

Means with the same letter (s) for each quality trait along the row is not significantly different from each other at $P < 0.05$. Values are mean ± SEM



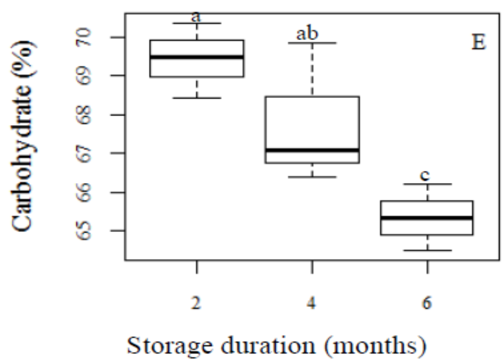


Figure 4.4 Box plots for carbohydrate content of stored maize A) under farm conditions for storage duration (P < 0.0001) and B) at different agro-ecology (P = 0.003); C) Under collector conditions along the storage duration (P= 0.002) and D) at different agro-ecology (P < 0.0001); E) Under wholesaler condition along the storage duration (P < 0.0001).
Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are the range values.

4.4.1.3 Calorific value

Significant effects of storage duration (P < 0.0001) and agro-ecology (P = 0.003) were observed on the calorific value of maize stored under farmer conditions (Fig. 4.5A and B). Under collectors and wholesaler storage conditions, the calorific value similarly decreased significantly (P < 0.05) as storage duration increased (Fig. 4.5C and D).

4.4.1.4 Major minerals

Fe, P, and Ca content were significantly affected by interaction effects of storage duration and agro-ecology under farmer and collector conditions (Table 4.5 and 6). However, Zn content was significantly affected by both storage duration and agro-ecology for each explanatory variable separately under farm storage conditions (P < 0.0001) (Fig. 4.6A and B). Similar results were observed for storage duration (P < 0.0001) and agro-ecology (P = 0.0006) under collector conditions (Fig. 4.6C and D). The mineral content of stored maize under wholesaler conditions was also significantly affected by storage duration (Fig. 4.7A and B).

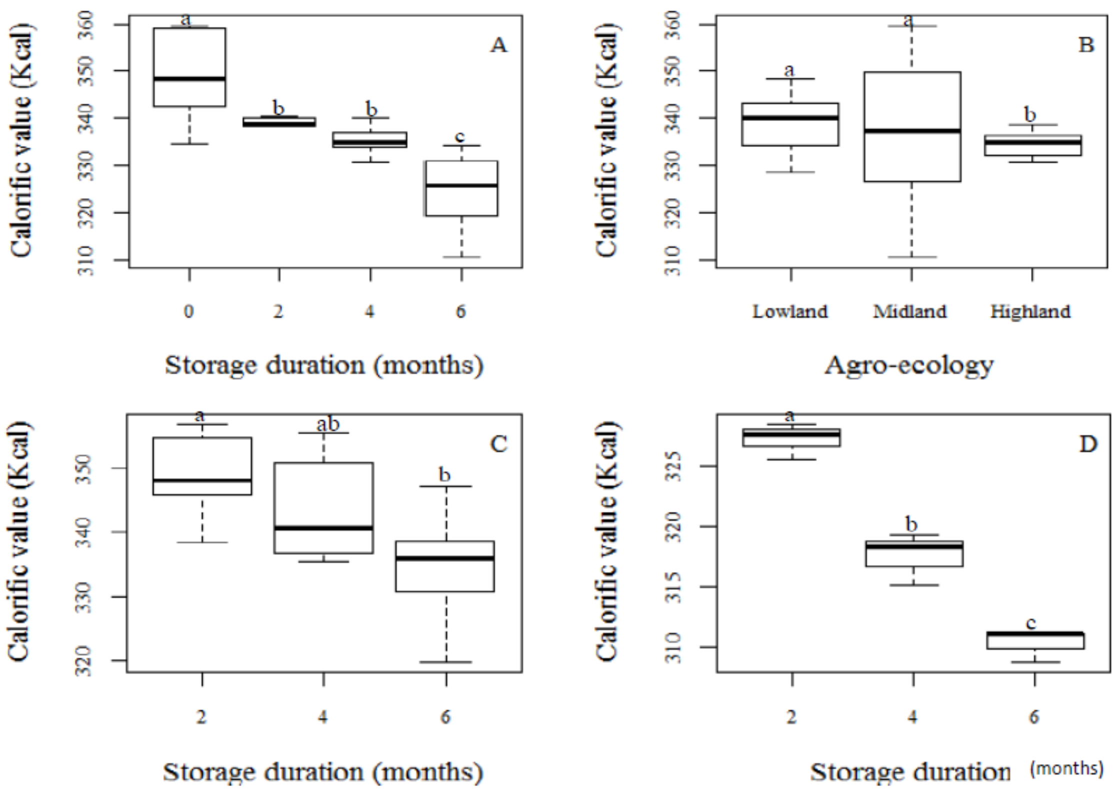


Figure 4.5 Box plots for calorific value of stored maize A) farm condition along storage duration (P < 0.0001) and B) across agro-ecology (P = 0.003); C) collector condition along storage duration (P = 0.01); D) wholesaler condition along storage duration (P < 0.0001).
Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Error bars are the range values.

Table 4.5 Major mineral content of maize kernels stored under farm condition

Minerals (mg/100g)	Agro-ecology	Storage duration (months)				P – Value
		0	2	4	6	
Fe	Lowland	0.6±0.3^{de}	1.3±0.3^{c-e}	2.9±0.3^{a-c}	4.3±0.3^{a}	0.01
	Midland	0.5±0.3^{e}	1.9±0.3^{b-e}	2.4±0.3^{bc}	4.4±0.3^{a}	
	Highland	0.4±0.3^{e}	2.0±0.3^{b-e}	3.5±0.3^{ab}	4.7±0.3^{a-c}	
Ca	Lowland	2.9±2.3^{g}	13.3±2.3^{fg}	43.0±2.3^{c}	77.1±2.3^{a}	< 0.0001
	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±2.3^{ef}	38.5±2.3^{cd}	55.2±2.3^{b}	
P	Lowland	261.2±23^{a-c}	221.1±23^{a-d}	291.9±23^{ab}	107.9±23de	0.002
	Midland	261.5±23^{a-c}	230.4±23^{a-c}	195.5±23^{b-d}	57.3±23^{e}	
	Highland	316.5±23^{a}	209.6±23^{a-d}	167.9±23^{c-e}	67.4±23^{e}	

Means with the same letter(s) are no significantly different from each other at P < 0.05 with interaction effect of storage duration and agro-ecology. Values are mean ± SEM.

Table 4.6 Major mineral content of maize kernels stored under collector condition

Minerals (mg/100g)	Storage duration (months)				
	Agro-ecology	2	4	6	P-value
Fe	Lowland	$3.40 \pm 0.3^{c\,d}$	$4.10 \pm 0.3^{b\text{-}d}$	7.50 ± 0.3^{a}	0.02
	Midland	2.70 ± 0.3^{d}	3.40 ± 0.3^{cd}	5.60 ± 0.3^{b}	
	Highland	2.90 ± 0.3^{cd}	4.60 ± 0.3^{bc}	5.30 ± 0.3^{b}	
Ca	Lowland	23.40 ± 2.5^{ef}	32.90 ± 2.5^{de}	53.90 ± 2.1^{bc}	0.006
	Midland	18.30 ± 2.5^{f}	$30.10 \pm 2.5^{d\text{-}f}$	67.10 ± 2.5^{a}	
	Highland	23.30 ± 2.5^{ef}	41.30 ± 2.5^{cd}	61.00 ± 2.5^{ab}	
P	Lowland	167.70 ± 17.7^{c}	257.70 ± 17.7^{b}	373.90 ± 17.7^{a}	0.04
	Midland	52.20 ± 17.7^{d}	139.60 ± 17.7^{cd}	178.20 ± 17.7^{bc}	
	Highland	67.20 ± 17.7^{d}	$206.90 \pm 17.7^{b\,c}$	214.3 ± 17.7^{bc}	

Means with the same letter(s) are no significantly different from each other at P < 0.05 with interaction effect of storage duration and agro-ecology. Values are mean ± SEM.

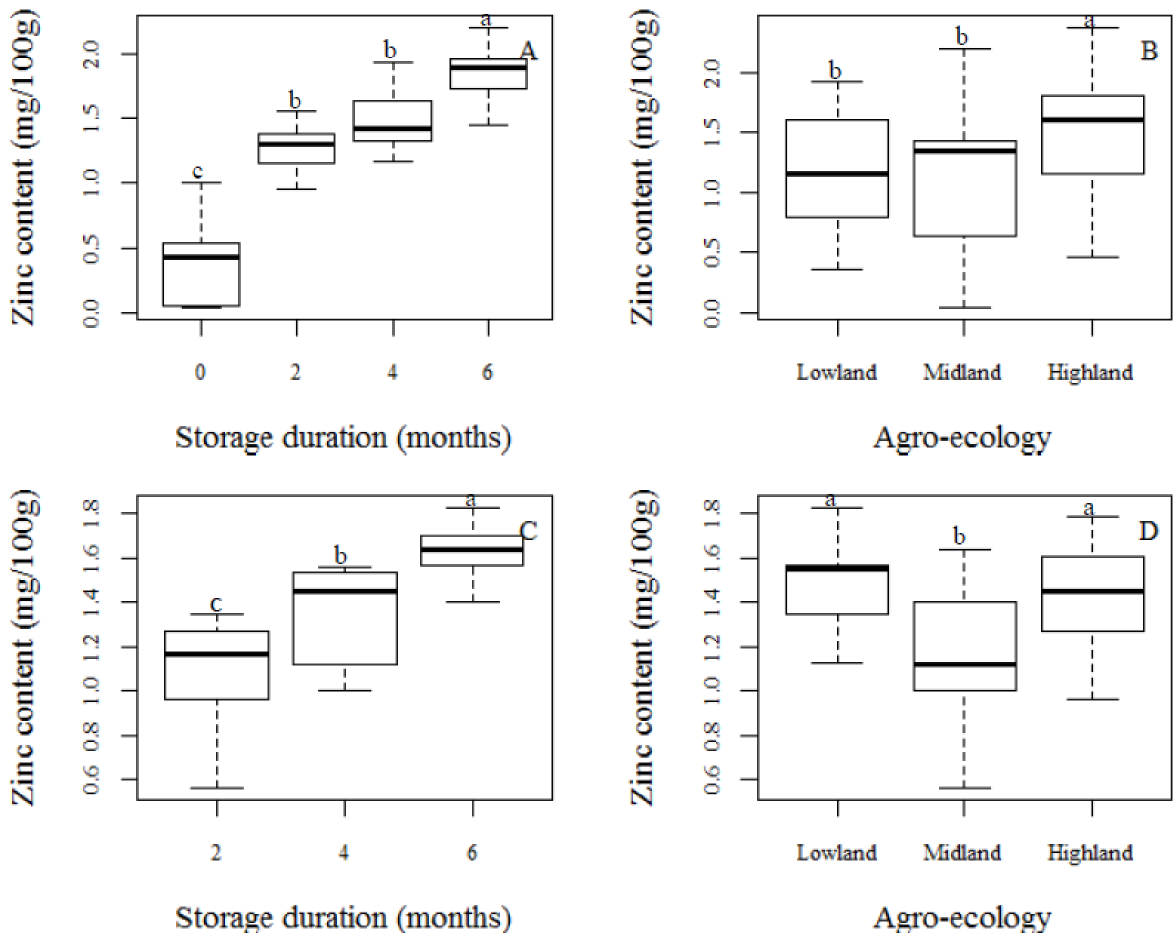


Figure 4.6 Box plots showing trend for Zinc content of stored maize kernels A) farm condition across storage duration (P < 0.0001) and B) agro-ecology (P = 0.0001); C) collector condition across storage duration (P < 0.0001) and D) agro-ecology (P = 0.0006).
Error bars are the range values. Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05.

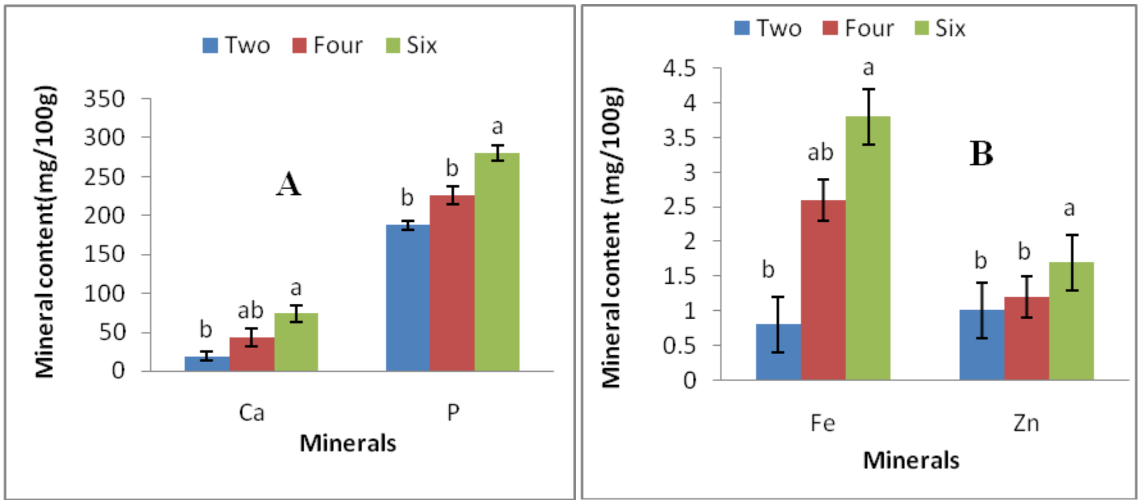


Figure 4.7 Mineral content of maize kernels stored under wholesaler condition A) phosphorus and calcium across storage duration in months (P= 0.001 for Ca; P=0.004 for P) B) Iron and zinc across storage duration in months (P=0.009 for Fe and P=0.007 for Zn).
Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Values are mean ±SEM.

4.4.2 Anti-nutritional content

The phytate content of stored maize under farm storage conditions was significantly affected by storage duration (P = 0.007) and differences in agro-ecology (P < 0.0001), and the trends are indicated in Figures 4.8A and B, respectively. The trend in phytate content showed a very slight increment initially but then showed a slight decline during the last sampling period. Both storage duration and agro-ecology showed a highly significant (P < 0.0001) interaction effect on condensed tannin content of maize stored under farmer conditions. The highest tannin content, however, was recorded at harvest (Fig. 4.8C). Maize sampled from collectors showed a significant (P < 0.01) interaction effect of storage duration and change in agro-ecology on anti-nutritional content (Fig. 4.9A and B).

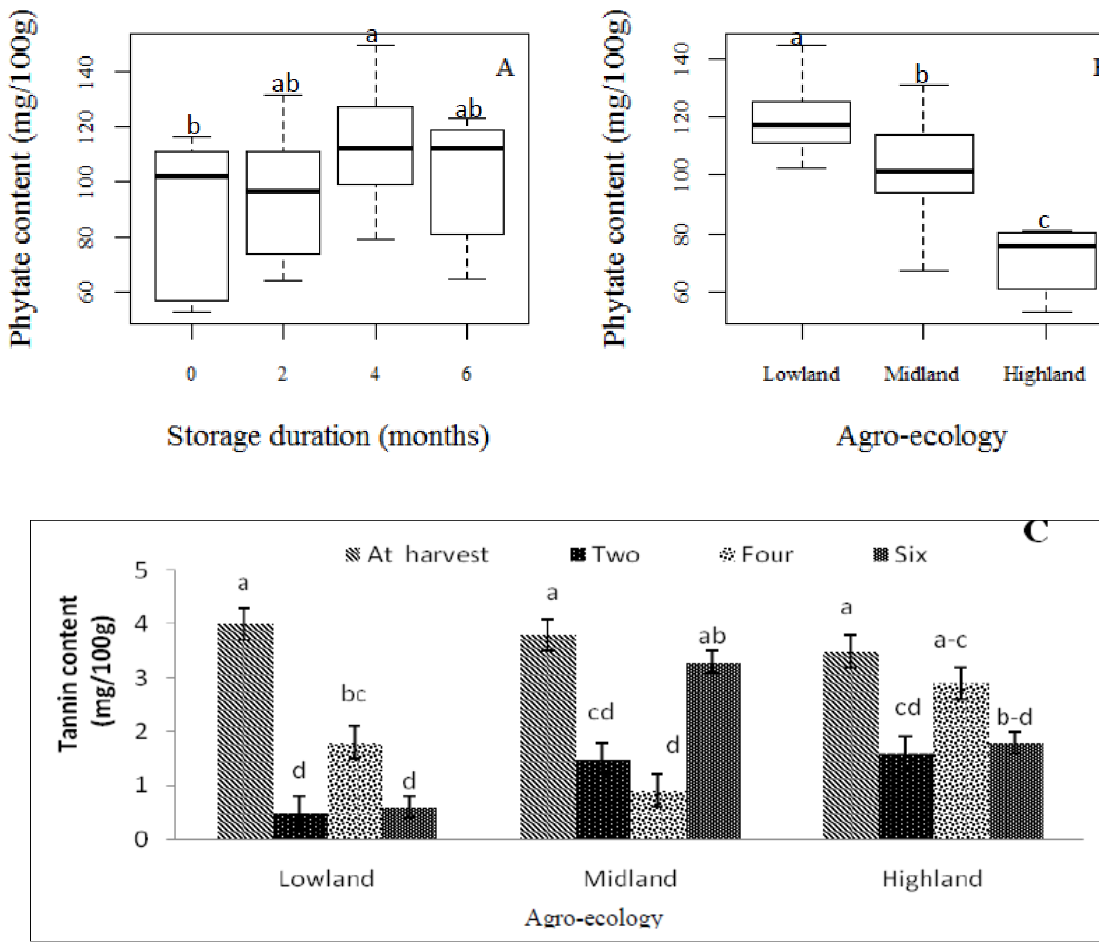


Figure 4.8 Anti-nutrient content of maize stored under farm condition A) box plots for Phytate along the storage duration (P=0.007) and B) agro-ecology (P < 0.0001) C) Tannin interaction effects of storage duration with different agro-ecology (P<.0001).

Error bars for Phytate are range values. Values are mean ±SEM for Tannin. Means with the same letter(s) for each figure not significantly different from each other at P < 0.05.

