POST-HARVEST KNOWLEDGE, PERCEPTIONS AND PRACTICES BY FARMERS AND DIVERSITY OF *FUSARIUM* SPECIES AND FUMONISIN CONTAMINATION OF MAIZE FROM RIFT VALLEY AND LOWER EASTERN REGIONS OF KENYA

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Post-Harvest Knowledge, Perceptions and Practices by Farmers and Diversity of *Fusarium* Species and Fumonisin Contamination of Maize from Rift Valley and Lower Eastern Regions of Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature …….....Date.....……

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This thesis has been submitted for examination with our approval as University Supervisors.

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DEDICATION

This work is dedicated to all the maize farmers in Kenya for their tireless efforts as they try to address the issue of food insecurity in the country. I also dedicate this work to my wife Mrs. Linner Koskei and children, Marvin Korir, Marlene Cherono, Maureen Cheruto and Marion Chepkoech for the support they accorded me during the entire period of my studies.

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ABBREVIATIONS AND ACRONYMS

AEZs	Agro-Ecological Zones
CI	Confidence Interval
CLA	Carnation Leaf-piece Agar
DMA	Dry Mid Altitude
DON	Deoxynivalenol
DT	Dry Transitional
ELEM	Equine leucoencephalomalacia
ELISA	Enzyme linked immunosorbent assay
EU	European Union
FAO	Food and Agriculture Organization
FB	Fumonisin B
FB_1	Fumonisin B_1
FB_2	Fumonisin B_2
FB_3	Fumonisin B_3
GDP	Gross Domestic Product
HLT	Highland Tropical
HPLC	High performance liquid chromatography

IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
IREC	Institutional Research and Ethics Committee
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KEMRI	Kenya Medical Research Institute
KNBS	Kenya National Bureau of Statistics
Kes	Kenya Shillings
LE	Lower Eastern
LLT	Low Land Tropical
LMICs	Low and Middle Income Countries
LOD	Level of Detection
MMA	Moist Mild Altitude
MT	Moist Transitional
MTRH	Moi Teaching and Referral Hospital
NACOSTI	National Commission for Science, Technology and Innovation
NIV	Nivalenol
OR	Odds Ratio
PDA	Potato Dextrose Agar

PCR	Polymerase Chain Reaction
PhD	Doctor of Philosophy
PICS	Purdue Improved Crop Storage
PPE	Porcine Pulmonary Edema
RV	Rift Valley
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
US	United States
US-FDA	United States Food and Drug Administration
WHO	World Health Organization
ZEN	Zearalenone

OPERATIONAL DEFINITION OF TERMS

Fumonisins	Naturally occurring toxins produced by several species of Fusarium species.
Fungi	Fungi (singular: fungus) are a kingdom of usually multicellular eukaryotic organisms that are heterotrophs (cannot make their own food) and have important roles in nutrient cycling in an ecosystem. Fungi reproduce both sexually and asexually, and they also have symbiotic associations with plants and bacteria. However, they are also responsible for some diseases in plants and animals.
Fusarium	A species of fungi responsible for Fumonisin mycotoxin production.
Mycotoxins	Toxic compounds that are naturally produced by certain types of moulds (fungi). Moulds that can produce mycotoxins grow on numerous foodstuffs such as cereals, dried fruits, nuts and spices. Mould growth can occur either before harvest or after harvest, during storage, on/in the food itself often under warm, damp and humid conditions. Most mycotoxins are chemically stable and survive food processing.

Post-harvest Management	Activities carried out on the maize immediately following the harvest. It determines the final quality of the product. Postharvest management includes the following activities: Harvesting, drying, threshing/shelling, cleaning/ winnowing, transport and storage.
Post-harvest behaviour	Activities or practices by maize farmers done after harvesting

ABSTRACT

Maize serves as a staple food in many Sub-Sahara African Countries with 90% of the Kenyan population depending on it. Although the area under maize cultivation has been increasing in Africa, its production has been reducing. Heavy post-harvest losses of the crop during storage have been a big challenge. Maize is susceptible to insects and fungal infestations leading to mycotoxin contamination including aflatoxin and fumonisins. Fumonisins are produced by the *Fusarium* species and despite its known health hazards, there is a dearth of data on fumonisin contamination in Kenya. Therefore, the main objective of this study was to determine post-harvest perceptions, knowledge and practices by farmers and diversity of *Fusarium* species and fumonisin contamination of maize from Rift Valley and Lower Eastern Regions of Kenya. A descriptive cross-sectional study was carried out among 165 and 149 farmers in the Rift Valley and Lower Eastern Regions of Kenya respectively. An interviewer administered semi-structured questionnaire was used to collect data from the farmers. Maize grains samples were collected for laboratory analysis. In the laboratory, the collected samples were cultured for *Fusarium* and other fungal growth. Determination of fumonisin contamination levels was also carried out. Data was analyzed using Statistical Package for Social Sciences (SPSS) version 24.0, with descriptive and inferential statistics used. Data from the two regions were compared using Chi-square and fisher's exact tests for categorical variables and two sample t-test and its non-parametric form, Mann-Whitney U test for comparison of means for continuous variables. A p value of < 0.05 was considered statistically significant. Majority (58.6%) of the respondents were females and farming was the main economic activity. The median quantity of maize harvested after shelling in the two regions was 6.5 bags (585 kg) (IQR=2-19) per household. The median amount of maize put aside before shelling as a result of rotting was 20 kg (IQR=0-90) per household. The quantity of discolored and mouldy grains consumed ranged from 0 - 90 kgs per household, 7 (2.2%) respondents consumed mouldy maize, 36 (11.5%) fed the mouldy maize to cows and 19 (6.1%) fed it to poultry. A small percentage (3.5%) believed that mouldy maize is safe for human consumption, 23.6% for animal consumption, while 15.0% considered it safe for brewing with the differences between the two regions (24.8% in RV verses 4.0% in LE) being statistically significant ($p < 0.05$). More than half 193 (61.5%) had good knowledge on causes and methods of minimizing moulding. More farmers from RV, 134 (81.2%) had good level of knowledge compared to 59 (39.6%) in LE, and the regional difference was statistically significant (P-value<0.001). Concerning storage practices, nearly half (48.4%) of the respondents stored maize while still on cobs in a separate room, 47.1% left it in the field without covering. Most (33.1%) farmers from the Lower Eastern consumed and sold maize while still green. Infestation by *Fusarium* species in the maize samples collected was 30.1% with *F. verticillioides* accounting for 80.8% of the *Fusarium* species isolated. Lower Eastern Region had higher Fusarium isolates compared to Rift Valley Region ($P < 0.05$). Of the 200 samples tested 133 (66.5%) had fumonisin levels below the level of detection, 63 (31.5%)

samples had fumonisin levels ranging from 0.1 ppm - 4.0 ppm while 5 (2.5%) samples had levels that were above 4.0 ppm. Lower Eastern had significantly higher number of samples with detectable level of fumonisin compared to Rift Valley (*P-value* <0.001). This study confirms that maize samples from Lower Eastern and Rift Valley are contaminated with significant levels of Fumonisins with a potential of negative health consequences.Poor post-harvest management practices among maize farmers and ignorance are likely risk factors for post-harvest losses and mycotoxin exposure with potential health and economic consequences. This calls for education campaigns on better post-harvest practices among famers as well as more research on the potential health consequences that these detected fumonisins pose to the consumer.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Agriculture is the economic backbone of most Sub-Saharan Africa (SSA) countries and contributes greatly to the Gross Domestic Product (GDP) of these countries while at the same time providing employment to many residents (AGRA, 2017). While agriculture contributes up to 70% of SSA countries income, 37% of it is from cereal crops of which maize is one of the main cereals grown in the region (World Bank, 2011).

More than 34 million hectares of maize were grown in SSA in the season of 2014/2015 producing approximately 70 million metric tonnes of maize. More than half of the consumed calories in East and West Africa are from maize (Macauley, 2015).