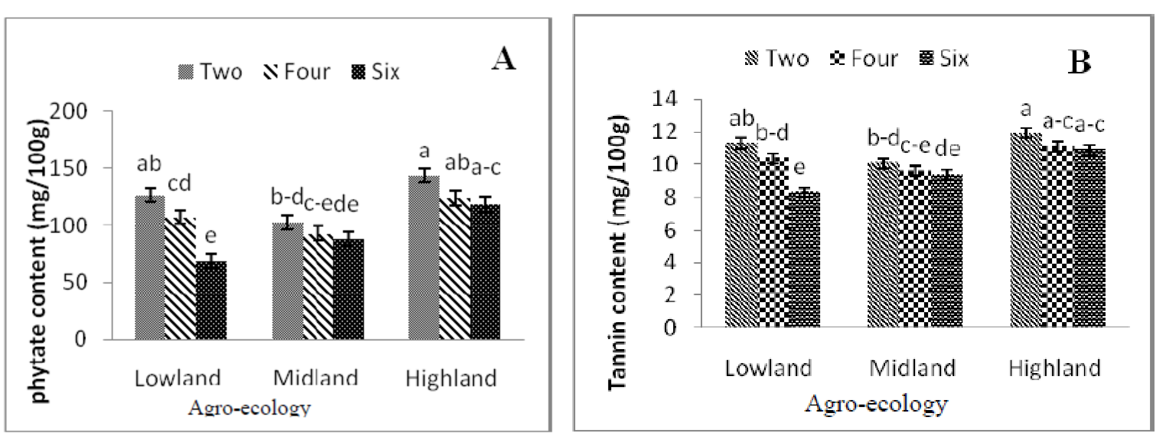


Figure 4.9 Anti-nutritional content of maize stored under collector store A) Phytate content and B) Tannin content; P-value = for Phytate P= 0.01 and P=0.01 for tannin.

Means with the same letter(s) for each figure are not significantly different from each other at P < 0.05. Values are mean ±SEM (Standard Error of Mean).

4.5 Discussion

Moisture content is one of the key factors in grain storage. It showed a slight decrement under farm storage conditions, but during the last months of data collection, it showed a percentage increase. As storage duration increases, particularly during last months of data collection it coincides with rainfall and moisture entered into the storage units through the perforated walls of the *gombisa* and so increased grain m.c. Stored maize kernels are hygroscopic in nature which absorb and release moisture from the surrounding external environment, and this affects the biological and biochemical activities of the kernels (Rashad et al., 2013). In contrast, with the present findings, declines in m.c. during storage have also been reported (Dubale et al., 2012; Oladele and Osipitan, 2013). On the other hand, increases in the m.c. of maize grain from 11.3% to 23.9% under traditional farm storage conditions have been reported from Uganda (Costa, 2014). The decline of maize kernel m.c. from 14.0% to 10.6% after eight months of storage, followed by an increase to 13.0% after twelve months of storage due to absorption of moisture from surrounding atmosphere, has also been reported (Bhattacharya and Raha, 2002). Stored maize kernels consist of a constant amount of dry matter but the water content varies (Devereau, 2002).

A higher maize m.c. above safe storage levels are one of the key factors in fungal growth and causes the nutritional quality of the product to deteriorate. It was observed during sample collection that mouldy maize kernels were very common in almost all stores. Higher kernel moisture content resulted in more susceptibility to the mould and insect damage that affects final quality (Rashad et al., 2013). Rainfall usually starts around March and reaches its peak for the year around July in the study region. In addition to moisture leakage into the stored product during the rainy season, m.c. at the loading stage (19% to 25% on average) was also not optimum for safe storage. The moisture content of maize kernels for long-term storage should be around 12% to 13% (Befikadu, 2014).

The present study found a reduction in protein content of up to 20.8%, 37.5%, and 11.4% for maize kernels stored under farmer, collector, and wholesaler storage conditions, respectively. Previous research reports on seven maize varieties, however, showed that crude protein content of different white maize varieties increased after weevil infestation (Tongjura et al., 2010). Another report, by contrast, found that maize kernels stored for three months showed a 7.1% of protein content reduction due to mite infestation, perhaps because of selective feeding by the mites on the germ part of the grain (Farhan et al., 2013). In a similar manner, fungi also invade and cause damage to the germ and endosperm part of the grain, and this deteriorates quality significantly (Meronuck, 1987). In other studies, only a slight decline in protein content of stored maize kernels was observed, followed by a slight increase after eight months of storage (Bhattacharya and Raha, 2002). Grain respiration, mould, and insect damage are among the key causes of protein content reduction in stored maize (Yakubu et al., 2010). Protein content reduction from 10.1% to 9.4% after nine months of storage in plastic bags under room temperature has also been reported (Stefanello et al., 2015). The high fungal contamination and insect pest damage observed during sample collection is the most probable reason for the high protein content deterioration observed in the present study. The different storage structures used by the different actors along the supply chain are not airtight and do not protect against external environmental conditions and insect pest damage, and this leads to quality deterioration.

Higher m.c. resulting in fungal damage to stored maize was observed in the highland agro-ecological setting under both farmer and collector storage conditions and led to a reduction in fat content. In agreement with these findings, another study reporting high m.c. of maize kernels (28-31%) also revealed a high reduction in fat content (Reed et al., 2007). Similarly, a decline in maize fat content from 5.9% to 5.3% after four months of storage due to damage by storage pests has also been reported (Farhan et al., 2013), as has a decline in fat content from 5.8% to 5.0% after nine months of storage in plastic bags at room temperature (Stefanello et al., 2015). We found a much greater decline in fat content than observed in other studies. This increased decline in fat content is related to the high initial moisture content and traditional storage structures in the study areas, which make it impossible to maintain the intrinsic characteristics of the kernels and protect them from storage pests.

Fibre content significantly increases as storage duration increases. A slight increment in maize fibre content after three months of storage was reported from Pakistan (Farhan et al., 2013). The same authors stated that the fibre content increased as a result of selective feeding by mites on the grain endosperm. The fibre content of maize grain is much higher in the bran than in the endosperm part of the kernel (Golob et al., 2002). Other researchers have also reported an increment in fibre content of maize over the storage period (Rashad et al., 2013). By contrast, Stefanello et al. (2015) reported that dietary soluble and insoluble fibre showed a decrement, but this change was not a significant difference after nine months of storage. The present study showed increments in fibre content of 103.4%, 90.9%, and 55.8% after six months of storage under farmer, collector, and wholesaler conditions, respectively. This finding clearly illustrates that much fibre is available in the product after six months of storage, but having more than the optimum fibre content in the diet can result in reduced nutrient absorption and other health impacts.

Ash content increased considerably with increasing storage duration across the supply chain. The ash content of different maize varieties is known to range from 1.7 ± 0.2 to 2.4 ± 0.05 mg/100 g (Hassan et al., 2009). As storage duration increased to 90 days, the ash content of stored maize increased from 1.9% to 1.91% (Farhan et al., 2013). For sorghum stored in soil pits an increase from 2.2% to 8.4% after 17 months of storage has also been reported (Dejene et al., 2006). Similarly, Stefanello et al. (2015) reported a maize ash content increment from 1.5% to 2.0% after nine months of storage. As with fibre, the ash content is higher in the maize bran than in the endosperm, and selective feeding on the endosperm by storage pests results in an increment in the ash content (Rashad et al., 2013). The extent of the ash increment in the present study was very high (57.1% to 120%) compared with the initial content. This has great implications for nutrient availability in the stored maize.

Significant reductions in CHO content were recorded under all actor storage conditions. This is consistent with the higher m.c. of stored maize, which enhances grain respiration rates and results in a reduction of CHO content (USID, 2011). Similarly, maize with a higher m.c. has higher rates of fungal contamination, and this has negative effects on nutritional content (Kumar and Kweera, 2013). Our findings are in line with these results: CHO declined as storage time increased due to damage caused by the bio-deterioration observed during the study. This agrees with the results reported by Bhattacharya and Raha (2002), who found a decline in CHO content in maize, caused by fungal damage, from 74.7% to 57.0% after twelve months of storage. Maize is one of the principal staple food crops in the study area, and the significant reduction in CHO content along the supply chain means less energy is available from maize for human consumption.

The present study revealed that calorific value, which depends on CHO, fat, protein, and dietary fibre content, declined across the storage period for all actors along the maize supply chain. Kumar and Kweera (2013) reported that maize with higher m.c. had higher fungal contamination and was lower in nutritional quality. A reduction in the energy value of stored maize as a result of mould damage has also been reported (Reed et al., 2007).

During the sample collection period in both production seasons, there was extensive insect infestation, especially in the lowland agro-ecology setting, as well as mould development in the highland maize growing areas, and these may have led to an increase in major minerals. Similarly, Farhan et al. (2013) stated that selective feeding of insects on grain endosperm resulted in an increase in mineral content (Fe, Ca, and Zn). The report by Tongjura et al. (2010) that found increases in calcium from weevil infestations in stored maize also supports our finding. Mineral content is much higher in maize bran, but the CHO content of maize bran is lower and storage pests mainly depend on CHO for their growth (Enyisi et al., 2014). Similarly, selective feeding by fungi on the CHO component of sorghum grain resulted in increases in both ash and mineral content (Dejene et al., 2006). Furthermore, weight loss resulted in an increase in grains per gram, and this may cause an increase in mineral content across the storage period. Weight loss of maize stored for six months under traditional *gombisa* storage structures in Jimma Zone ranged from 41% to 80% due to damage by insect pests (Sori and Ayana, 2012). Similarly, under different traditional farm storage conditions weight losses in maize cob have been reported from Senegal (Gueye et al., 2013). Weight losses of 11.8% to 67.1% after three months of storage due to insect damage have been reported from maize in Kenya (Tefera et al., 2011).

Both tannin and phytate content showed a decrement as the storage duration increased. A study conducted in Pakistan showed that the anti-nutrient content of different maize varieties ranged from 30.0 ± 0.03 to 33.3 ± 7.8 mg/100 g (tannin) and 330.6 ± 1.8 to 670.7 ± 5.6 mg/100 g (phytate) under normal conditions (Hassan et al., 2009). Similarly, Hambidge et al. (2004) reported that the phytate content of different maize varieties ranged from 380 ± 0.10 to 750 ± 1.10 mg/100 g based on the dry-weight basis for the samples collected from North America. The concentration of phytate in matured cereal grains largely depends on plant nutrient consumption and the stage of maturity at harvest (Oberleas, 1973). In general, as opposed to the assumption those anti-nutritional components tend to increase during the storage; both phytate and tannin content seem highest at harvest which invites for more research considering maize hybrid currently under production, nature of traditional storage systems and factors during production.

4.6 Conclusions

This study aimed to determine the nutritional and anti-nutritional content of stored maize under different agro-ecological conditions and different supply chain actors in Jimma Zone, southwestern Ethiopia. The results showed that m.c. at the loading, the stage was not optimum for safe storage. In addition, m.c. decreased as the storage duration increased, except under farm storage conditions, where moisture content increased, mainly due to rainy seasons. Farmers' traditional storage structures are not airtight and not effective in protecting stored maize from external environmental conditions and the bio-deterioration that causes nutritional decline. Our findings also revealed that the nutrient composition of stored maize, especially protein, fat, CHO, and calorific value, significantly declined across the storage period for different actors and their different storage structures. The storing of maize by all actors along the maize supply chain resulted in high-quality losses that have great implications for nutrition insecurity in society. On the other hand, fibre and ash content showed increases over the storage period. Similar trends were observed for major minerals, including Fe, Ca, and Zn.

There is thus a need to develop and/or modify and disseminate appropriate storage technologies that reduce nutrition quality losses. There is a need to determine moisture content at the harvest and loading stages for safe storage. Moreover, there is also need for training and awareness creation at the producer level to promote effective on-farm storage techniques that will minimize quality losses. Attention should also be paid to effective pest management that will help to improve the nutritional quality of stored maize and secondary metabolites produced by fungal pathogens.

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5 Potential for mycotoxin-producing fungal growth in various agro-ecological settings and maize storage systems in southwestern Ethiopia

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5.1 Abstract

The objective of this study was to evaluate the potential growth of mycotoxin-producing fungi under different agro-ecological settings and storage methods in southwestern Ethiopia. The districts of Sokoru, Omonada, and Dedo, representing three agro-ecological settings, were considered for the study. Six farmers' fields were selected from each agro-ecology for monitoring pre-harvest weather conditions, while three farmers' and three collectors' storage systems were considered for post-harvest study. Additional warehouses were also included for current study. Fungal pathogens were isolated and identified once per month over a six-month storage period. Both long-term climate and pre-harvest weather data indicated that all agro-ecological conditions were conducive to the growth of the target fungal species. Temperatures inside the farmers' storage systems showed significant ($P = 0.04$) positive correlations with ambient conditions. Significant ($P < 0.05$) positive correlations were also observed between the relative humidity under the farmers' storage and the ambient conditions. In contrast, there were no significant correlations between the collector's storage and ambient conditions for either temperature or relative humidity. A simple linear regression model revealed that there was a negative relationship between frequency of mycotoxin-producing fungi and the temperature inside the farmers' storage systems; whereas, fungal occurrence was positively and significantly ($P < 0.05$) correlated with the relative humidity. Both temperature and humidity were associated with fungal frequency of occurrence in the collectors' store-houses and the wholesalers' warehouses. The farmers' traditional storage methods are not climatically controlled to maintain post-harvest product quality. Therefore, a simple and accessible climate-controlled storage structure is necessary for the resource-poor growers of the study area.

Keywords: Actors, agro-ecology, weather variables, toxicogenic fungi, storage.

5.2 Introduction

Maize is a highly important cereal crop but it is subjected to severe post-harvest losses in Africa (Dubale et al., 2012; Tefera, 2012; Befikadu, 2014). Generally, preventing post-harvest losses is a challenge for producers in developing countries but it is an imperative aspect of food security (IFPRI, 2010; Sori and Ayana, 2012; Tefera, 2012). Homdork et al. (2000) stated that most of the time storage systems in developing countries are traditional and not climatically controlled due to high cost and are not readily available. In general, crop storage practices and structures in Ethiopia are traditional systems which promote the proliferation of pathogens and insect pests. Under such conditions, stored products such as maize may be vulnerable to these pests (Gabriel and Hundie, 2006; IFPRI, 2010; Dubale et al., 2012; Sori and Ayana, 2012; Befikadu, 2014; Dubale et al., 2014).

In Ethiopia, cereal grains are stored in *gotera*, *gombisa*, sacks, pots, underground pits, baskets, store-houses and warehouses (Gabriel and Hundie, 2006; Dubale et al., 2012; Garbaba et al., 2017). The g*ombisa* is the most popular on-farm storage structure of maize in the southwestern Ethiopia. It is usually unplastered structure mostly made from bamboo. Its roof is covered with thatched grass. Maize stored in cobs for an average of six months (Garbaba et al., 2017). This structure is not generally climate-controlled and its contents are exposed to the external environment, leaving crops vulnerable to fungal pathogen contamination. Traders in the southwestern part of the country store shelled maize in sacks (Befikadu, 2014; Garbaba et al., 2017). Maize is hygroscopic; even when it is dried thoroughly, its kernels can absorb water when they are subjected to high relative humidity (Devereau et al., 2002; Rashad et al., 2013). To preserve the longevity of maize seeds for germination, it should be protected from adverse conditions that leads to microorganism growth resulting in deterioration (Oyekale et al., 2012). Dried maize can accumulate high levels of aflatoxin at 25°C and 86% (±3%) equilibrium relative humidity. Climate control, then, helps to limit the proliferation of *Aspergillus flavus*, a major aflatoxin producer (Muchilwa and Hensel, 2016).

Various species of fungal pathogens in southwestern Ethiopia have recently been reported. The dominant fungal genera isolated from post-harvest maize were *Fusarium*, *Aspergillus*, and *Penicillium*. These pathogens reduce both crop yield and quality (Dubale et al., 2012; Garbaba et al., 2017). Another recent study in southern Ethiopia found that *Aspergillus*, *Fusarium*, *Penicillium*, and *Trichoderma* species were the dominant fungal pathogens on maize, in a descending order of frequency. All tested samples were contaminated with varying levels of aflatoxin exceeding the safety limits set by the Food and Drug Administration (FDA) and the European Union (EU) (Chauhan et al., 2016). Another study conducted in northwestern Ethiopia determined that the average pre- and post-harvest maize aflatoxin concentrations were 18.38 $\mu g\ kg^{-1}$ and 43.36 $\mu g\ kg^{-1}$, respectively. These results clearly indicate that aflatoxin contamination occurs both before and after harvest, and that the concentration of the toxin significantly increases along the post-harvest process chain (Assaye et al., 2016). An assessment of aflatoxigenic *Aspergillus* species in the food commodities from a local market in Addis Ababa showed that *A. flavus* and *A. parasiticus* were the dominant species isolated from various foodstuffs (Gemeda et al., 2014). Overall, the findings reported for various parts of the country revealed that mycotoxin-producing fungi are prevalent contaminants in stored maize.

Various participants in the maize supply chain in southwestern Ethiopia performed similar pre- and post-harvest handling practices without changing to controlling climatic conditions. Most of the research focused on the roles of temperature and relative humidity on fungal growth under laboratory conditions. Nevertheless, very little data is available to evaluate the effects of changing climatic conditions in different agro-ecological settings and storage methods which support the growth of major mycotoxin-producing fungi. It is also necessary to know the environmental conditions from post-flowering to physiological maturity to harvest in order to determine the susceptibility of an area to fungal pathogen growth and whether it could be an inoculum source during the post-harvest process. Therefore the aims of this study were 1) to assess the potential role of temperature and relative humidity of an area during post-flowering to physiological maturity of maize for mycotoxin-producing fungal growth 2) to investigate the maize storage methods at various agro-ecological settings in southwestern Ethiopia for the growth of major mycotoxin-producing fungi along the maize post-harvest supply chain.

5.3 Materials and methods

5.3.1 Description of study area

The research was conducted in Jimma Zone, located in Oromia Regional State in southwestern Ethiopia. Agriculture is the main economic activity in this region. The major crops produced there are maize, *teff*, and sorghum**.** The elevation ranges from 800-3,360 m above sea level (m.a.s.l.) and the average annual rainfall is 1,600 mm within 8-10-month period. The temperature varies from 7-30°C. The present study was conducted in Sokoru, Omonada, and

Dedo districts, representing lowland, midland, and highland of the agro-ecological settings, respectively. Those districts represent amongst the highest maize production areas from the Jimma zone (CSA, 2009; ZOFED, 2013). Abalti Peasant Association (PA) represented the lowland agro-ecology, Nada Chala PA was the midland agro-ecology, and Mole PA portrayed the highland agro-ecology were selected for current study. For the collector storage, the district/town centre was selected as a study site for each agro-ecological setting (Table 5.1).

Table 5.1 Agro-ecological settings and coordinates of the study sites

Actor	Agro-ecology /town	PA/town	Altitude (m.a.s.l)	Coordinates	
				Latitude (N)	Longitude (E)
Farmer	Lowland	Abalti	1476	08°17′	037°57′
	Midland	Nadda Chala	1886	07°36′	037°12′
	Highland	Mole	2054	07°28″	036°59′
Collector	Lowland	Sokoru town	1810	07º55′	037º25′
	Midland	Nada town	1823	07º38′	037º15′
	Highland	Sheki town	2234	07º30′	036º52′
Wholesaler	Jimma	Jimma town	1734	07º46′	036º49′

5.3.2 Experimental setup and procedures

5.3.2.1 Pre-harvest micro-climate

Six farms from each agro-ecological setting were selected for pre-harvest weather monitoring. Microclimatic relative humidity and temperature data for each selected farm were recorded using data loggers (Testo 174 H, Testo SE & Co. KgaA, Lenzkirch, Germany) with an accuracy of ±3% for relative humidity and ±0.5°C for temperature. Each data logger was first configured to record weather variables every 20 min then placed in each maize field 1.5 m above the ground. Data were collected from the maize tasselling and silking stage until physiologically maturity and harvest. Finally, all data collected were complemented with two decades of historical climatic data for each agro-ecological setting from the flowering to the harvest stage in order to evaluate the effects of climatic conditions on fungal growth.