In Kenya, maize is the staple food to the majority of the population (Laboso & Ngeny, 1997) with an annual per capita consumption of 77 kg of maize and maize products (FAO, 2011). Most of the maize harvested is stored in many parts of the country, mainly in households to ensure continuous supply between seasons. Traditional storage methods are mainly used (Nukenine, 2010) but have the disadvantage of being susceptible to insects and pest attack (Lathiya *et al*., 2008) among other unfavorable conditions that might lead to maize contamination and spoilage.

Although the area under maize cultivation has been increasing in Africa, production and supply of the same in the region has been declining (De Groote *et al*., 2011). This has been attributed partly to climate change and heavy post-harvest loses (Auffhammer, 2011).

The post-harvest loses has been reported to hamper food security and food safety situation in Africa leading to high food prices due to scarcity. Food and Agriculture

Organization (FAO, 2010) has estimated these loses to be 20-30% of the total production valued at approximately US$ 4 billion annually. Limited food supply has also been associated with many conflicts, armed wars and political instability in parts of Africa.

The main reasons that have been given for high maize post-harvest loses include biological agents including pests, fungi and rodents, poor post-harvest maize handling practices, open air and informal marketing systems and, unfavorable physical and environmental factors (Hell & Mutegi, 2011; Tefera *et al*., 2011). Maize farmers lose a good percentage of their produce due to poor post-harvest management practices with most of it occurring during the storage period. This necessitates mitigation measures which have been shown to have benefits that outweigh the costs associated with the losses (FAO, 2010).

With lack of proper storage methods that are effective and affordable, farmers resort to storage methods that are ineffective. Maize stored using such methods experience substantial pest damage, fungal infestation and rodent attack (Kadjo *et al*., 2016). Poor post-harvest practices also result in mould growth, dry matter loss in the grains and poor grain quality (Magan & Aldred, 2007).

Maize is susceptible to fungi especially of the *Aspergillus* and *Fusarium* species from the period of its growth to harvest and also during transport and storage period hence being contaminated with mycotoxins associated with these fungal species, especially aflatoxins and fumonisins (Shephard, 2008).

Fusarium species is a fungi that is responsible for the production of mycotoxins with the ability to cause toxicity in animals, plants and humans (Abbas *et al*., 2013). *Fusarium* species can infest plants during different stages of development. They cause diseases in plants such as seed rot, ear and kernel rot, root and stem rot, and rudimentary ear rot (Meissle *et al*., 2010). The most common mycotoxins produced by *Fusarium* species include fumonisins, zearalenone, and trichothecenes (Schollenberger *et al*., 2005)

The *Fusarium* species known to produce fumonisins include; *Fusarium verticilliodes* (also called *Fusarium moniliforme*), *F. oxysporum, F. proliferatum,* and *F. globosum* (Weidenbörner, 2001). *Fusarium verticilliodes and F. proliferatum* have been shown to be the main *Fusarium* species responsible for the production of fumonisin (Zhang *et al*., 2013). However, the dominance of fumonisin producing *Fusarium* species in a given region have been shown to vary with geographical locations and the existing environmental conditions (Ferrigo *et al.*, 2016). There exists nearly more than 28 forms of fumonisins. Of these, fumonisin B_1 and B_2 have been shown to be the most economically important contaminants of maize and maize products (Alberts *et al*., 2016; Alizadeh *et al.*, 2012)

Maize and its products have been frequently cited to be contaminated with high aflatoxin and fumonisin levels (Matumba *et al*., 2015; Matumba *et al*., 2014). Mycotoxins have been cited as a major problem in SSA with the problem being promoted by poor farming practices, climatic conditions and post-harvest handling practices. These provides a conducive environment for insect infestation as well as fungal growth and survival and subsequent mycotoxin production (Kumar *et al*., 2008).

Most (75%) of the maize grown in Kenya is by small scale farmers who do it under conditions likely to result in mycotoxins contamination. In Kenya, there are no mechanisms to guarantee food safety during the value chain from production to consumption (Kang'ethe, 2011). The high cost of carrying out mycotoxins analysis, means very few African Countries can afford to carry out mycotoxins monitoring in their food systems. Similarly, Kenya has got a very limited capacity to conduct such mycotoxins monitoring including fumonisins. The Kenyan government therefore, adopted the EU/WHO regulatory limits for mycotoxins monitoring which it is yet to be fully implement (Hell & Mutegi, 2011; Whitaker *et al*., 2011).

1.2 Statements of the Problem

From the review of literature, there is paucity of data regarding farmers knowledge, perceptions and practices of post-harvest maize management practices, with no such studies having been conducted in Rift Valley and Lower Eastern Parts of Kenya. The area has been less explored despite its importance in informing better food safety practices. Lack of proper knowledge and practices on maize management post-harvest has the potential of resulting in huge postharvest losses and maize contamination by mycotoxins.

A number of studies have reported fumonisin contamination of maize and maize products in SSA. *Fusarium verticillioides* has been commonly associated with fumonisin contamination in the region (Kamala *et al*., 2016; Boutigny *et al*., 2012; Kimanya *et al*., 2010; Alakonya *et al*., 2009; Adejumo *et al*., 2007; Bankole & Mabekoje, 2004; Kedera *et al*., 1999). Fumonisin has been reported to be the second most prevalent mycotoxin contaminant of maize in SSA after aflatoxin.

Various levels of fumonisin contamination have been reported in different parts of SSA with some sites reporting positive fumonisin contamination in all tested samples. Phoku *et al*., (2012) reported levels as high as 8, 819 µg/kg (8.819 ppm) in South Africa. In Kenya, fumonisin levels of 1,170 µg/kg (1.17 ppm) has been reported in Makueni (Bii *et al*., 2012).

In humans, fumonisin ingestion has been associated with oesophageal and liver cancer (Sun *et al.*, 2007). It has also been reported to cause food poisoning outbreaks associated with diarrhea, abdominal pain and borborygmi (Bhat *et al*., 1997). Ingestion of maize and its products contaminated with fumonisin has also been shown to be fatal to animals. Fumonisins causes leukoencephalomalacia in horses and porcine pulmonary oedema syndrome in pigs. It also causes liver, heart and kidney toxicity in cattle, sheep, horses, rabbits, pigs and rats (Bucci & Howard, 1996). Experiments in rats and mice have shown that fumonisin B_1 results in liver tumors in mice and, liver and kidney tumors in

rats (IARC, 1988).

While *Fusarium* species infestation in maize can be controlled through proper post-harvest management practices, once produced in maize, fumonisins cannot be removed and they are passed on in the maize food chain hence the need to control it before it is produced.

The presence of mycotoxins in food is often overlooked in Africa due to public ignorance about their existence, lack of regulatory mechanisms, dumping of food products, and the introduction of contaminated commodities into the human food chain during chronic food shortage due to drought, wars, political and economic instability (Wagacha & Muthomi, 2008).

Health hazards in both humans and animals associated with fumonisin contamination have been reported world over including Kenya. However, there exists limited data on fumonisins and its associated *Fusarium* species diversity in Kenya . *Fusarium* species infestation and fumonisin contamination is thought to be highly prevalent in maize. A few studies have attempted to look at fumonisin contamination in Kenya and the results of those studies showed that some of the samples analyzed had fumonisin levels higher than the recommended levels (Bii *et al*., 2012; Kedera *et al*., 1999; Kedera *et al*., 1994). However, these studies were conducted long ago hence no date on current trends, hence incidence of contamination remains unknown despite maize being a major staple food in the country. Besides, there is lack of local regulatory guidelines that specify the required standards and acceptable mycotoxin levels in maize for human consumption in Kenya.

1.3 Justification

Maize is a staple food in Kenya with Rift Valley being the countries grain basket. If maize produced in the country is contaminated by fumonisins, it is likely to result in deleterious effect to the consumers. hence as a safety precaution, determining its

presence and levels is key. Lower Eastern is a known hotspot for Aflatoxin, produced by Aspergillus fungus. A related species to fusarium producing fumonisins. Despite this relationship, there is scarcity of studies that have investigated presence of fumonisin in these regions.