5.3.2.2 Storage

On the farm, growers usually store maize in cobs for an average of 6 months. The dominant storage structure used by farmers is the traditional *gombisa.* A *gombisa* was built with locally available materials at each agro-ecological setting for current study. As result, similar structures were seen on every selected PA site. The structures were cylinders with circumferences of 6.28 m, diameters of 2.0 m, and conical roof lengths of 1.6 m. The bases of the *gombisa* were 2.5 m long, 2.0 m wide, and 1.6 m high. In all the agro-ecological settings studied, each *gombisa* was made of bamboo and had a roof covered with thatched grass. The structure was assembled on a level surface and four pillars were used to support its roof.

Bako Hybrid (BH-660) maize was produced on all the study sites. A total of 2.54 m^3 of maize in cobs were loaded into each traditional storage structure. Three data loggers (Testo 174 H, Testo SE & Co. KgaA, Lenzkirch, Germany) were placed in three different locations inside each *gombisa* (bottom, middle, and top) after being configured to record data every 30 min. The mean data values of the three loggers were used to plot a curve. Similarly, data logger was placed outside near to storage structure without direct expose to sun-shine at each study site to record the ambient temperature and the relative humidity.

The collector store was assembled from various types of timber and corrugated sheet metal. The store-house was generally plastered inside and out. The floor was either made of mud or covered with plastic. Collector store-houses lack windows or ventilation system. The average area of each collector storage was 8 m × 8 m = 64 m^2. Shelled maize was stored in a non-airtight sack with a capacity of 100 kg. On average, 50,000 kg of shelled maize was kept in each store-house. In this study, data loggers were placed in the lower, middle, and upper layer of the stored maize. The mean values were used to plot the curves for the various agro-ecological settings. One data logger remained outside to track ambient conditions.

The wholesaler storage resembled that of the collectors. They were constructed from various types of timber and corrugated sheet metal. Both the inside and outside walls were sealed with mud, and the floor was made of concrete. Each store had a window and a ventilation system below the roof and running about half a meter round the whole warehouse. Wholesaler warehouses were more expensive and larger than collector storage. Maize was stored as shelled kernels in a non-airtight sack capable of holding 100 kg. Three data loggers were placed at different levels inside each sack, and another was placed outside to record ambient condition similar to farm and collector system. The study was conducted for six months during the 2014/2015 production and storage season.

5.3.2.3 Historical meteorological data

Precipitation data and minimum and maximum temperatures over two decades for each agro-ecological setting were also collected from the Ethiopian Meteorological Agency (EMA) and used in the current study (EMA, 2016).

5.3.3 Mycotoxin-producing fungal pathogen isolation and identification

Following standard methods, mycotoxin-producing fungal pathogens found on maize kernels were grown, isolated, and identified to the genus level monthly for six months of storage (Magnoli *et al*., 2003; Deacon, 2006; Hocking, 2006; Narayanasamy, 2006; Pitt and Hocking, 2009; Atukwase et al., 2012). Frequency of occurrence for isolated fungal genera were calculated using previously developed techniques (Meer *et al.*, 2013).

5.3.4 Parameters considered and data analysis

Daily monitored temperature and relative humidity from the maize tasselling and silking stage until physiologically maturity and harvest were summarized as table 2 (Means ±SEM). The potential growth of major mycotoxin-producing fungal (*Fusarium*, *Aspergillus*, and *Penicillium)* was correlated to the pre-harvest weather data and the long-term climatic data. Mean temperature and mean relative humidity data from the bottom, middle, and top layers of the storage systems were plotted as dynamic graphs (Dygraphs). Trends in each variable were identified based on the available information. These included the period required for fungal growth or the potential for fungi to start growing and the time at which the fungi could multiply and produce mycotoxins.

Pearson's correlation coefficient analysis was used to determine the relationship between temperature and relative humidity outside and inside the store. This metric was used to assess how effectively the various storage systems could protect the maize from external climatic factors. A simple regression model was also developed and used to estimate mycotoxin-producing (*Fusarium*, *Aspergillus* and *Penicillium*) frequency of occurrence correlated with temperature and relative humidity inside the storage systems. The model was constructed using Minitab version 16.

5.4 Results

5.4.1 Climatic conditions

5.4.1.1 Long-term climatic conditions

Variation in precipitation and temperature were site-dependent. The mean annual precipitation values for the lowland, midland, and highland were 1,330.8 ± 166.9, 1,405.6 ± 286.5, and 2,033.4 ± 348.4 mm y^{-1}, respectively (data not shown). Precipitation also varied between seasons within the study area. High precipitation levels occurred in June, July, and August. Daily maximum and minimum temperatures on a monthly basis found to vary between study sites, but the daily averages clearly showed that certain parts of the year were warmer than others (data not shown). At those times, mycotoxin-producing fungal growth was favoured. In the highland agro-ecological setting, there was slightly less seasonal temperature variation than the other regions.

5.4.1.2 Pre-harvest microclimates

Table 5.2 shows temperature and relative humidity data obtained for the 2014/15 production season from the maize tasselling and silking stage until harvest. Under all regimes, the relative humidity declined as the maize matured physiologically up to harvest. The trend for temperature, however, was the opposite, especially for lowland maize. The mean temperature was 23°C (range: 12-39°C) and the mean relative humidity was 65% (range: 19-99.9%) for lowland agro-ecology. Conversely, mean values of 20°C and 73% were recorded in the midland maize production area. Minima of 7°C and 26% and maxima of 34°C and 99.9% were recorded at the same agro-ecological setting. The mean values in the highland agro-ecology from flowering to harvest were 18°C and 81%.

5.4.2 Storage systems

Farm level: Monitored climate conditions inside farmers' traditional storage structures exhibited high variation for temperature and humidity data (Figs. 5.1A-C). Figure 5.1A shows high variation in relative humidity (9-89%), with a mean value of 45% during the storage period at the lowland agro-ecological setting. The temperature varied from 16-35°C with a mean value of 25°C. The lowest relative humidity and the highest temperature were recorded in March (the dry period). Similar trends were observed in the midland agro-ecological setting. The lowest (13°C) and highest (32°C) temperatures were recorded inside the farmers' traditional storage systems, and the mean value was 20°C (Fig. 5.1B). The mean relative humidity was 66% (range: 17-94%) at the same site. At the highland agro-ecological setting, a mean temperature of 19°C and ≤99.90% relative humidity value were recorded during the maize storage period (Fig. 5.1C). The relative humidity increased in every agro-ecological setting starting in March until the end of storage. Conversely, the temperature gradually declined from March onwards (Figs. 5.1A-C). For all curves, the roll period (moving average) reduced the data spikes attributable to the lowest and highest values.

Table 5.2 Summarized data for temperature and relative humidity from the maize tasselling and silking stage until harvest across agro-ecological settings.

Time	Variable					
	Temperature (^oC)			Relative humidity (%)		
	Lowland	Midland	Highland	Lowland	Midland	Highland
01 Sep	21.0±0.3	18.4±0.3	17.5±0.3	77.4±1.7	82.4±1.7	84.8±1.7
08 Sep	21.5±0.3	18.5±0.3	18.1±0.3	75.2±1.7	82.0±1.7	82.5±1.7
16 Sep	22.0±0.3	18.9±0.3	18.1±0.3	74.7±1.7	81.6±1.7	85.1±1.7
24 Sep	21.1±0.3	19.4±0.3	18.3±0.3	78.9±1.7	78.9±1.7	82.3±1.7
01 Oct	22.0±0.3	19.3±0.3	18.1±0.3	76.9±1.7	80.8±1.7	84.9±1.7
08 Oct	22.4±0.3	19.4±0.3	18.5±0.3	74.3±1.7	79.9±1.7	83.4±1.7
16 Oct	24.6±0.3	20.4±0.3	18.4±0.3	57.7±1.7	70.5±1.7	79.9±1.7
24 Oct	23.1±0.3	20.3±0.3	18.2±0.3	53.4±1.7	64.7±1.7	77.3±1.7
01 Nov	23.4±0.3	20.1±0.3	18.3±0.3	48.4±1.7	61.1±1.7	73.5±1.7
08 Nov	23.7±0.3	20.5±0.3	17.7±0.3	43.9±1.7	57.3±1.7	71.9±1.7

Values are mean ± SEM. Both weather variables data recorded every 30 minutes and daily average values used for data analysis.

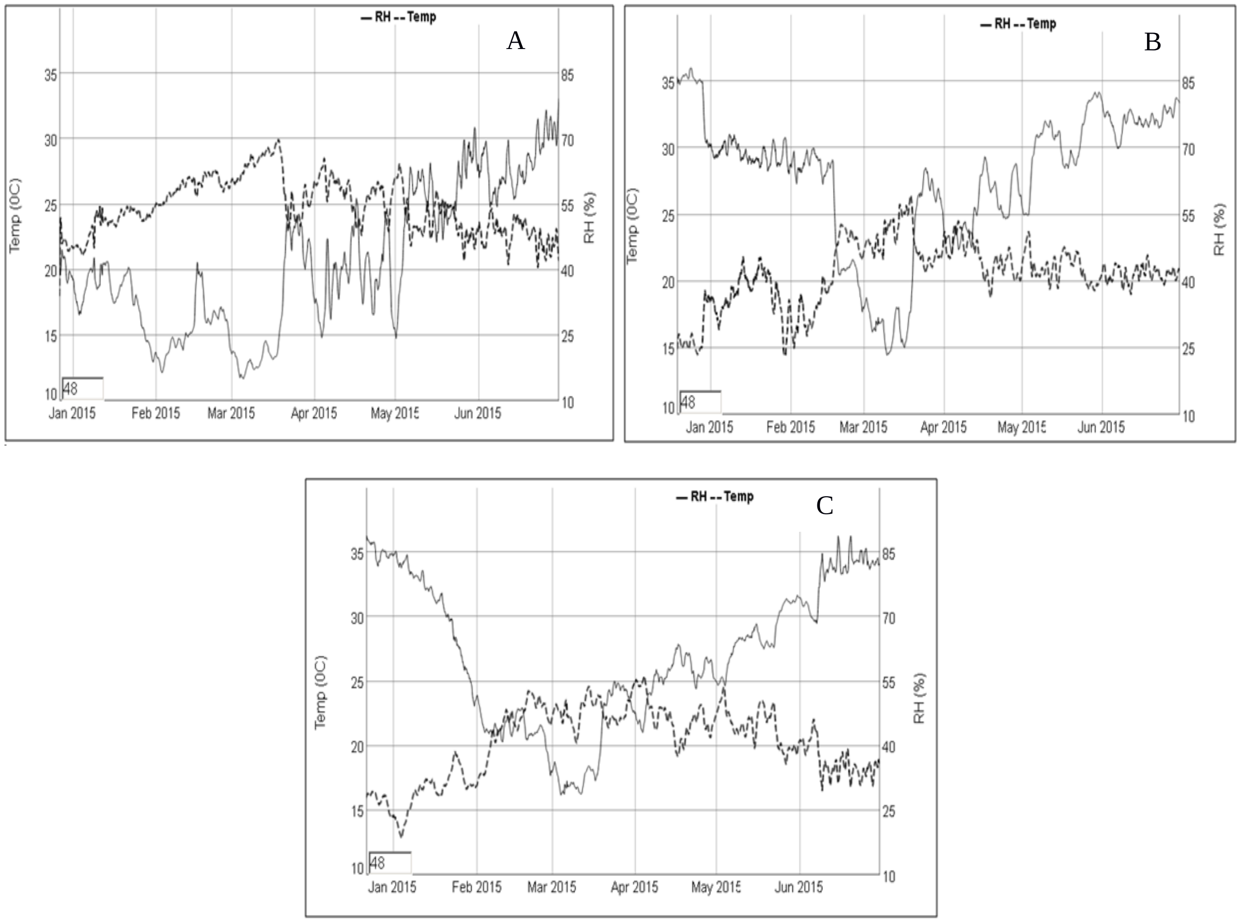

Figure 5.1 Dygraph for temperature and relative humidity trends inside farmers' traditional maize storage systems A) lowland B) midland and C) highland agro-ecological settings.
Each curve plotted with mean value of the three data loggers in each *gombisa*. Also, each curve plotted with 48 roll period (mean value of 48 data points).

Traders' store: The traders' storage showed only very slight fluctuations in both temperature and relative humidity (Figs. 5.2A-D). At the lowland agro-ecological settings, the temperature ranged from 18.1-30°C, with a mean value of 25.1°C. The relative humidity ranged from 43-80.7% (Fig. 5.2A). At the midland agro-ecological settings, the mean temperature was 23.8°C (range: 16.6-28.9°C). At the highland agro-ecological settings, the temperature varied from 16.1-27.6°C with a mean value of 23.5°C (Figs. 5.2B and 2C). The relative humidity had an average of 61.9%. Its highest value was 89% at the midland and ≤94% at the highland agro-ecological settings. The relative humidity inside the wholesaler storage structures ranged from 39-66% with a mean value of 55%. The temperature ranged from 20°C to 29°C with a mean value of 25°C during the storage period (Fig. 5.2D). For all curves, the roll period reduced the minimum and maximum data spikes.

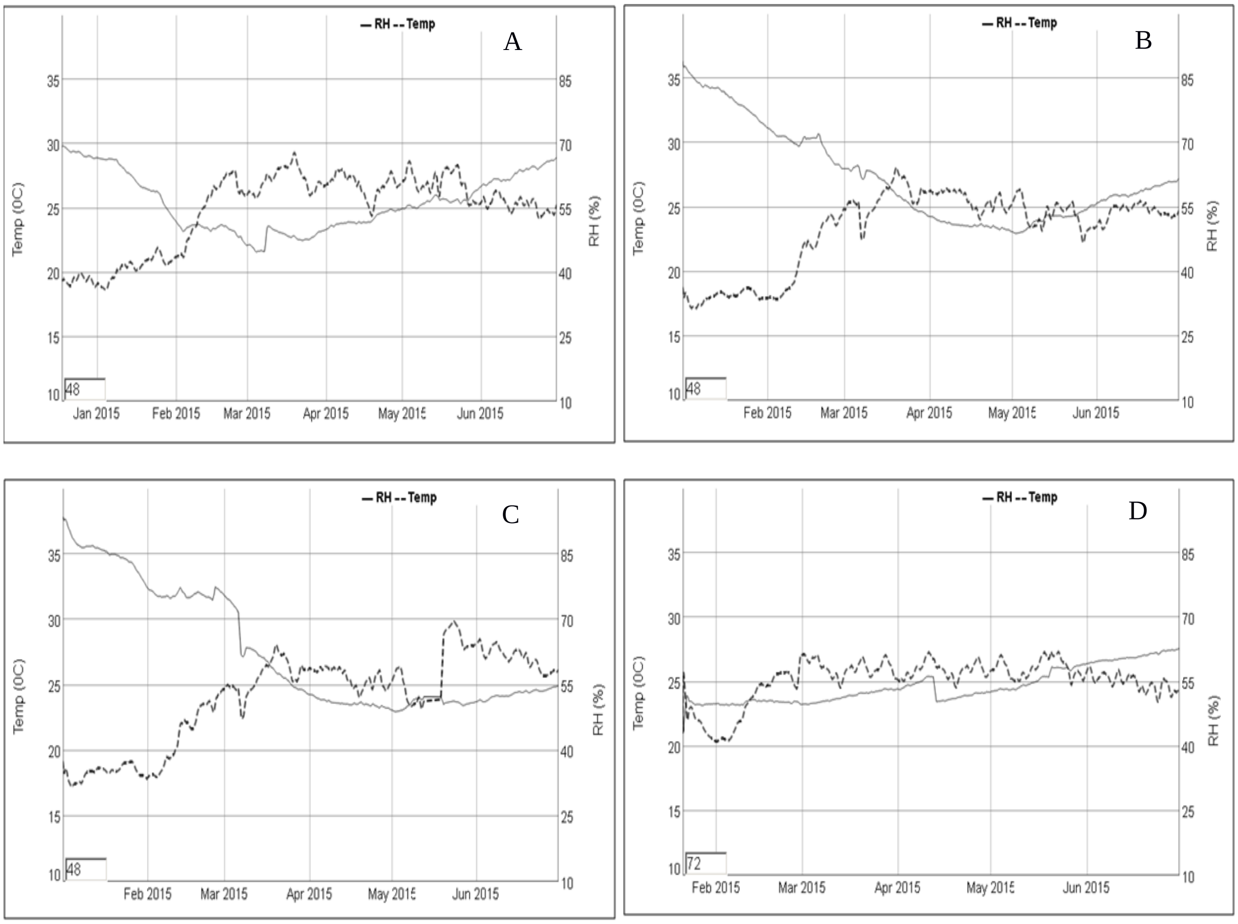

Figure 5.2 Dygraph for temperature and relative humidity trends inside traders' maize storage systems in different agro-ecological settings A) lowland B) midland and C) highland collectors store-houses; D) wholesaler storage condition.
Each curve plotted with mean value of the three data loggers at different layer in each sack. Also, each curve plotted with 48 data points (collectors' store) and 72 data points as roll period for wholesaler store (mean value data points used to plot the curve).

5.4.3 Relationship between inside store and ambient weather conditions

There was a positive correlation between inside and outside temperature and relative humidity for the farmers' storage systems in all agro-ecological settings (Table 5.3). Temperature had a moderate to high positive correlation coefficient (range of r = 0.686-0.974). The range of r for relative humidity was 0.683-0.955 and the differences were significant (P < 0.05). In contrast, inside and outside temperature and relative humidity were only weakly correlated for the collectors' store-houses in all agro-ecological settings. The differences were not statistically significant (P > 0.05) (Table 5.3). The inside and outside temperatures were moderately correlated for the wholesaler storage facilities.

Table 5.3 Pearson's correlation for temperature and relative humidity comparing inside stores of different actors maize with the ambient conditions.

Agro-ecology/ town	Actor	Temperature (°C)		Relative humidity (%)	
		r-value	p-value	r-value	p-value
Lowland	Farmer	0.974	0.0001	0.955	0.0001
	Collector	0.180	0.699	0.293	0.524
Midland	Farmer	0.847	0.008	0.683	0.062
	Collector	0.187	0.693	-0.363	0.377
Highland	Farmer	0.686	0.041	0.728	0.026
	Collector	0.084	0.858	-0.584	0.169
Jimma town	Wholesaler	0.596	0.158	0.920	0.003

5.4.4 Relationship between mycotoxin-producing fungi occurrence and weather conditions

A simple linear regression model revealed that there was a negative and non-significant relationship between frequency of mycotoxin-producing fungi occurrence and the temperature inside the farmers' traditional storage systems (Table 5.4). There were, however, positive and statistically significant ($P < 0.05$) recorded for *Aspergillus* and *Penicillium* with relative humidity for all agro-ecological settings (Table 5.4). But, neither temperature nor relative humidity showed significant association with *Fusarium* spp. occurrence under farm store. Linear regression revealed a negative correlation between frequency of mycotoxin-producing fungal occurrence with temperature and relative humidity for about half of the collectors' storage systems. The differences were not statistically significant ($P > 0.05$) and table 5 shows regression equation for all mycotoxin-producing fungi. *Fusarium* occurrence was negatively correlated with both temperature and relative humidity in the wholesalers' storage structures, unlike *Penicillium* and *Aspergillus* (Fig. 5.3). Nevertheless, the differences were non-significant ($P > 0.05$) for both mycotoxin-producing fungi.