Regulatory levels require information on the levels of mycotoxins to protect consumers. International standards require that maize meant for human consumption should have a maximum of 1-4ppm depending on the product and regulatory body. European Union and World Health Organization (WHO) recommends that maize used for human consumption should have low level of fumonisin contamination of 1 mg/kg (1 ppm).

US Food and Drug Administration (FDA) recommends 2 mg/kg (2 ppm) of fumonisins in degermed dry milled corn products and 4 mg/kg (4 ppm) in whole and partially degermed corn products (US FDA, 2001). However, in Kenya, the National Food Safety Policy (NFSP) and the Public Health Laws do not provide specific standards and guidelines on acceptable mycotoxin levels.

Without data on mycotoxin contamination levels locally, it is likely that consumers will continue feeding on fumonisins contaminated maize unknowingly. Understanding the existing *Fusarium* species and its associated mycotoxins is vital in informing the development of mycotoxin prevention strategies (Stumpf *et al*., 2013). It is also essential to understand if there is regional variations in fumonisn levels and postharvest maize management practices to inform targeted intervention approach. Besides, information on the postharvest practices of farmers is essential In informing the likely pathway of contamination hence guiding the type of intervention measures to be put in place.

1.4 Hypothesis

H_0: There is no significant difference in maize postharvest management perceptions and practices, *Fusarium* spp infestation and fumonisins contamination between Rift Valley and lower Eastern regions of Kenya

1.5 Research questions

1) What are the perceptions and level of knowledge of and attitude towards post-harvest handling and storage of maize by farmers in the Rift Valley and lower Eastern regions of Kenya?
2) What are the post-harvest handling and storage practices of maize by farmers in the Rift Valley and lower Eastern regions of Kenya?
3) What are the *Fusarium* species found in stored maize in Rift Valley and lower Eastern regions of Kenya?
4) What are the levels of fumonisin contamination of maize samples from the Rift Valley and lower Eastern regions of Kenya?

1.6 Objectives

1.6.1 Broad objective

To determine post-harvest knowledge, perceptions and practices by farmers and diversity of fusarium species and fumonisin contamination of maize from Rift Valley and Lower Eastern Regions of Kenya.

1.6.2 Specific objectives

1) To determine the perceptions and level of knowledge of and attitude towards post-harvest handling and storage of maize by farmers in the Rift Valley and lower Eastern regions of Kenya.
2) To determine the post-harvest handling and storage practices of maize by farmers in the Rift Valley and lower Eastern regions of Kenya.
3) To assess the diversity of fusarium species from stored maize samples in Rift Valley and lower Eastern regions of Kenya
4) To determine the fumonisins concentration level in stored maize samples from the Rift Valley and Lower Eastern regions of Kenya

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Agriculture is the economic backbone of most sub-Saharan Africa (SSA) countries and contributes greatly to the Gross Domestic Product (GDP) of these countries while at the same time providing employment to many residents (AGRA, 2017). Maize serves as a staple food in many of these countries with 90% of the Kenyan population depending on it. In Kenya, annual per capita consumption of maize and maize products is 77 kg (FAO, 2011). Heavy post-harvest loss of the crop during storage has been a big challenge. Maize is susceptible to pests, insects and fungal infestations leading to mycotoxin contamination including aflatoxin and fumonisins (Hell & Mutegi, 2011; Tefera *et al*., 2011).

Fumonisins are produced by the *Fusarium* species and causes known health hazards. The most toxigenic and predominant form produced by *Fusarium moniliforme*, is fumonisin B_1 (FB_1) which together with fumonisin B_2 (FB_2) are responsible for about 70% of all fumonisins found in nature and food. Fumonisin B_1 has been classified by the International Agency for Research on Cancer (IARC) as a Group 2B possible carcinogen to humans (Becker-algeri *et al.,* 2016). They occur worldwide and are found predominantly in maize and in maize-based animal feeds (Voss *et al.,* 2007). Animal and human health problems related to these mycotoxins are almost exclusively associated with the consumption of contaminated maize or its derivatives (Becker-algeri *et al*., 2016). There exists a gap on information regarding fumonisin contamination of maize in Kenya. This study provides data on farmers' postharvest practices, *Fusarium* infestation and fumonisin contamination of maize in Kenya.