Table 5.4 The relationship for mycotoxin-producing fungi occurrence with temperature and relative humidity of maize stored under farmers' storage systems

AE	Temperature				Relative humidity			
	Regression equation	P-value constant	r^2 (%)	p-value slope	Regression equation	p-value constant	r^2 (%)	p-value slope
LL	ASFO = -3.77temp+105	0.157ns	37.5	0.196ns	ASFO=0.65RH+15.4	0.047*	87.4	0.006**
	PSFO = -4.22temp+127	0.284 ns	20.9	0.362ns	PSFO = 0.91RH+16.6	0.210 ns	76.6	0.022*
ML	ASFO = -1.0temp+28.8	0.652 ns	13.0	0.742ns	ASFO = 0.52RH+24.4	0.097 ns	67.9	0.044*
	PSFO= -2.14temp+60.3	0.502 ns	17.0	0.613ns	PSFO= 0.784RH+33	0.073 ns	76.6	0.022*
HL	ASFO= -1.0temp+28.4	0.254 ns	19.1	0.386ns	ASFO =0.29RH+9.77	0.170 ns	70.4	0.037*
	PSFO= -3.30temp+90.9	0.030 *	60.3	0.069ns	PSFO = 1.62RH+14.0	0.068 ns	92.0	0.002**

Where: AE = Agro-ecology; LL = Lowland, ML= Midland; HL = Highland; ASFO = *Aspergillus* spp. frequency of occurrence; PSFO = *Penicillium* spp. frequency of occurrence; Temp = Temperature inside farmers' storage systems and RH = Relative humidity inside farmers' storage systems. Statistically significant ** P <0.01; * < 0.05 and ns= non-significant.

Table 5.5 The relationship for mycotoxin-producing fungi occurrence with temperature and relative humidity of maize stored under collectors' storage systems

Agro-ecology	Regression equation	
Lowland	FSFO = -3.07Temp +120	FSFO = 0.135RH +48.9
	ASFO = -0.31Temp +14.7	ASFO = 0.267RH - 7.62
	PSFO = 0.80Temp +15.3	PSFO = 0.502RH +1.80
Midland	FSFO = -3.50Temp +160	FSFO =0.794RH +14.7
	A SFO= -0.57Temp +22.1	ASFO =-0.225RH +19.1
	PSFO = 0.58Temp +11.0	PSFO = -0.911RH +81.4
Highland	FSFO = -3.21Temp +144	PSFO = 0.743RH +19.8
	A SFO= 1.17Temp - 22.8	ASFO = -0.270RH +22.4
	PSFO = 4.24Temp - 75.6	PSFO = -1.01RH + 89.0

Where FSFO = *Fusarium* species frequency of occurrence; ASFO = *Aspergillus* species frequency of occurrence; PSFO = *Penicillium* species frequency of occurrence; Temp = Temperature inside collectors' storage systems and RH = Relative humidity inside collectors' storage systems.

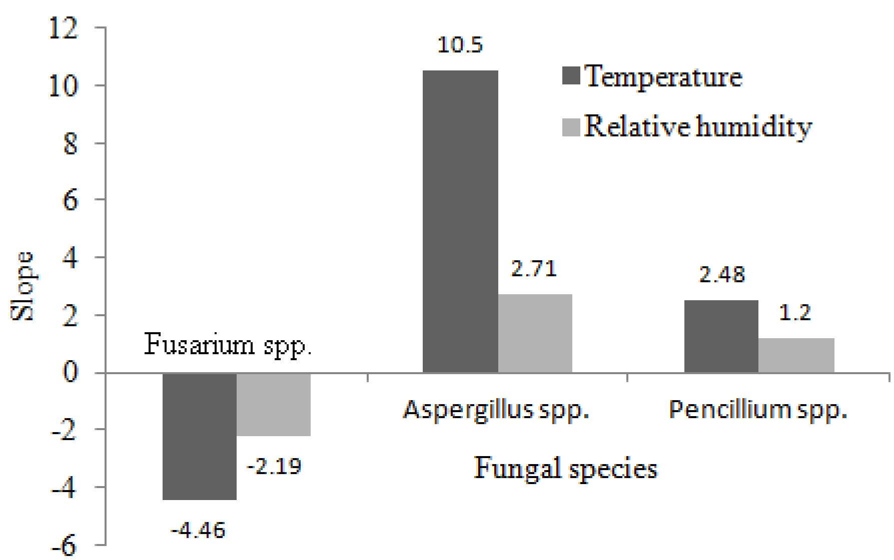

Figure 5.3 The relationship between the frequency of mycotoxin-producing fungi occurrence with temperature and relative humidity for maize in wholesaler' storage system.

Slope values for simple linear regression results of temperature and relative humidity inside the store plotted versus fungal pathogens. Constant values of 158, -230 and -25 recorded for temperature inside the store for *Fusarium, Aspergillus* and *Penicillium* species, respectively. Constant values of 165, -114 and -29 recorded for relative humidity with respective orders.

5.5 Discussion

The average long-term precipitation data at the peak of maize harvest in the lowland-, midland- and highland agro-ecosystems were collected as indicator for fungal infection while the crop was in the field. The amount of precipitation during the maize harvest was high on most of the sites studied. In some cases, the monthly rainfall was >100 mm, which favours rapid fungal infestation. Mean fungal pathogen incidences of 14.7%, 19.8%, and 20.1% were recorded (Meshesha, 2013) during the maize harvest at the lowland-, midland-, and highland agro-ecological settings, respectively.

Czembor et al. (2015) stated that long-term meteorological data help to predict the risk and incidence of mycotoxin-producing fungi at each agro-ecological setting and differentiate between them. Furthermore, Cotty and Jaime-Garcia (2007) indicated, in their study, the influence of climate on aflatoxin-producing fungi that temperature and rainfall influence contamination both during crop development and after maturation. The authors further stated that the risk of aflatoxin contamination increases when the crop receives >50 mm rain during ball opening. Farmers at the midland and highland agro-ecosystem sites in the current study left the crop to dry in the field before harvest. This practice increased the risk of exposing the crop to unseasonal rain which could influence fungal contamination before harvest. A large outbreak of aflatoxicosis occurred in Kenya because of unseasonal rains during maize harvest and poor household grain storage systems (Lewis et al., 2005). Furthermore, Tarekegn et al. (2006) stated that the rate of increase in mould incidence after sorghum grain flowering and until harvest was linearly correlated with rainfall in the range of 1.1-148 mm. Mukanga et al. (2010) pointed out that steady rainfall towards the beginning of the harvesting period creates ideal conditions for the infection of maize kernels with *Fusarium, Stenocarpella, Aspergillus, Penicillium*, and other fungi which cause ear-rot.

The mean temperatures from maize silking and flowering until harvest were also conducive to the proliferation of mycotoxin-producing fungi. Differences in both precipitation levels and min/max temperatures across the agro-ecological settings also directly affected the incidence of mycotoxin-producing fungi. The precipitation levels and temperature ranges in the present study would render the maize more susceptible to *Fusarium* infestation than to the other mycotoxin-producing fungi because the climate conditions favoured the growth of *Fusarium*. Marin et al. (1998) stated that *Fusarium* performs better at high water activity than *Aspergillus*, *Penicillium*, *Eurotium*, or *Trichoderma.* Fungal mycotoxin production starts at pre-harvest and continues post-harvest provided that conditions inside the storage facility are conducive to it. Nevertheless, the initial infection level may still prevail over the effects of the climatic conditions on mycotoxin production in the stored grain (Homdork et al., 2000; Doohan et al., 2003).

The climatic conditions inside the traditional farmers' storage structures varied with external weather. Both climatic variables were optimal for the growth of mycotoxin-producing fungi when the grain was already infected before and/or during harvest. Relative humidity at the midland-highland agro-ecological settings was >80% and the temperatures there created ideal conditions for fungal growth during the initial storage period. In lowland agro-ecosystems, farmers harvest the maize with their stalks and stack them to dry before de-husking the maize cobs. For this reason, the initial humidity is relatively low when the maize is loaded into the storage structure. Because the rainy season is from March onwards, however, the relative humidity inside the storage structures at all agro-ecological settings increases at that time and provides conditions favourable for fungal growth inside the stores. Conversely, the temperature at this time declined very slightly at all agro-ecological settings. As a result, both the temperature and relative humidity inside the traditional farm storage structure create conditions that promote the growth of major mycotoxin-producing fungi. The optimum temperature for *in vitro Fusarium* growth ranged from 15°C to 30°C (Popovski & Celar, 2013). A study on wheat grain showed that storing the product at 15°C and a relative humidity of 62% maintain both seed source and grain quality. Conditions of 25°C and 73% relative humidity are suitable for grain storage. When the RH increases to 90%, however, the storage conditions are no longer amenable to seed source or grain product preservation. The incidences of *Fusarium* and other seed-borne fungal infections increases, and they produce secondary metabolites like mycotoxins which can accumulate during storage (Homdork et al, 2000). The authors stated that 15°C and 84% relative humidity, and 25°C and 90% relative humidity could reduce seed viability and vigour probably by increasing storage fungus density. A *gombisa* is not climatically controlled, which means that it allows moisture to enter the stored product and enhances the growth of any fungi present. Shotwell et. al. (1975) stated that the *Aspergillus* can form hotspots in stored maize near windows leaking rain into the storage system and creating moisture levels supporting fungal growth and aflatoxin production.

Unlike the farmers' traditional storage structure, there was little variation in the temperature and relative humidity in the traders' stores over a six-month period. Nevertheless, mycotoxigenic fungi still could have grown at the temperatures and relative humidity recorded during that time interval. For instance, the mean temperatures in the collectors' stores were 25°C, 24°C, and 23.5°C for the lowland-, midland-, and highland agro-ecological settings, respectively. In contrast, their respective relative humidity were ≤80%, ≤89%, and ≤94%. Such was also the case for the wholesalers' storage except their initial relative humidity was lower than that of the collectors' storehouses. The wholesalers would usually receive newly-harvested maize from the collectors and its initial moisture content would start decreasing immediately. In this way, there would be a reduction in the high initial relative humidity to which the maize was subjected in the collectors' storehouses for the first few weeks. In most cases, the initial moisture content of the grain at the loading stage increased the relative humidity inside the store. Over time, both the maize moisture and the storage facility relative humidity would decrease. Therefore, it was the storage conditions themselves which made the stored product susceptible to fungal growth.

The effectiveness of the storage systems at protecting the grain from external weather conditions was evaluated with a simple linear correlation between the internal and external temperature and relative humidity. For the farmers' traditional storage systems at all agro-ecological settings, a direct relationship between the inside and outside temperature and relative humidity was determined for both variables. Therefore, traditional storage structures play only a minor role in protecting the product from external weather conditions. Williams et. al. (2014) stated that hermetic storage technologies create environments with low oxygen and high carbon dioxide levels which suppress the proliferation of moulds and insects on stored grain. Rate of fungal colony-forming unit (CFU) counts increased 3-fold for 15% moisture content to 10,000-fold for 20% moisture content after 8 weeks for opening of hermetic storage bags with certain time intervals (Tubbs et al., 2016).

The collector's store showed a weak correlation between internal and external temperature and relative humidity. One possible reason is that these parameters varied only slightly in the collectors' storage systems compared to ambient conditions. The storage systems were not hermetic, however, and they could not inhibit fungal growth. In contrast, the correlation between interior and ambient temperature and relative humidity was moderate to high for the wholesalers' stores. Overall, their storage conditions resembled those of the collectors. Most wholesalers, however, do not plaster ~1 m of the inside and outside walls near the ceiling. This ventilation gap equilibrated the internal conditions with those of the ambient ones. A major problem with the traders' storehouses was unsanitary conditions conducive to fungal growth.

A simple linear regression model correlating the frequency of occurrence of mycotoxin-producing fungi with interior temperatures revealed negative and non-significant differences. At all agro-ecological settings, as storage duration increased, the rainy season occurred and both external and internal temperatures decrease. Nevertheless, this decline in temperature may not have sufficed to lower the incidence of fungal pathogens because the final temperatures were still high enough for optimum fungal growth. There were, however, positive, significant ($P < 0.05$) correlations between the frequency of occurrences of *Aspergillus* and *Penicillium* and the relative humidity inside the farmers' storage facilities at all agro-ecological settings. Therefore, both conditions play significant roles in the colonization of fungal pathogens in farmers' stores. Pardo et al. (2005) stated that the maximum growth of *Aspergillus ochraceous* occurred at 30°C and a relative humidity range of 80–90% but this rate was not significantly different from those measured at 20°C or at 30°C with a relative humidity of 100%. Nevertheless, the incidence of *Fusarium* was non-significant. The low r^2 value at all agro-ecological settings may account for this discrepancy. This finding underscores the fact that *Fusarium* is regarded as a field pathogen rather than a post-harvest one (Barney et al., 1995). It may also explain the antagonism of storage pathogens against field fungi (Magan et al., 1984). In contrast, Talley et al. (2002) stated that microclimate strongly influences fungal occurrences in many different habitats.

The simple linear regression model developed for climatic variables in collectors' storehouses returned weak associations with the frequency of mycotoxin-producing fungi occurrence. Therefore, the collectors' storage systems in the various agro-ecological settings maintained and protected the stored product from external weather conditions quite well. Nevertheless, frequency of mycotoxin-producing fungi occurrence did not dramatically decreased and was not significantly lower than that determined for the producers' storage systems. Initial moisture content, fungal inoculum source, host susceptibility, and handling practices may all affect the occurrence and growth of mycotoxin-producing fungi in the stores. Unlike *Fusarium*, the incidences of *Penicillium* and *Aspergillus* were positively correlated with the length of time the maize was stored in the wholesalers' facilities.

5.6 Conclusions

The maximum and minimum temperature and precipitation data between the time of maize silking and flowering until physiological maturity and harvest indicated that mycotoxin-producing fungi would grow well in all agro-ecological settings. Therefore, long-term climatic data from the study area could be used to predict fungal occurrence and help apply the appropriate management and corrective action. The maize product itself may be a potential fungal inoculum source inside the storage facilities during the post-harvest process. The farmers' storage structures are not designed to maintain seed and grain quality under the hot and humid conditions characteristic of southwestern Ethiopia. These facilities actually increase the risk of mycotoxin-producing fungal infestations. The seed derived from stored maize may actually be an inoculum of fungal pathogens at any step in the post-harvest process and even in the next growing season. Storing maize in these traditional structures reduces seed and grain yield and quality. Therefore, low-cost, climatically controlled storage structures that are simple to operate should be accessible to the resource-poor farmers in the study area. In addition, the moisture contents of the stored products must be measured during the loading stage because this factor significantly affects fungal propagation inside grain storage facilities.

5.7 Acknowledgement

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6 Development of a photovoltaic driven ventilation system to modified traditional Ethiopian gombisa for on-cobs-maize drying and storage

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6.1 Abstract

Unsafe moisture content at loading and the climatically uncontrolled nature of traditional storage structure (*gombisa)* together with ventilation dependent on wind alone, results in mycoflora growth and development on maize in the system. Therefore, this paper was aimed to develop and test a photovoltaic driven ventilation system fitted to a *gombisa* for natural air in-bin drying of on-cobs-maize and increase the shelf life of the stored product. A modified *gombisa* was constructed from locally available materials in Germany. An appropriate fan type and size, humidistat set at 70% and two 20 W_p photovoltaic panels were utilized for ventilation purpose, fan control and to power the fan, respectively. In total 1.76 m^3 of on-cobs-maizes with an average moisture content of 0.22 on d.b. (kg/kg) were also used for the study. Data was collected on solar irradiance, photovoltaic voltage, current, inlet duct air velocity and temperature and relative humidity inside the storage system. Similarly, moisture content of on-cobs-maize, ambient temperature and relative humidity data were also collected for both experiments. The result for the temperature and relative humidity trends revealed higher variability and fluctuation for ambient compared with inside the modified *gombisa*. Ventilation of on-cobs-maize for 10-12 days resulted in a reduction of moisture content (d.b.) to almost 0.14 (kg/kg) which generally is considered safe for mould growth conditions. A computational fluid dynamics simulation result revealed the uniformity of the drying of on-cobs-maize using the ventilation system fitted to the modified *gombisa*. Secondary data of solar irradiance obtained from Jimma area, Ethiopia compared to the current experiment show higher energy availability, demonstrating high potential to apply ventilation and drying system to the region. Storing maize inside modified *gombisa* played a role in protecting the stored product from outside weather conditions. Also, monitored temperature, relative humidity and energy output showed the system was able to bring the product to safe moisture content for storage without mould development. This promising research result needs to be tested and validated in tropical regions of the world.

Keywords: modified g*ombisa*, maize in cobs, temperature, relative humidity, ventilation system

6.2 Introduction

Fungal pathogen growth and development has been commonly reported from traditional maize storage structures of southwestern Ethiopia. It is evident that both high quantity and quality losses were recorded from the aforementioned region of the country (Dubale et al., 2014; Garbaba et al., 2017). The region is characterized by hot and humid climatic conditions that favors fungal growth in both pre- and post-harvest maize. More importantly, farmers in study areas mostly leave the maize in the field to dry for harvesting which coincides with rain showers. This, in addition with the climatically uncontrolled nature of the traditional storage structures results in mycoflora growth and development. Unsafe moisture content (w.b.) of maize at the harvesting and loading stage of 16 - 28 (%) and moisture re-wetting during the whole storage duration result in nutritional quality deterioration (Dubale et al., 2014; Garbaba et al., 2017).

In Ethiopia, harvested maize is stored for gradual consumption until next season's harvest, also to fetch a better price and to keep the seed for the next planting season for subsistence farmers where maize is the main and dominant staple food crop for rural society. Therefore, for long-term storage, the product should be dried to a safe moisture content to overcome concern of mycotoxin-producing fungal growth. *Gombisa* is the dominate storage structure used to store maize in southwestern of Ethiopia. However, losses during storage using this structure is very high particularly due to mould development and other storage pests (Rashid, et al., 2010, Dubale et al., 2012; Befikadu, 2014). Moisture content (m.c.) at harvesting and loading is one of the key factors for maize PHLs in store. This necessitates drying technology and design of climatically controlled storage structures that prolong shelf life of the stored commodity. Such type of technology should be as low cost as possible, accessible and of simple technology so poor farmers are able to tackle the main constraints they are facing. Therefore, one of the possibilities can be improving locally available traditional storage structure, *gombisa*, for on-cobs-maize drying and storage.

Basically, grain drying is broadly categorized into hot air drying, ventilation and nearly ambient/ low temperature methods (Jayas and Ghosh, 2006). Hot air drying methods can adversely affect the quality of dried maize (Brown et al., 1979; Jayas and Ghosh, 2006; Abasi and Minaei, 2014). More importantly, it may not be economically viable for subsistence farmers due to its elevated cost (Jayas and Ghosh, 2006; Singh et al., 2014). On the other hand, low-temperature drying provides a better quality of maize and energy efficient techniques (Brown et al., 1979; Mittal and Otten, 1982). Its reasonable cost, less supervision requirements and low fire hazard are among some of the basic benefits of nearly ambient or unheated grain drying. On the other hand, drying grains with unheated air is a slow process and depends on local weather conditions (Foster, 1953; Sharp, 1982; Atungulu and Zhong, 2016). The main factor to be considered for low temperature dryer design is the airflow rate necessary to dry the grain to a safe storage level without significant losses in quality (Sharp, 1982). In general, the efficiency of natural air in-bin drying depends on ambient conditions, initial moisture content, gain depth, airflow rate, fan control strategies (intermittent or continuous ventilation) and storage-bin configuration type (Sharp, 1982; Atungulu and Zhong, 2016).

For drying purposes use of fossil fuels as an energy source can be either inaccessible or economically unaffordable for subsistence farmers located in rural areas. Therefore, using solar energy is more feasible, most abundant and economically affordable especially in tropical regions of the world where solar power is available as natural resources but less exploited (Noyes et al., 2002; Hossain and Bala, 2007). For the last couple of decades research has focused on possible use of solar energy for low temperature in-bin drying to overcome the increasing cost of drying using other sources of energy. Musembi, et al., (2016) also described the cost of energy and minimizing PHL damages during food processing.

Several studies have been conducted on fan control strategies for the drying of different commodities to a safe moisture content level, either experimentally or by means of mathematical modeling (Foster, 1953; Mittal and Otten, 1982; Smith and Bailey, 1983; Sharp, 1984; Moreira and Bakker-Arkema, 1992; Lawrence et al., 2015; Atungulu and Zhong, 2016). The easiest way of fan control is to allow it to run until drying is completed. However, such conditions result in carrying moist air into the stored products. As a result, a fan control system with a humidistat or a clock to switch off/on was recommended (Sharp, 1982). Fan control strategies are important in the conditioning of the final grain and avoiding damp air intake to the storage by controlling ambient humidity (Sharp, 1984). A review by Moreira and Bakker-Arkema (1992) summarized 23 fans and heaters control strategy used for in-bin drying. The review showed several of them are more complicated with only five of them employed for the in-bin drying control scheme. Among them, humidistat control of the upper relative humidity (RH) limits is among the few currently in use for similar purposes. Smith and Bailey (1983) stated that setting relative humidity at 70% to 80% as an upper limit could overcome the problem of mould growth during the drying process.

A *gombisa* is not climatically controlled to overcome problems of external weather variables that facilitate mycotoxin-producing fungal growth. To overcome the problem, a modified *gombisa* was constructed for the experiment. In addition, photovoltaic panels were used to generate power for ventilation and drying purposes of on-cobs-maize to safe moisture content during storage. Therefore, this research was commenced with the aim to develop photovoltaic fitted ventilation systems to modified *gombisa* for natural air in-bin drying of on-cobs-maize to increase the shelf-life of the product.

6.3 Materials and methods

6.3.1 Study site

The study was carried out at the solar and irrigation research station of the Agricultural and Biosystems Engineering Department, Witzenhausen campus of Kassel University based in the north eastern Hesse region of Germany during the summer of 2016. The research was carried out between July and September 2016.

6.3.2 Construction of modified *gombisa*

Gombisa is a cylindrical granary type and made up of locally available materials, mostly bamboo, by farmers for maize storage. The roof is covered by natural or thatch grass. For the current study, a similar structure was initially constructed with locally available materials with little modification from the traditional ones. The base of the *gombisa* was supported with four pillars that hold all the weight on it and pillars were deep rooted and cemented to make the supports strong. Each support was 1.5 m apart from the adjacent ones and the base of the storage structure covered an area of 4 m^2. A perforated floor was established 30 cm above the base of the storage structure for the ventilation process. The erected portion of the *gombisa* was made up of three layers, the inner one of strong mesh wire to hold up the system, followed by a plastic sheet with the main objective of minimizing the influence of the external environmental conditions on the stored product. Finally, to avoid direct contact with external weather conditions and leakage of moisture, the plastic sheet was covered with bamboo. The storage structure had a diameter of 1.5 m and a height of 1.8 m. Four poles were also deep rooted into the ground to support the structure from four directions. The roofing was covered by a plastic sheet and its upper layer was of elephant grass to avoid raising the temperature and leakage of water during rainy periods. A window like structure was installed for loading and unloading the product (Fig. 6.1).

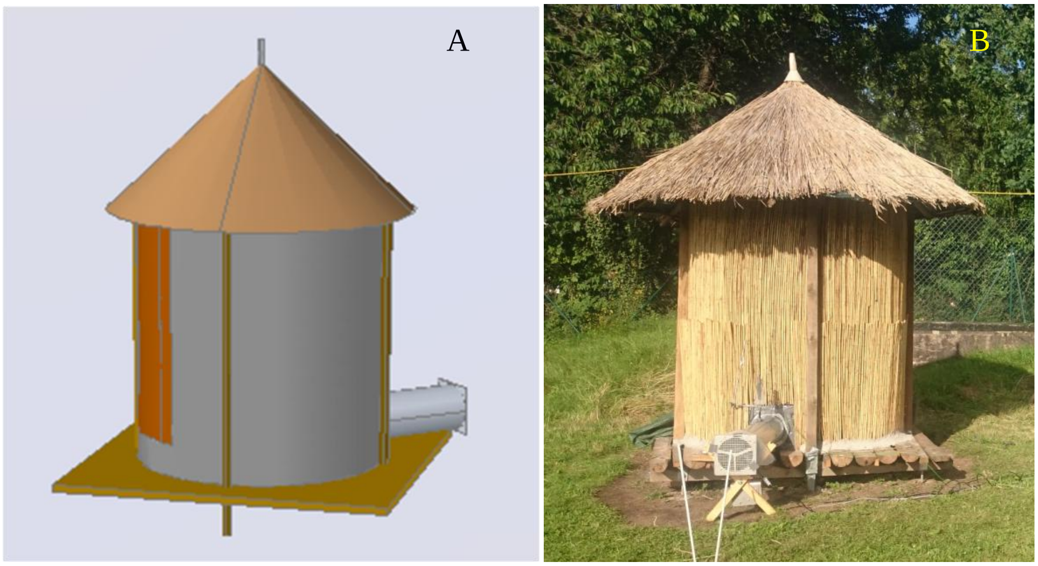

Figure 6.1 Show *gombisa* for A) Three dimensional drawing of modified *gombisa* B) Photo of constructed modified *gombisa* at Witzenhausen, Germany.

6.3.3 Installation of ventilation system

6.3.3.1 Fan type and size

The necessary characteristics of the fan were calculated based on the diameter of *gombisa* (1.5 m long), maize bulk height (1 m), and the volume of maize cobs to be stored (1.767 m^3). According to Mujumdar (2006) adequate air flow rate in maize cobs ranged from 250 to 500 $m^3/h\text{-}m^3$, which for the *gombisa* results in 441 to 883 $m^3\ h^{-1}$ of the total air flow rate and 0.0694 to 0.1389 $m\ s^{-1}$ for superficial velocity. Pressure drop of ear maize was calculated using the (ASAE Standards D272.3 (2007) as:

$$\Delta P/L = aQ^2/\ln(1+bQ),$$

Where *a* is 1.04E+04 while *b* = 325 constant values. *P* is pressure drop in Pa; *L* is height of maize in cob form (m) and *Q* is airflow in $m^3/h\text{-}m^3$. Taking a superficial velocity of $0.1 m^3/s\text{-}m^2$ which corresponds to 636.17 $m^3\ h^{-1}$ for the *gombisa*, the formula gives us a pressure drop of 29.6 Pa.

A brushless direct current (DC) axial fan type was selected which can approximately produce the required airflow rate. Since the fan would be directly coupled to a photovoltaic panel, the actual working point of the system will vary with the weather conditions. The fan has a nominal voltage of DC 48 V and a nominal current of 0.5 A. Its dimensions were 200x200x60 mm. The air duct was connected to a plenum chamber and fan to force the air to directly enter the perforated floor and move up to the stored on-cobs-maize for drying and ventilation.

6.3.3.2 Photovoltaic system

Two 20 W_p photovoltaic panels were used to power the fan. One solar panel had an open circuit voltage of 22.18 V and a short circuit current of 1.33 A. The second panel had an open circuit voltage of 22.3 V and a short circuit current of 1.22 A. The panels were connected in series to give an open circuit voltage of 44.38 V, which is close to the fan's nominal voltage.

6.3.3.3 Fan control

An automatic fan control system for the ventilation system was employed based on the relative humidity of the external environmental conditions. For this purpose a low cost battery powered humidistat was constructed. The device consisted of a digital temperature and relative humidity sensor connected to a microcontroller board. Based on the relative humidity measurement made at specified short intervals, the fan can be turned on/off by a relay. The set point of the humidistat (the relative humidity above which the fan is to be disconnected) can be changed. For the tests, the humidistat was set to RH 70% to control and allow the fan to run and reduce the risk of moist air entering the *gombisa* and re-wet the stored on-cobs-maize. The humidistat was sheltered with a small cover for protection from any external damage.

6.3.4 Maize sample, experimental procedure and data acquisition

On-cobs-maize was used for both experiments. In total 1.767 m^3 of on-cobs-maize with an average length of 22 cm was used in this study. In order to raise the m.c. (d.b.) to an average of 0.22, preconditioning for adsorption was carried out in June 2016 for the first experiment and in August 2016 for the second experiment. Absorption was done in a controlled climatic chamber approximately one month before each experiment by controlling temperature and relative humidity. Once the m.c. (d.b.) reached 0.22, which is the average m.c. at which farmers harvest and load the product into *gombisa*, on-cobs-maize were transferred to the *gombisa* for drying and ventilation.

Maize drying and ventilation was carried out approximately two weeks for both experiments. A photodiode type pyranometer was placed near the photovoltaic panels to measure solar irradiance. The voltage of the photovoltaic panels was directly measured by a data logger (Fluke Hydra) for data acquisition. The current of the panels and air velocity were measured using a shunt resistor (10Ω ±0.01%) and hot wire anemometer with accuracy of ±1%, respectively. All sensors except the hot wire anemometer, which was directly connected to separate computer, were coupled to the Fluke Hydra data logger to record measurements every five minutes, which was also connected to the computer for data storage (Fig. 6.2).

Data loggers (Testo 174 H, Testo SE & Co. KgaA, Lenzkirch, Germany), with an accuracy of ±3% for relative humidity and ±0.5°C for temperature were kept outside under the roofing of the *gombisa* on both sides to record ambient weather conditions. Five similar data loggers were spaced uniformly down the vertical centerline of the *gombisa* with a 25 cm interval inside the stored maize to record both temperature and relative humidity. Before data collection, each data logger was configured to record data every five minutes. In order to monitor the moisture content of the stored product along the experimental period, three cobs from different levels (0, 25, 50, 75 and 100 cm) above the plenum chamber of stored maize were tagged (Fig. 6.2). The weight of each cob was measured early in the morning each day (7:30am) and late afternoon (7:30pm) using a sensitive balance, KERN PRS (0.001g). At the end of each trial, the sample cobs were oven dried to calculate moisture content (ASAE standard D245.5, 2007; Chen, 2003).

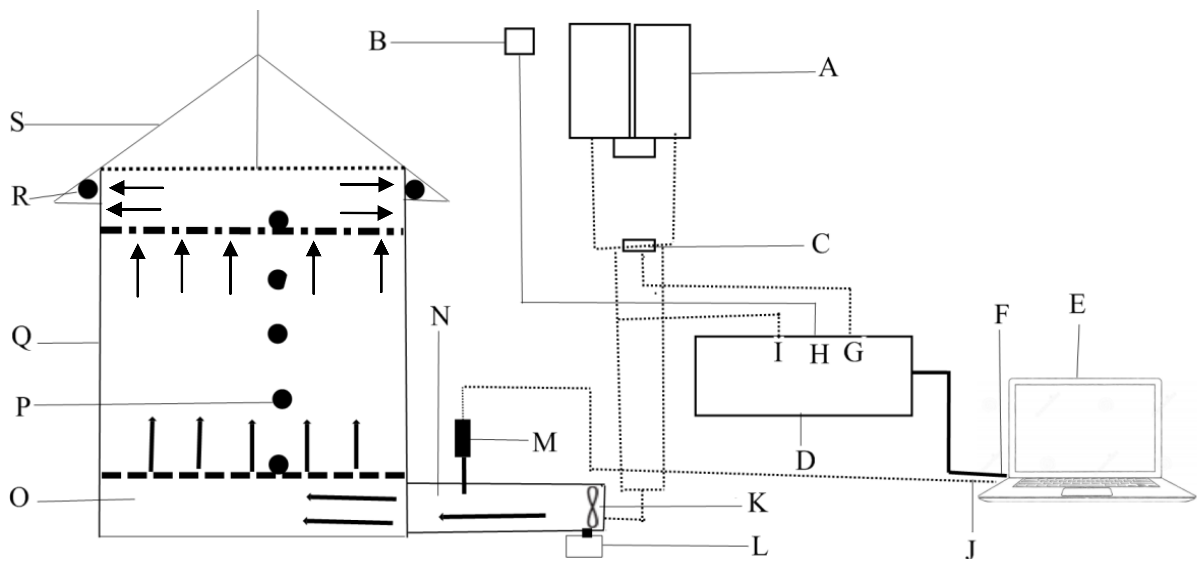

Figure 6.2 Sketch for experimental set-up of modified *gombisa* for on-cobs-maize ventilation and drying.

Where: A = Photovoltaic (PV) panels, B = Pyranometer, C = Shunt resistor, D = Fluke Hydra Data logger, E = Computer, F = point for connection of data logger with computer, G = Current H = Solar irradiance, I = Voltage form PV-panels, J = Air velocity from hotwire anemometer, K = Fan and inlet air, L = Humidistat connected to fan, M = hot wire anemometer, N = Air duct, O = Air plenum, P = Testo 174 H kept at 25cm interval inside stored maize, Q = Body part of modified gombisa, R = Testo 174 H data logger for ambient condition and S = Roofing of gombisa. ⟶ = Indicate direction of air flow.

6.3.5 Computational fluid dynamics simulation

A computation fluid dynamics (CFD) simulation was done to evaluate the airflow distribution and uniformity in the *gombisa* using the software ANSYS Fluent. The *gombisa* geometry was drawn and a grid produced which consisted of about 500000 elements. Only one half of the actual *gombisa* was drawn due to its symmetry. The 1 m column of maize in cobs was modeled as a porous medium using resistance coefficients calculated from a pressure drop data to the ASAE standard D272.3 (2007). At the air inlet the air velocity was set at 5.63 m s^{-1} which corresponds to an airflow rate of 636.17 $m^3 h^{-1}$. The k-ε realizable turbulence model was used.

6.4 Results

6.4.1 Fan control system

Figure 6.3 shows the trend for ambient relative humidity, PV-power, and relative humidity set point for first and second experiments. The result showed the fan switched on and off perfectly at the relative humidity set point (70%) for both experiments. During the first experiment, a slight fluctuation in PV-power was observed due to cloudy days (Fig. 6.3A). However, better and more constant values were recorded for the second experiment during fan operation (Fig. 6.3B). On average the fan operated 10.8 h per day with mean average PV-power of 7.12 W for the first experiment. However, it was 8.13 daily average fan operating hours with a mean value of 8.04 W PV-power per day for the second experiment. During the second experiment the fan switched on around 11:30 am most of the days due to external weather conditions that made short ventilation hours compared to the first experiment. On the other hand, during the first experiment the fan switched on at around 9:30 am, as weather conditions were better and longer day time during July compared to September that made the fan operating hours longer.

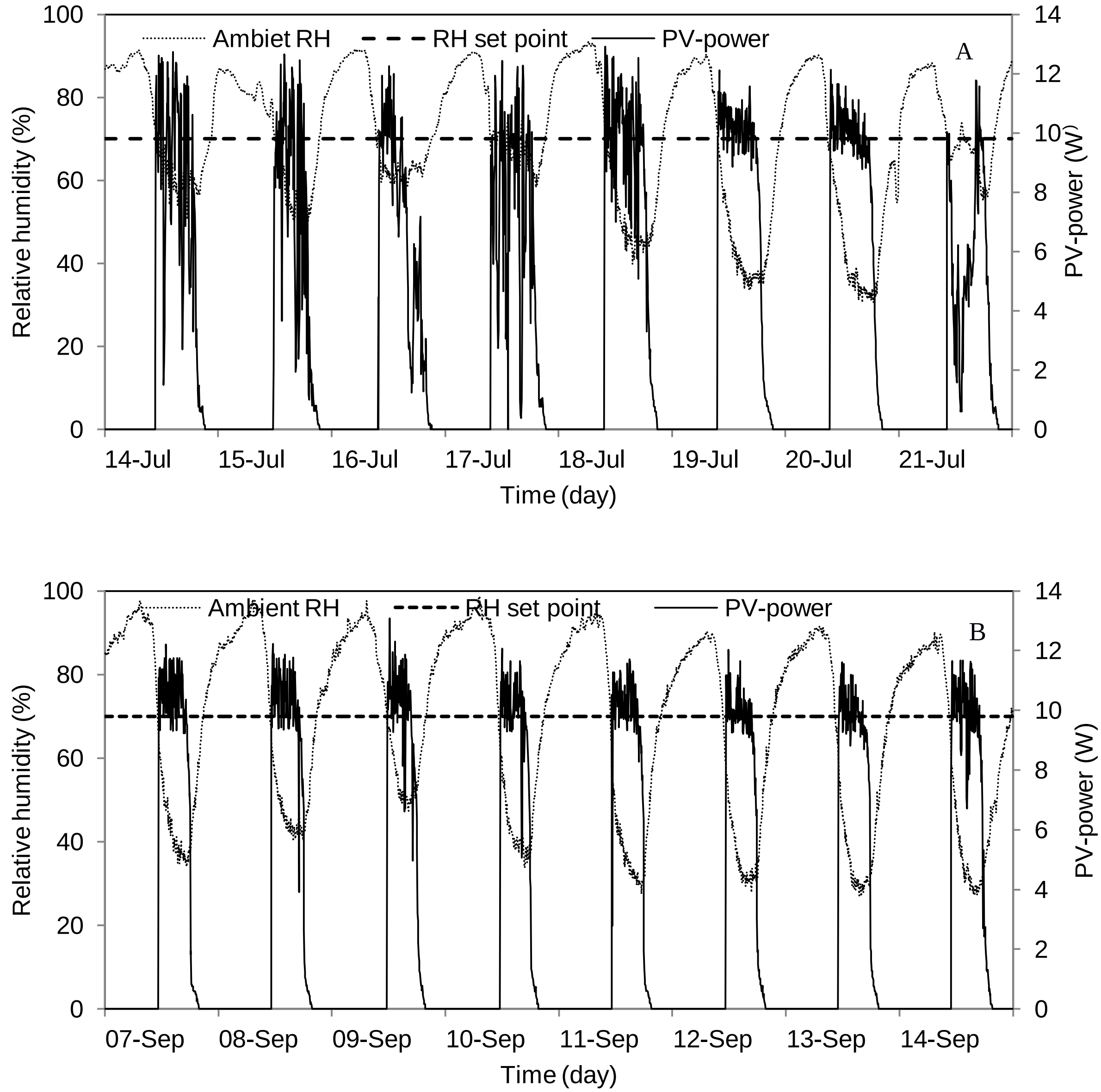

Figure 6.3 Plot of ambient relative humidity, relative humidity set point and photovoltaic power for consecutive eight days A) First experiment (07-14 July 2016), B) Second experiment (14-21 Sept. 2016) Witzenhausen, Germany.

6.4.2 Temperature and relative humidity trend

The directly coupled photovoltaic ventilation system for on-cobs-maize drying was assessed based on temperature and the relative humidity trend inside the store (Testo data logger for 50 cm above perforated floor) and ambient conditions for both experiments. The mean daily variation of temperature inside the stored on-cobs-maize was 3.7 ±1.9°C, with minimum daily deviation of 1.6°C and maximum value of 8°C. On the contrary, daily mean variation of ambient temperature was 12.6 ±3.4°C with a maximum of 17.9 and minimum 5.6°C for the first experiment. Comparably, daily mean variation of temperature throughout the second experiment was 6.6 ± 3.3°C, 11.8°C (maximum) and 1.1°C (minimum) inside the stored on-cobs-maize. However a high mean daily variation (15.9± 6.1°C) maximum value of 23.3°C and minimum (3.1°C) was recorded for ambient weather conditions (Fig. 6.4). Generally, ambient temperature showed high variability within a day, but temperature inside the store revealed very slight variation, indicating that the modified *gombisa* played a role in protecting the maize from external weather conditions.

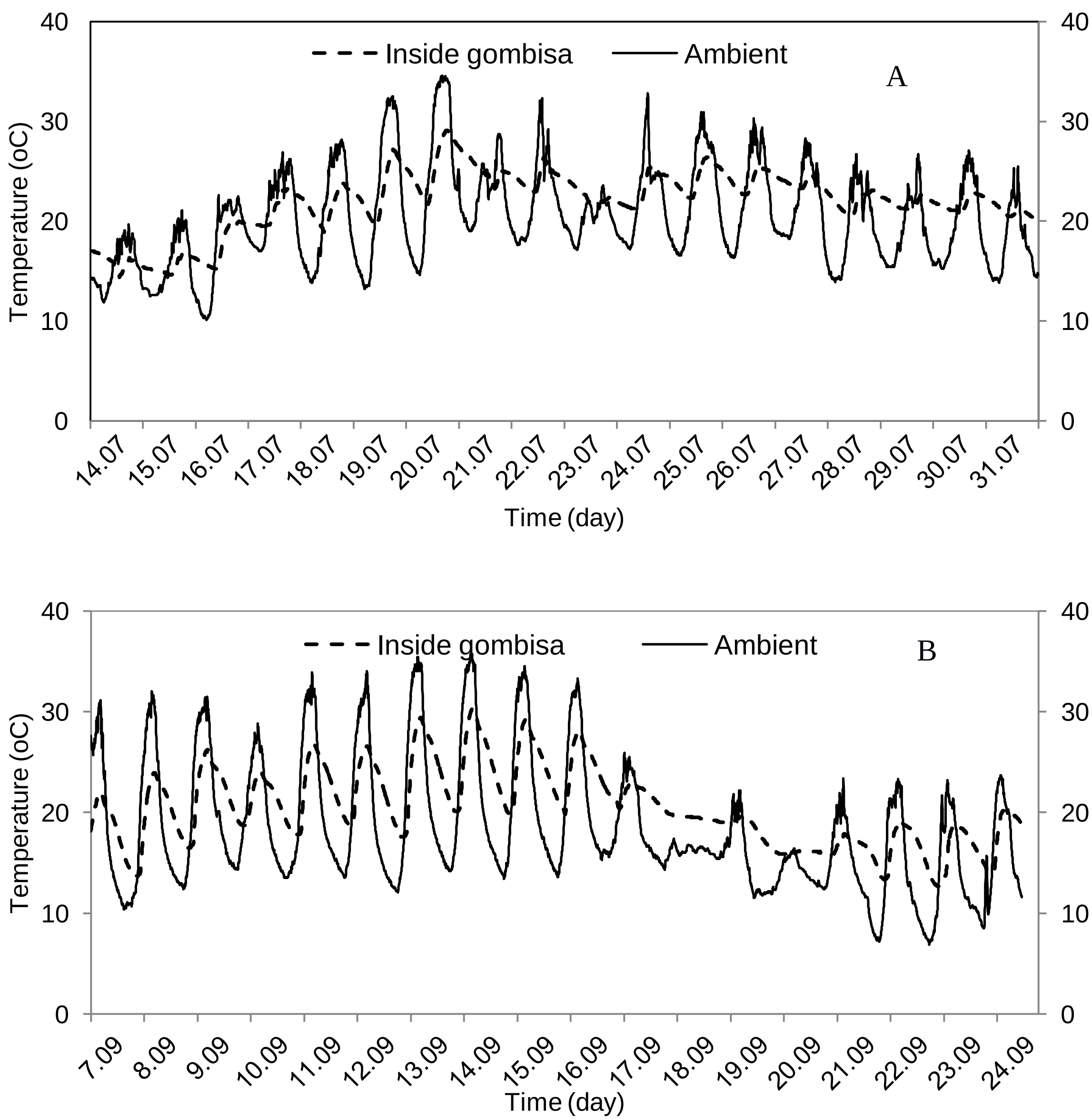

Figure 6.4 Plot of temperature inside modified *gombisa* and ambient condition versus drying time of on-cobs-maize A) First experiment (July 2016) B) Second experiment (September 2016) at Witzenhausen, Germany.

Daily relative humidity variation inside the *gombisa* showed a maximum value of 22.2 percentage points, minimum variation of 5.4% and a mean value of 10.8 ± 5.0 % (±SD) during the first experiment. The ambient relative humidity had a maximum variation of 57.8%, a minimum of 24% and a mean value of 44.1 ± 8.7 (±SD) percentage points. In a similar manner, the daily variation of relative humidity inside the *gombisa* showed a maximum of 32.3%, a minimum of 6.1% and an average value of 20.5 ± 8.9 (±SD) percentage points for the entire duration of the second experiment. However, a higher ambient daily variation with a maximum of 58.9 %, a minimum of 17.6% and an average value of 44.9 ± 12.6 (±SD) percentage points were recorded for the second experiment. It can be seen from figure 6.5A & B that for both experimental trials there was less daily variation of relative humidity inside stored on-cobs-maize as opposed to ambient conditions.

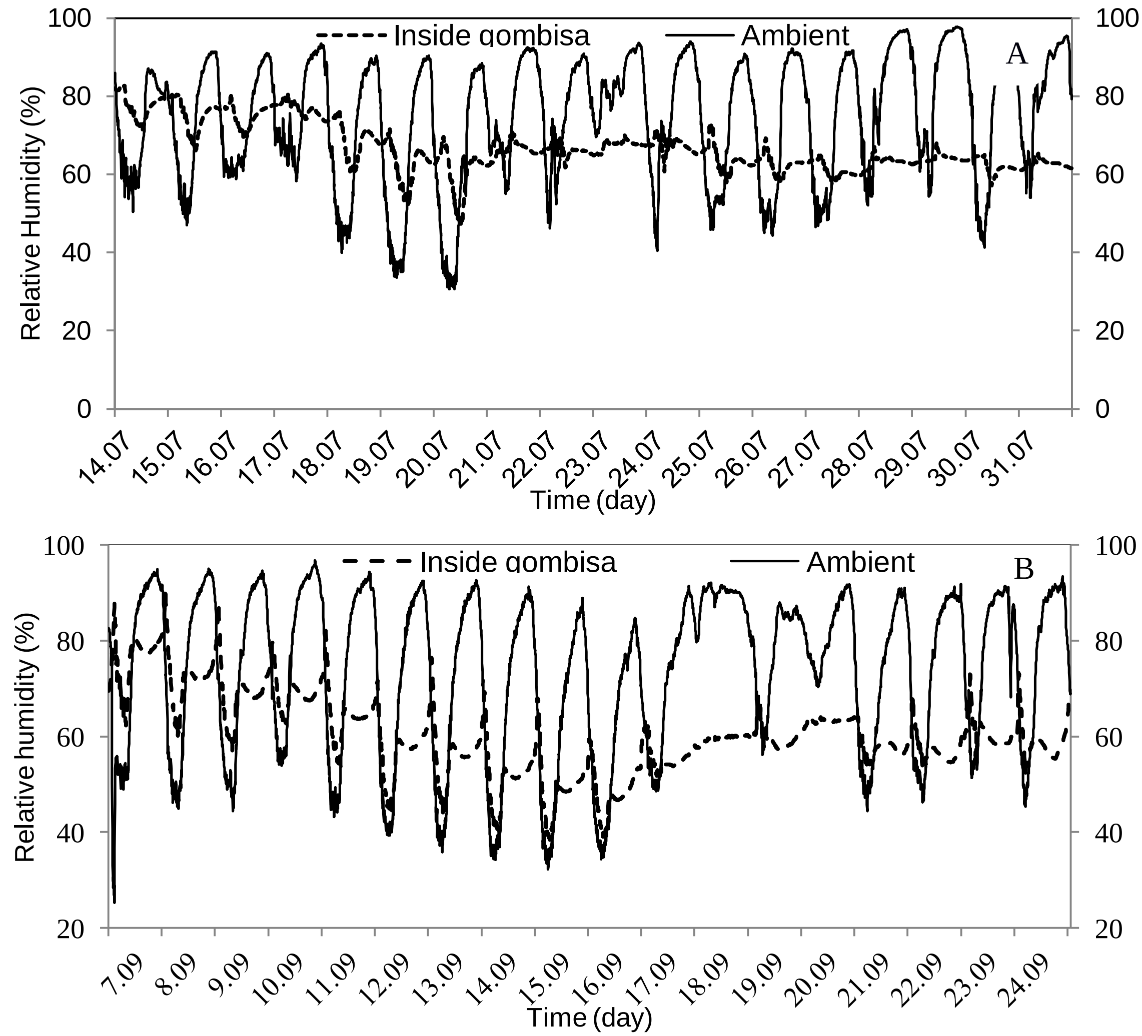

Figure 6.5 Plot of relative humidity inside modified *gombisa* and ambient condition versus drying time of on-cobs-maize A) First experiment (July 2016) B) Second experiment (September 2016) at Witzenhausen, Germany.

Person's correlation results showed that there was positive association between ambient relative humidity and inside the store. Also, holds true for ambient temperature and inside the store. For both weather variables and experiments, it yielded statistically highly significant relationship between ambient and inside the store ($p < 0.000$, Table 6.1), indicating that the probability of this correlation occurring by chance is less than 1 in 1000.

Table 6.1 Pearson's correlation for temperature and relative humidity comparing inside modified *gombisa* with ambient conditions during both experiments.

Experiment	Weather variable			
Time	Temperature		Relative humidity	
	r-value	P-value	r-value	P-value
July 2016	0.661	0.000	0.331	0.000
September 2016	0.705	0.000	0.340	0.000

6.4.3 Temperature and relative humidity during fan operations

Five-minute interval data of the inlet (0 cm above perforated floor) and outlet (100 cm above perforated floor) temperature and relative humidity during fan operation are shown in Fig. 6.6 and 6.7

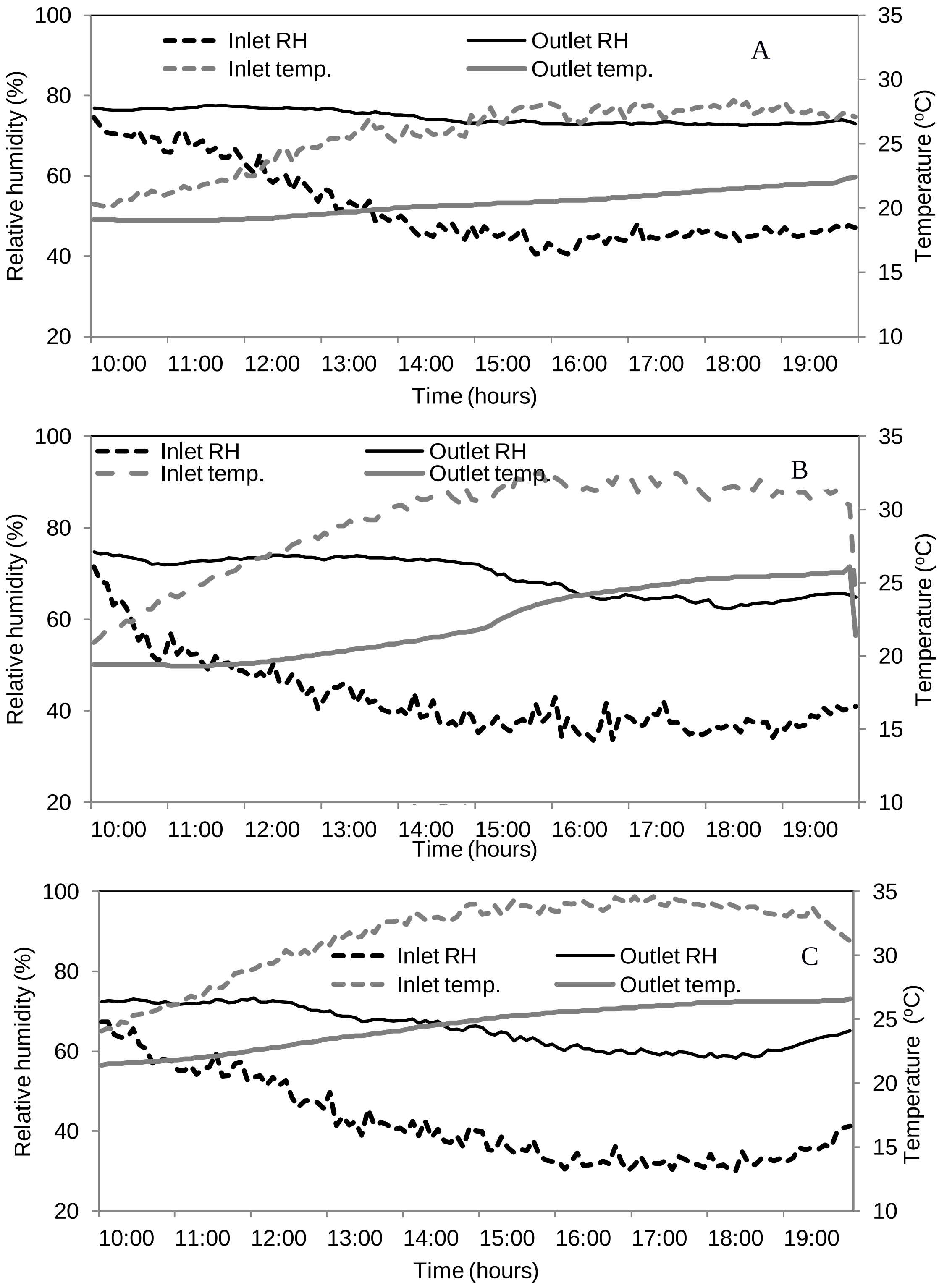

Figure 6.6 Plot of inlet and outlet temperature and relative humidity versus time during fan operating hours for first experiment A) 18 July 2016 B) 19 July 2016 C) 20 July 2016, Witzenhausen, Germany.

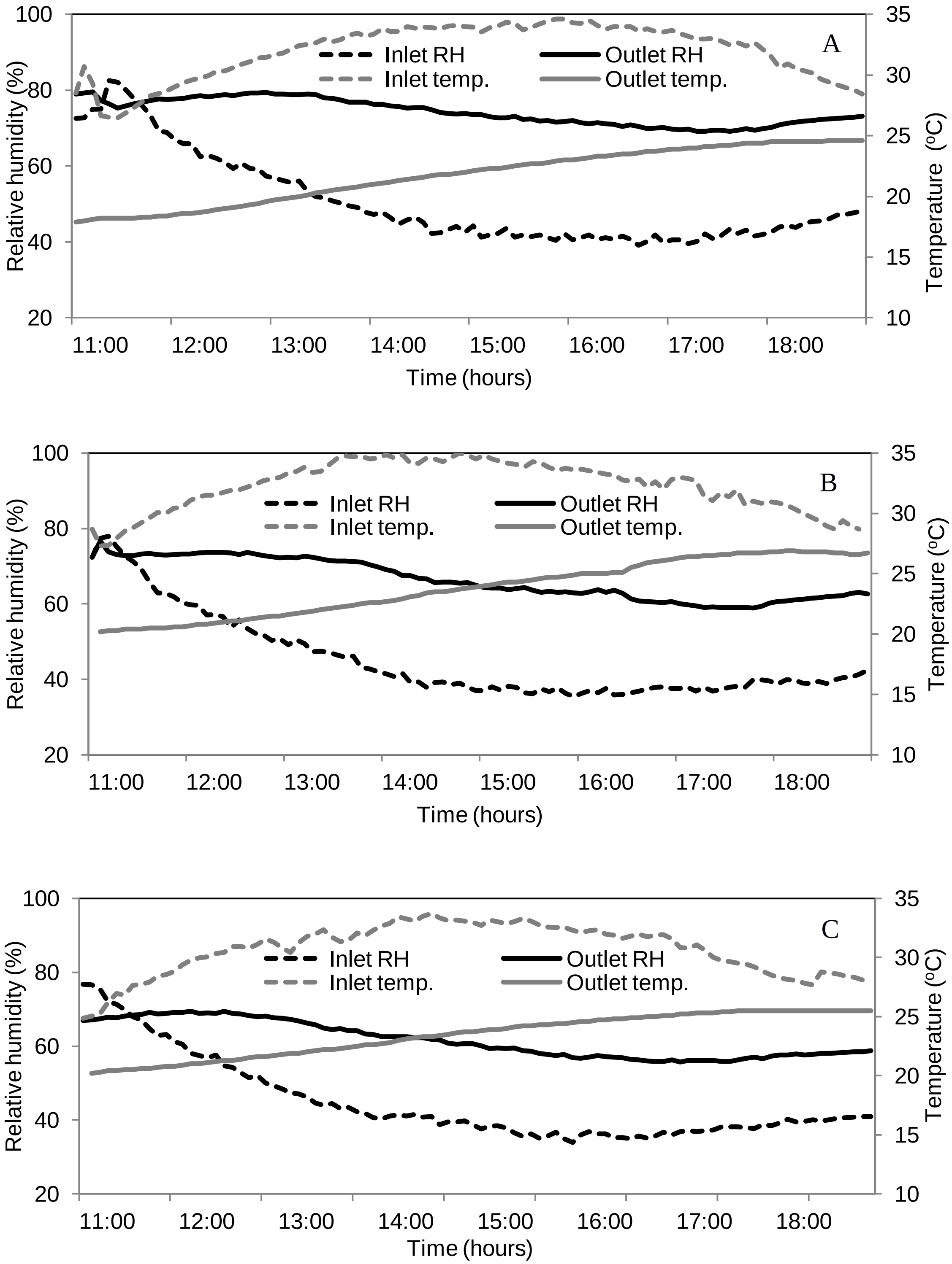

Figure 6.7 Plot of inlet, outlet and ambient temperature and relative humidity versus time during fan operating hours for second experiment A) 12 sep. 2016 B) 13 sep. 2016 C) 14 sep. 2016, Witzenhausen, Germany.

6.4.4 Assessment of solar irradiance, air velocity and photovoltaic panels' power

The variations of solar irradiance, air velocity and photovoltaic panels' power of hourly average for a day are presented for both experiments on figure 6.8A & B. On the 20th July 2016 the trend of solar irradiance increased sharply from 09:30 and reached a maximum value of 864 Wm^{-2} at 13.00, and then very slightly decreased until the fan switched off. Similarly, air velocity inside the duct also slightly increased and reached a maximum average value of 4.69 m s^{-1} for the day. However the maximum value for the day was 5 m s^{-1}. Photovoltaic panels generated mostly about 10 W throughout fan operating hours of the day. Generally the 20th July 2016 was one of the cloud free days. Consequently it showed less fluctuations in all parameters considered for data measurement for the day.

Throughout the second experiment, the fan usually switched on after 11 am due to high morning relative humidity (RH >70%, at which the fan switched on) due to seasonal change. However, during the experiment most of the days were cloud free for ventilation and drying process. The measurements on 10 September 2016 showed a maximum hourly average of 655 W m^{-2} of solar irradiance. Similarly to the first experiment throughout the day photovoltaic panels produced nearly 10 W except morning section. Maximum mean hourly average of 5.17 m s^{-1} of air velocity was recorded for September 10, 2016. Generally the solar irradiance, air velocity and photovoltaic panels power for 20th July 2016 were 658 W m^{-2}, 4.22 m s^{-1} and 9.65 W, respectively. Similarly, values of 439 W m^{-2}, 3.34 m s^{-1}, and 9.14 W were recorded for the second trial (10 September 2016).

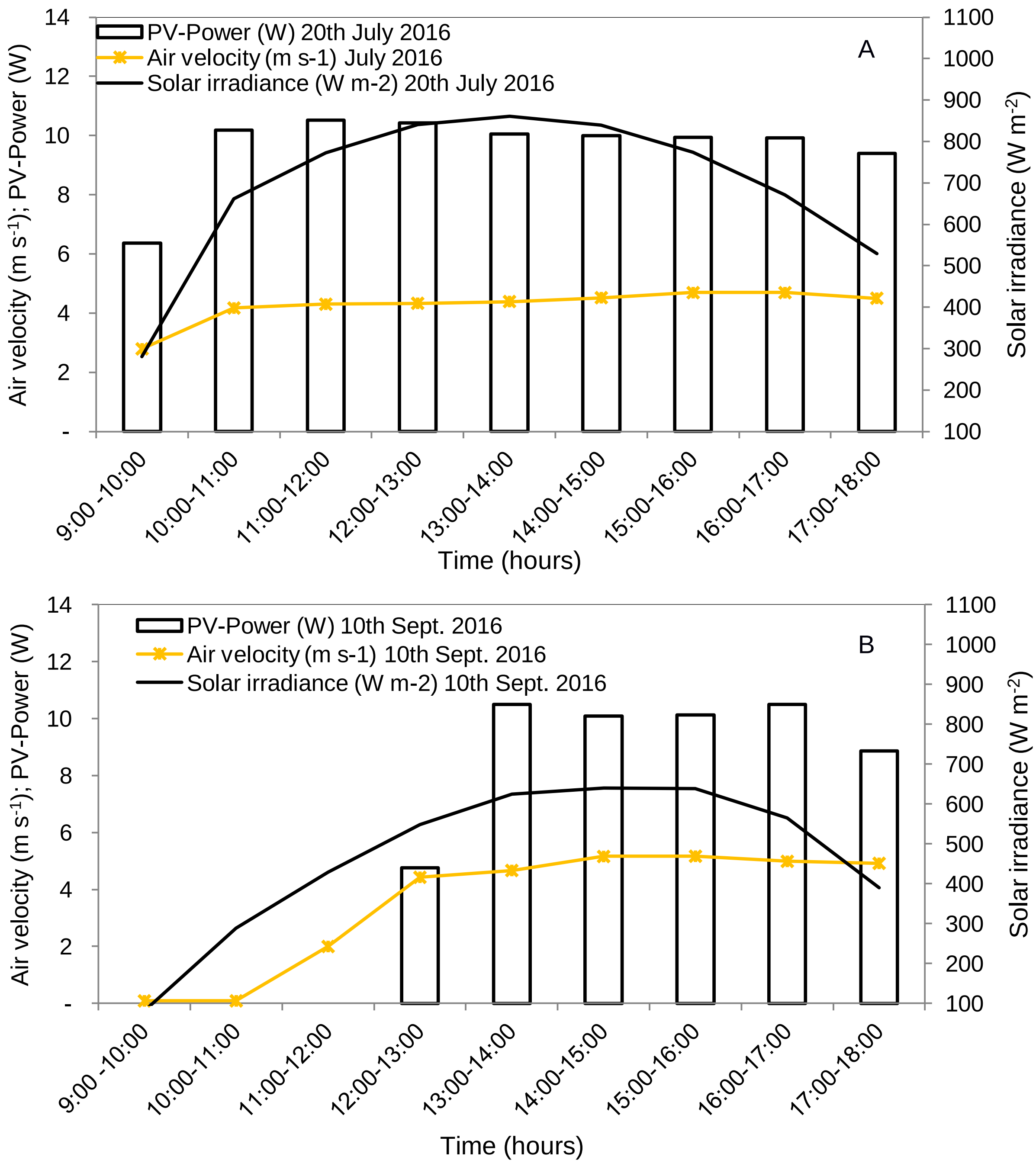

Figure 6.8 Shows hourly averages for solar irradiance, PV-power and air velocity during fan operating hours A) 20th July 2016, B) 10th September 2016.

6.4.5 Drying of on-cobs-maize

It can be observed from Figure 6.9 that the m.c. (d.b.) decreased as ventilation and the drying duration increased for both experimental periods. Figure 6.9A revealed that within 10 to 12 days of the ventilation period m.c. (d.b.) decreased nearly to 0.14. Similarly a second experiment

(Fig. 6.9B) took nearly 12 days to bring moisture content to a similar level of content d.b. nearly 0.14. There were cloudy days during the first experiment which reduced the photovoltaic ventilation system efficiency for the drying process especially during last days of the experiment, though the result still showed a reasonable and acceptable trend to reduce the m.c. to a safe level. There was good weather with mostly bright sun-shine for the period of the second experiment which gave us a good trend of reduction in m.c. during ventilation days (Fig. 6.9B). However, generally shorter ventilation hours per day were observed for the second experiment compared to first round experiment.

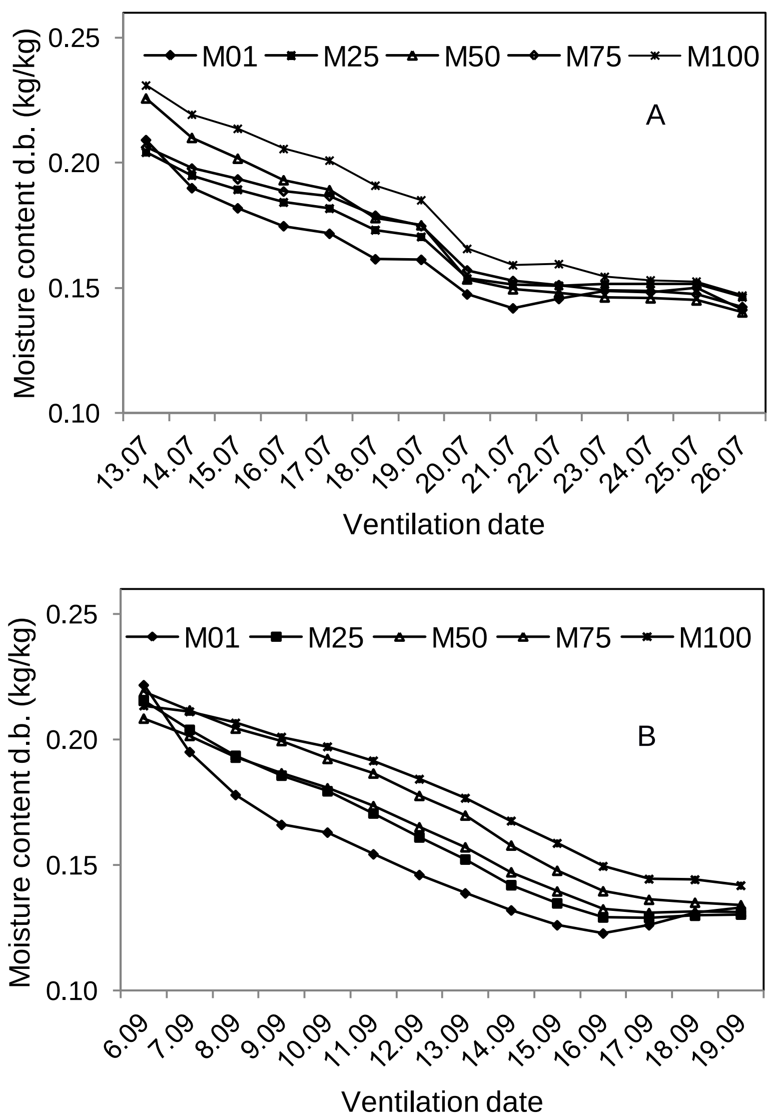

Figure 6.9 Drying curve for on-cobs-maize showing moisture content (d.b.) *vs* ventailation time at various postions inside modified *gombisa* A) First experiment (July 2016) B) Second experiment (Septumber 2016) at Witzenhausen, Germany.
Where: M01; M25; M50; M75 and M100 are 0 cm, 25 cm, 50 cm, 75 cm and 100 cm of on-cobs-maize samples kept above plenum chamber, respectively.

6.4.6 Computational fluid dynamics simulation

The CFD simulation result in Figure 6. 10 showed air velocity distribution in the maize bulk 10 cm and 50 cm above the bottom of the maize bulk. It can be seen that a slightly higher air velocity developed at the side opposite to the air inlet. However, as the air moved upwards through the bulk the air velocity rapidly equalized and halfway through the bulk the airflow was nearly uniform.

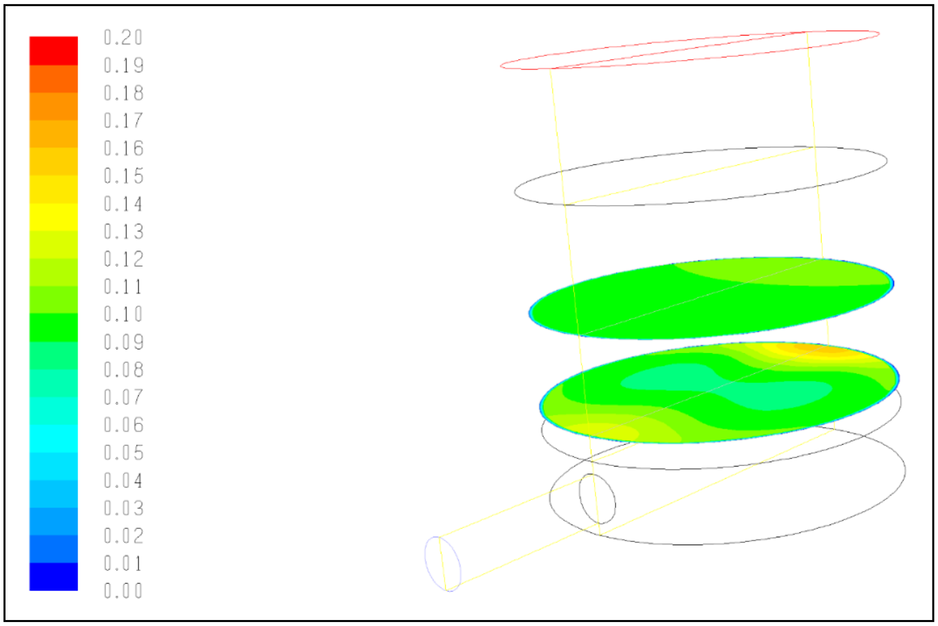

Figure 6.10 Velocity profiles at 0.1 and 0.5 m above perforated floor.

6.4.7 Application of the system to tropical regions

It is hardly possible to find electricity in rural parts of Ethiopia, including the southwestern part where the extent of maize PHLs is very high mainly due to high moisture content at harvest and loading, which leads to growth of mycotoxin-producing fungi. Therefore, use of directly coupled photovoltaic fan for ventilations system can be suited for on-cobs-maize drying to reduce moisture content to a safe level where the electric grid is not available. The prototype of directly coupled PV-ventilation systems developed and tested showed promising result which can be used in the tropical regions. For this purpose secondary data of solar irradiance during maize harvesting and the loading stage of the Jimma area was obtained and compared with the current experiment. The result showed solar irradiance of the Jimma area showed a better trend with energy output compared with five consecutive days compared with Witzenhausen, Germany (Fig. 6.11). The figure clearly indicated that there was by far less fluctuation of solar irradiance of Jimma area (Fig. 6.11A) compared with solar irradiance values of Witzenhausen, Germany area (Fig. 6.11B). Solar energy of Jimma area depicted better trend and abundantly accessible which can be applied for intended research work. Therefore, solar energy could be a potential resource and also feasible renewable energy in the area where it is most abundant in nature for ventilation and on-cobs-maize drying purposes.

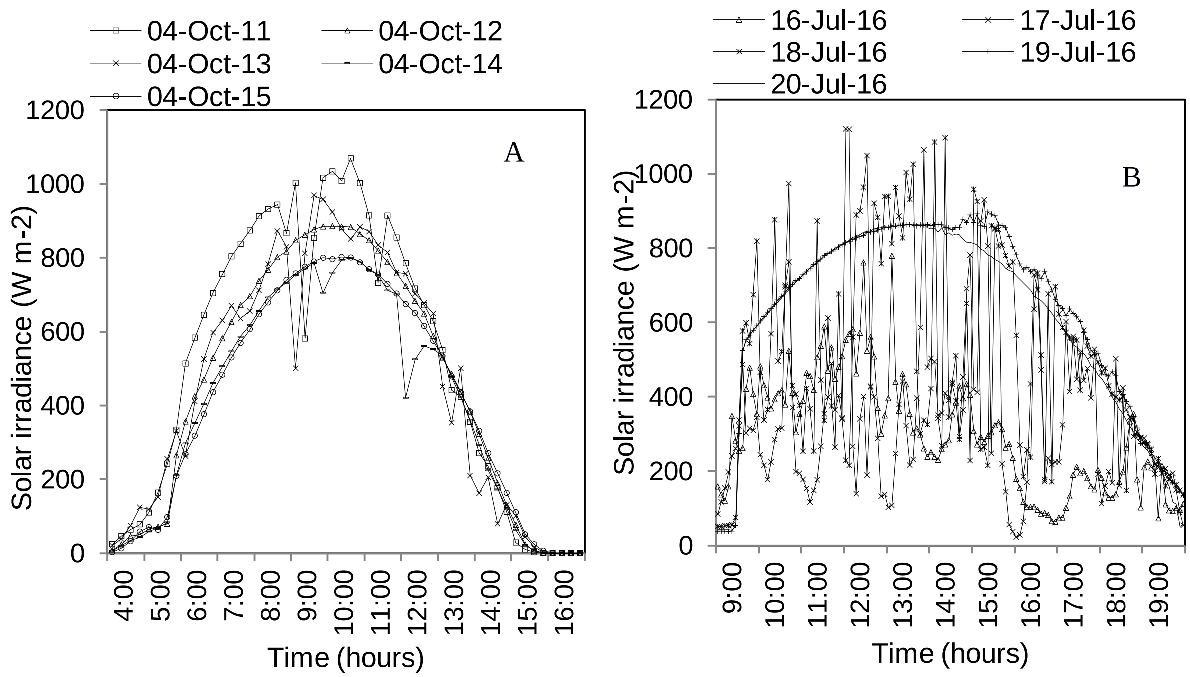

Figure 6.11 Solar irradiance *versus* time in hours A) 04 Oct. 2011, 04 Oct. 2012, 04 Oct. 2013, 04 Oct. 2014 and 04 Oct. 2015 of the Jimma, Ethiopia (source: EMA, 2016), B) 16 to 20 July 2016, Witzenhausen, Germany.

6.5 Discussion

Monitored data during both experiments for temperature and relative humidity showed a high variation in ambient conditions compared to inside the modified *gombisa* of stored on-cobs-maize. The result clearly showed that even though external environmental conditions highly fluctuate within a day, inside the store relatively depicts less variation. This demonstrates that the storage system can play a role in protection from the impact of external weather variations that play a key role in the growth and development of mycotoxin-producing fungi.

During the drying process of on-cob-maize, inlet relative humidity was lower than outlet conditions as the outlet contain more water that was carried out from the drying process. However, it resulted in reducing the outlet temperature compared to inlet conditions. Drying of on-cobs-maize brought m.c. of an average of 0.22 to nearly 0.14 d.b. (kg/kg) within about 10-12 days of the ventilation and drying periods. A fan control strategy was set at ambient relative humidity of maximum 70% to switch on for ventilation and drying purposes. A simulation study conducted using long-term weather data by Atungulu and Zhong (2016) for the assessment of fan control strategies for natural-in-bin rough rice drying from a m.c. of 22% to a safe m.c. took 10 days for an airflow rate of 2.77 $m^3 min\text{-}t^{-1}$. In a similar study with an airflow rate of 2.08 $m^3 min\text{-}t^{-1}$ using five fan control strategies (continuous fan operating, fan running only at night, only during the day, set window of equilibrium moisture content of natural air and set window of air equilibrium m.c. with supplementary heating), all operation strategies could dry the rough rice from an initial m.c. of 16%, 18%, 20% and 22% to an average and safe m.c. (13%) in the bin (Atungulu and Zhong, 2016). Natural air drying system makes equal distribution of m.c. in the whole store and no dead corners occur where mould can easily grow and contaminate the whole store.

6.6 Conclusions

A photovoltaic module fitted ventilation system to modified traditional Ethiopian *gombisa* for on-cobs-maize drying and storage was developed and tested under field conditions. The experimental results showed that the developed fan control systems performed as expected during both experiments. A computational fluid dynamics simulation result revealed the uniformity of the drying of on-cobs- maize using a photovoltaic panel fitted ventilation system to traditional modified Ethiopian *gombisa*. Ambient temperatures and relative humidity showed a high variability compared with the inside of the store indicating the structure playing a role in protecting the stored product from external climatic variables that favor development of mycoflora. The solar irradiance, air velocity and photovoltaic power for a day were able to reduce the m.c. of the stored product to nearly 0.14 d.b. (kg/kg) within 10 to 12 days of ventilation. The results also highlighted that the system can be a potential technology to be tested and used in tropical regions. Future research needs to evaluate quantity and quality losses of stored on-cobs-maize product in tropical regions compared with traditional storage systems.

6.7 Acknowledgement

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7. General discussions and conclusion

This chapter presents the overall discussion of the results of the research proposed with aim of minimizing maize PHL across agro-ecological settings and storage methods focusing on mycotoxin-producing fungi in southwestern Ethiopia. The main components of the research includes: field survey for documentation of maize PH handling practices, laboratory analysis to determine mycoflora epidemiology and nutritional quality deteriorations, field evaluation of traditional storage structures and; finally development and test of modified traditional Ethiopian *gombisa* for on-cobs-maize drying and storage. In chapter three, four, five and six detailed methodologies, results and discussions have been presented for each chapter. However, the key findings of the research in complement with some of the literatures have been presented here. Furthermore, practicability and possibility of research findings to transfer to other commodity or/and regions or countries also highlighted for each chapter.

7.1 Actors' post-harvest maize handling practices and allied mycoflora epidemiology

Understanding and examining different practices of maize PH handling and mycoflora epidemiology was used as pedestal information for subsequent research activities carried out under laboratory conditions, field evaluation of traditional storage structures and development of modified *gombisa*. The findings revealed about ten PH handling activities have been carried out along maize PH supply chain by different actors from farm/harvesting to table. However, those traditional maize handling practices are not in a position to reduce losses. And, maize PHL was estimated at 31% by different actors' along maize supply chain. In similar, Tefera (2012) reported that maize PHL of 14-36% occurs in Africa. Survey result also disclosed that loss during storage was identified as critical loss point. Different researchers have noted that high maize PHL during storage (Baidoo et al., 2010; Rembold et al., 2011; Sori and Ayana, 2012). Moisture content at loading also identified as favorable condition for mycloflora growth during storage. Furthermore, conventional storage structures in use are not climatically controlled to minimize storage fungal pathogens contamination that resulted in quantity and quality losses. Among seven fungal genera isolated, characterized and identified, *Fusarium, Penicillium* and *Aspergillus* spp. were the most dominant ones. Those fungal genera are known for producing of mycotoxins that have impact on human and animal health consumed on contaminated products (Rundbergeta et al., 2002; Nesci et al., 2003; Jonathan et al., 2004; Stumpf et al., 2013; Kiarie et al., 2016).

This study approaches loss assessment and estimation considereing main actors along maize supply chain. Such loss estimation methods can be adopted for other crops, localties or regions taking into consideration of the key actors along supply chains. While conduting PHL, identification of critical loss point(s) are pertinent to develop action plan for intervation targeting feasible and sustainable solutions with limited available resources in the area. Generally, it is recommended to have concreate and realiable information and data of PHL that can be used as base information to design loss management strategies.

7.2 Nutritional quality deterirations of stored maize

Most loss assessment and management studies have been focused mainly on quantity losses. To bridge the gap, in this study nutritional and anti-nutritional analysis of stored maize including different agro-ecological settings and actors store were considered. Moisture content at the loading stage and during subsequent periods was not optimal for safe storage especially under farmers' conditions. This circumstance is one of the key factors that favors fungal growth and causes the nutritional deterioration in stores. Nutritional quality losses due to poor PHM have been reported (Golob et al., 2002) and due to bio-deterioration (Rehman, 2006; Reed et al., 2007; Farhan et al., 2013; Paraginski, et al., 2013) from different countries. Nutritional quality deterioration has great implications for nutrition insecurity and unrecognized undernourishment of the society. Storing maize under traditional conditions along its supply chains resulted in substantial quality losses.

It is generally acknowledged that maize rich in starch, good sources of antioxidants, fibers and other nutritional values that valued the commodity as good staple food crops for subsistence farmers in developing countries. Farmers in Ethiopia particularly southwest part of the country depend on maize as main food source for daily consumptions. Therefore, it is worth to mention that quality deterioration has great significance from nutritional security point of view for such area that needs foremost attention of quality loss interventions. In general, not only quantity loss but also quality loss reduction mechanism has to be considered while conducting good agricultural practices to minimize loss.

7.3 Role of agro-ecology and storage methods on toxicogenic-fungi growth

Maize is ranked on top as important cereal crop in Ethiopia but it is subjected to sever quantity and quality losses as indicated under chapter 3 and chapter 4. Specially, loss during storage was identified as critical loss point (chapter 3). Storage structures in use are rudimentary types and role of those structures for the growth of mycoflora in the store was not investigated. Therefore, this chapter was aimed to evaluate the potential growth of mycotoxin-producing fungi under different agro-ecological settings and storage methods in south-western Ethiopia. The outcomes of this study revealed that both long-term climate and pre-harvest weather data were conducive for the growth of the target fungal species in all agro-ecological conditions. Cotty and Jaime-Garcia (2007); and Czembor et al. (2015) also distinguished similar findings on role meteorological data to predict the risk and incidence of mycotoxin-producing fungi both during crop development and after maturation. Chapter 3 also asserted that farmers' traditional storage systems at all agro-ecological settings exhibited a direct relationship between the inside and outside temperature and relative humidity that indicates the minor role of the structure in protecting stored products from external environmental conditions that favours the growth of mycotoxin-producing fungal pathogens.

Based on weather conditions of the study area, it is possible to conclude that maize product harvested can be a potential contaminate for fungal inoculums source during storage. Relative humidity and temperature inside *gombisa* of the study area were optimal for the growth of storage fungi pathogens. In addition, the hot and humid climate nature of Jimma area affects the moisture content of the stored maize that further facilitates growth, development and dominance of mycotoxin-producing fungi already contaminated during pre- /and during harvesting and subsequent chain of activities. High moisture content at harvesting and loading stage supplemented with non-climatic controlled nature of *gombisa* favors both field and storage fungi growth. Improvement of PHM including harvesting practices at optimum moisture content, better handling practices and sanitation are very imperative to minimize infection and development of fungal pathogens along chain of activities. On the other hand, improvements of locally available storage technologies which are affordable and easily managed by farmers are crucial to reduce maize PHL both in quality and quality. In order to overcome quality losses (reduction in germination, alterations of nutritional content and processing quality) and outstandingly, contamination of mycotoxins need great effort for improvement of maize PH handling and better storage technologies. Furthermore, not only maize but also other food crops produced in the study areas stored using traditional storage structures which are not protective for PHL and need research attentions for improvement.

7.4 Photovoltaic driven ventilation system fitted to modified *gombisa* for maize drying

Chapter 3, chapter 4 and chapter 5 described maize PHL (quantity and quality), un-safe moisture content at loading stage and non-climatically controlled nature of *gombisa* that results in mycoflora growth and development on maize in the storage system. Thus, this demand for the modification and/or development of traditional storage technology that best fits to local conditions to minimize maize PHLs. Hence, chapter 6 initiated with aim of developing a photovoltaic driven ventilations system fitted to modified *gomibsa* for natural air in-bin drying of on-cobs-maize and increase the shelf life of the product. The moisture content of the stored product reached nearly 0.14% (d.b.) within 10 to 12 days of ventilation from about 0.22 (d.b.). This result is also in line with CFD theoretical simulation test that showed the uniformity of the drying of on-cobs-maize using a photovoltaic panel ventilation system fitted to modified traditional Ethiopian *gombisa*. Ambient temperatures and relative humidity showed a high variability compared to the inside of the store (modified *gombisa*) that indicates the role the structure play in protecting the stored product from external climatic variables that favor the development of mycoflora.

Developed technology can be best suited for subsistence farmers as it is not high-tech and easily managed by less qualified personnel. Furthermore, construction of modified *gombisa* from locally available materials makes the technology economically affordable to utilize by resource poor farmers too. Similarly, the same technology can be used with minimum modification to store sorghum at the study area. Farmers in the study area usually store their sorghum as un-threshed using *gombisa.* The issue of high initial moisture content at loading stage is also one of the possibilities for fungal development inside the store. Therefore, evaluating the technology for sorghum storage can also be potential candidate in minimizing loss during storage. Storage structures like cribs are used commonly for maize storage in Africa that need modification for drying and storage of the commodity. Consequently, current research findings can be potential technology to be tested in other tropical countries where solar energy is abundantly available for use.

7.5 Contribution of research for post-harvest loss reduction and future line of work

This research work focuses on the reduction of maize PHL caused by mycotoxin-producing fungi along agro-ecological settings and supply chain in southwestern Ethiopia and a component of a big project (Reduction of Post Harvest Losses and Value Addition in East African Food Value Chains, RELOAD, No. 031A247A-D) implemented with collaboration of four countries. REOAD project initiated with the aim of reducing post-harvest losses along value chain in East-African food production which imposed unacceptable waste of scarce resources, undernourishment and aggravates poverty in Ethiopia, Kenya and Uganda. Based on available data, the project has developed scientific agenda for Ethiopia focusing on reduction of cereals post-harvest loss which is a dominant commodity in the country and maize ranked on top. Consequently, this specific research was conducted in southwestern Ethiopia and contributed new scientific knowledge that can be used as pedestal information and pin pointed the constraints for next research work like estimated maize PHL, maize PH handling practices, role of biological agents on quantity and quality loss, different type of maize storage technologies and its role for maize PHL. On the other hand, this thesis work not only contributes information; but also innovated modified storage technology developed and tested under field condition to reduce loss during storage which identified as critical loss point. This finding helps both producers and consumers by reducing maize PHL and avail more food source for utilization. Furthermore, it increases the income source of the producers by increasing the shelf-life of the product and make available during off-season of the crop. Therefore, this research work clearly did contribute to the final goal of RELOAD project that aimed at reduction of staple food crop PHLs in Ethiopia.

Modified Ethiopian *gombisa* has been developed and tested under field condition at Witzenhausen, Germany. However, the finding needs to be evaluated and tested under end users condition of the tropical regions. Special emphasis should focuses on comparison of the stored products quality and quantity loss during storage duration, cost-benefit analysis with traditional storage structures. Furthermore, need of research focus on training and awareness creation for different actors with regards to effective use of storage technologies that will minimize losses. Additionally, attention should also be paid to effective pest management that will help to improve loss reduction of stored maize and impact of secondary metabolites produced by mycotoxin-producing fungal pathogens. Also, research has to focus on integrated approach of PHL reduction mechanisms including evaluation of different maize varieties grown in the area with aim of developing maize variety tolerate or resistant for fungal development both pre- and post-harvest as result maize can be stored longer for selling, human consumption or animal feed with minimum mycotoxins contamination.

The core finding of the research highlights documentation of major PH handling practices with respective losses along chain of activities. During research period moisture content at harvesting and loading; and loss during storage were identified as critical factors contribute for maize PHLs. This complemented with use of traditional storage structure under different agro-ecology resulted in high quantity and quality losses and favors growth and development of mycotoxin-producing fungi. To tackle the bottle neck of traditional storage structure and reduce both quantity and quality losses, modified storage structure was developed; tested and promising result was obtained during field evaluation.

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8 Summary

Maize (*Zea mays* L.) botanically belongs to family *Graminae and* identified as the grass family. The genus *Zea* consists of four species of which *Z. mays* L. is economically important one. Maize is the important cereal food crop in sub-Saharan Africa (SSA) both in total area coverage and caloric consumption. Research reports demonstrated that maize is an important food security crop especially for Africans and Latin American. The crop utilized in various forms compared to other cereals and crucial for food security in SSA. In this region of the world, it is dominant food crop mainly produced by smallholder farmers for food. Similarly, in Ethiopia, maize is the dominant staple food crop, source of income and one of the main sources of calories particularly in the major maize producing regions of the country. The crop ranks first both in total production and yield per hectare in the country. In general, maize is cultivated under wide range of environmental conditions and soil types than any other crops in the country. As result, it has been included in the national food security strategy via intensive agriculture system in Ethiopia. Maize production and productivity in the country has doubled its yield in less than two decades and is the second in SSA in yield/ha. However, this boost in production and productivity threatens to be negated by high PHLs which in turn affect food security

There is little and fragmented information available that reveals high maize PHLs in the country. Specifically focusing on mycotoxin-producing fungi which cause quantity and quality loss and more importantly posing serious hazard to consumer health. Moreover, there is no research activity carried out that encompasses maize PHLs that includes the whole activity chains from farm to fork. Additionally, issues leading to high PHL favoring mycoflora growth were not fully identified and characterized. In general, there is no tangible information and evidence that address all actors and activity chains from production to consumption level to reduce maize PHL. Identifying available PH handling practices along the activity chains add knowledge for the reduction of maize PHL. Stored maize is a man-made ecosystem which affects quality and quantity changes because of interactions between different factors such biological, chemical and physical parameters. Therefore, the current research was designed with aim of developing maize PHLs reduction mechanism attributed by mycotoxin-producing fungi under different agro-ecology and supply chain in southwestern Ethiopia. In order to address the ultimate goal of the research four separate studies have been executed.

The first study dealt with assessment of maize PH handling practices and the fungal pathogens dynamic associated with maize stored by producers, collectors, and wholesalers in selected

districts of the Jimma zone in southwestern Ethiopia. Survey result showed ten different PH activities practiced by actors in study sites. However, many of the activities didn't seem effective to preserve harvested maize as they lead to tremendous PHLs. Maize PHLs has been estimated to be 31% and losses during storage were identified as a critical intervention point. Moisture content at loading stage could not increase the shelf life of the commodity. Comparing all biological agents, loss due to fungal pathogens in the store ranked on top. Germination test showed a significant decrease ($P < 0.01$) as storage duration increased under all actors' condition. Contrarily, mould incidence on cobs and kernels significantly increased ($P < 0.05$) as storage duration increased. In this study, seven fungi genera were identified, but *Fusarium, Penicillium* and *Aspergillus* spp. were the predominant fungi occurring in all the maize sampled along the supply chain; which also known to produce mycotoxins and cause health hazards to both humans and animals that feed on it. Generally, post-harvest handling practices identified during survey periods were not able to reduce losses; especially farmers' practices were liable to mould growth on stored maize.

The second study evaluated nutritional and anti-nutritional content of stored maize in different agro-ecological settings involving different actors. Our findings revealed that the nutrient composition of stored maize, especially protein, fat, CHO, and calorific value, significantly declined across the storage period for different actors and their different storage structures. The moisture content significantly ($P < 0.05$) decreases as storage duration increases under different actors and agro-ecological conditions. But, showed increment during the final months under farmers' storage conditions that favors growth of mycotoxin-producing fungi. But, fibre, ash, and major mineral (Ca, Zn, and Fe) content increased significantly over the storage period. Phytate and tannin content varied with storage duration and agro-ecological setting. Storing maize under traditional conditions along the supply chain resulted in substantial quality losses. This has great implication on nutrition insecurity and undernourishment with hidden dietary hunger for the society.

The third study evaluated the potential role of temperature and relative humidity of an area during post-flowering to physiological maturity of maize for mycotoxin-producing fungal growth. It also evaluated the role of maize storage methods for growth of major mycotoxin-producing fungi along the maize PH supply chain at various agro-ecological settings under field conditions. The results confirmed both long-term climate and pre-harvest weather conditions were conducive to the growth of the target fungal species. Temperatures inside the farmers' storage systems showed significant ($P = 0.04$) positive correlations with ambient conditions. Significant ($P < 0.05$) positive correlations were also observed between the relative humidity under the farmers' storage and the ambient conditions. In contrast, there were no significant correlations between the collector's storage and ambient conditions for either temperature or relative humidity. A simple linear regression model revealed that there was a negative relationship between frequency of mycotoxin-producing fungi and the temperature inside the farmers' storage systems; whereas, fungal occurrence was positively and significantly ($P < 0.05$) correlated with the relative humidity. Both temperature and humidity were associated with fungal frequency of occurrence in the collectors' store-houses and the wholesalers' warehouses. The farmers' traditional storage methods are not climatically controlled to maintain PH product quality. Therefore, a simple and accessible climate-controlled storage structure is necessary for the resource-poor growers of the study area.

The fourth study dealt with the aim of developing photovoltaic ventilation systems fitted to modified *gomibsa* for natural air in-bin drying of on-cobs-maize and storage at witzenhausen, Germany. Theoretical simulation (CFD) results showed the uniformity of the air velocity rapidly after certain distances above the plenum chamber. Trend of temperature revealed high variability and fluctuation for ambient compared with inside the store. A similar result was observed for the relative humidity during both experiments. Ventilation of on-cobs-maize for 10-12 days resulted in a reduction of m.c. to almost 0.14 (d.b.). Solar irradiance data obtained from Jimma area, Ethiopia showed better energy output compared to the current experiment, demonstrating a possibility to apply ventilation and drying system to the tropical region. The result showed storing maize inside modified *gombisa* plays a role in protecting the stored product from outside weather conditions. Also, monitored temperature, relative humidity and energy output showed the system was able to reduce the product to safe moisture content for storage without mould development. This promising research result needs to be tested and validated under tropical regions of the world.

Appendix

Harvesting practices, storage technology and associated constraints of maize post-harvest handling practices in southwestern Ethiopia

Questionnaire part I (For producers)

Name: Respondent:____________________Interviewer:________________ Code_________

Name of district__________________________ PAs* ________________________________

Zone _________________*Gare* _________________ Agro-ecological zone _______________

Altitude _________________ Longitude ____________________ Latitude ________________

*Note * PA stands for peasant association within district where interview conducted*

1. 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	

2. 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 shelling 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) ≤25% b) From 26 to 50% c) From 51to 75% d) ≥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? ________

3. 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 do 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 structures do you use? If you stored as cobs

a) *Gotera /Gombisa* b) *Dibignit* c) Sacks e) others, specify __________________

14. What type of maize storage structures do you use? If you stored as shelled maize or grains

a) *Gotera /Gombisa* 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)__________________

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) with cobs? a) Use pesticides b) Use of plant material c) Use other traditional protect ant (Specify)_____________________________

25. Describe briefly how you apply your treatment to the grain contaminated with moldy ______

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? ____

4. 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.____

8. How did you store your maize?

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

i. ____

ii. ____

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. ____

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. ____

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

i. ____

ii. ____

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

i. ____

ii. ____

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

i. ____

ii. ____

19. Do you think consuming moldy 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 moldy 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
i			
ii			

Questionnaire part II (For development agents and experts)

Name ____________________________ Sex: ____ Age ____ Mobil no.________________

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 Produced (%)	Reason
i.			
ii.			

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

Maize variety	Advantages	Disadvantages
i		
ii		

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

No.	Storage structures	Proportion	Reason
i			
ii			

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 constraints 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

No.	PHM activities	Advantage	Disadvantage

---

i

ii

13. How much of maize grain do you think can lost 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 your source information about mould in maize? 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 farmers about mould management? Yes_________No_______________

i) If Yes, What type of teaching methods do 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

<u>Questionnaire part III </u>(For collectors and wholesalers)

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, trading 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. Is there a storage insect pest problem in your store? a) Yes b) No

10. If yes, how is the incidence of insect pest trend for last five years in store? a) Increased b) Reduced c) Constant d) I don't observe/know the incidence

11. If the answer for question no. 9 is yes what do you think the major cause for this? ________

12. Do you have the problem maize grains germination in the storage? a) Yes b) No

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

14. 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

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

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

16. Is there ventilation system other than window and door a) Yes b) No

17. Frequency of cleaning the whole store

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

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

19. Do you have any idea to improve?

i) Maize production at farm level ____

ii) Maize quality improvement ____

iii) Trading ____

iv) Storage structures ____

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

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

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

No.	PHM activities	Advantage	Disadvantage
1			
2			