2.2 Farmers' maize post-harvest perceptions and practices

Several studies have shown varied levels practices on the post-harvest handling and storage of maize. A study by Mendoza *et al*., (2017) involving 280 participants in Guatamala found that 88% of the interviewed farmers prefer to dry the maize cobs after harvest by laying them in stacks exposed to direct sunlight. The harvested maize was stored together with those purchased from the market until consumption. Among the storage practices, 62% of surveyed families store the maize as shelled kernels, while 38% store them as cobs. When storing shelled maize, bags were the preferred storage facilities among 81% of farmers, while only 14% use metal silos. Among farmers who stored maize as cobs, 74% used the *tapanco* (space which is above the kitchen and below thatched roof) as the preferred storage structure. The same study found out that 41% of the farmers indicated storing the maize for at least 4 months. During the storage time, 61% of farmers performed grain quality checks once a week. Moreover, 65% perform pest control during storage. However, in most cases, the control methods applied was not preventive but corrective. According to the study, 49% of the farmers reported that the main cause of maize loss between harvest and consumption was the improper drying of grains leading to high moisture content that eventually led to insect and fungal infestation.

In Tanzania, an assessment of post-harvest practices among 333 farmers noted that poor knowledge and skills by the farmers on post-harvest management are largely responsible for the food losses. The study reported that 77% of the surveyed farmers had inadequate household foods and 41% received food aid during the previous year (Abass *et al*., 2014).

This study suggested that increasing farmers' technical know-how on adaptation of the farming systems to climate variability, and training on post-harvest management could reduce food losses ultimately reducing poverty levels and household food insecurity. It found that farmers carried out drying, dehulling, sorting, shelling and winnowing processes manually mostly by women before storage. In the case of shelling, pickets

were used for thrashing the maize cobs. Pre-harvest handling of maize involved mainly leaving the crops on the field to fully mature, ripen and/or dry. After maturity, ripening or field drying, basic harvesting and processing methods were used for de-hulling, sorting, shelling and winnowing. Although every farmer in this study did some cleaning or processing to transform the farm outputs into various products, only 65% of the surveyed farmers claim to have been involved in processing.

In Uganda, a qualitative study using Focus Group Discussions involving 54 participants by Tibaingana *et al*., (2018) showed that smallholder maize farmers use eight different storage types acquired either through purchase, construction or donation. These storage types included use of sacks, granaries, pots, old Jerry-cans, closed crib made of poles, storage above the fire. The majority used sacks, followed by granary and very few smallholder farmers used pots. The same study found out that the poor nature of storage demonstrated the need to increase extension services. It reported further that poor storage exposed farmers to a number of drawbacks. The cost of acquiring the storage type varied according to the type, size and location. Farmers used these storage types due to accessibility, flexibility, affordability, and ancestral attachment.

A study to assess the post-harvest maize management by small-scale farmers in Kisumu County in Kenya, 33.3% of the 120 farmers reported drying their maize by stoking and leaving them standing in the field until it dried, (41.7%) dried it on concrete floors and plastic sheets, and the minority (25%) dried it by spreading it on bare grounds. Drying maize on bare grounds exposes the grain to soil contamination, domestic animals and bad weather causing both quality and quantity losses. In the same study, (60%) had no knowledge to test for moisture content in maize while only (40%) knew how to test moisture levels using traditional methods (Dudi, 2014).

Out of those farmers who knew how to test maize for moisture content only (15%) tested their maize before storage, the remaining farmers did not and stored their maize with very high moisture content that exposed them to moulding and fungal attacks. According to the study, majority (70%) of the farmers stored their maize in the living room, and

(50%) stored their maize in cribs. This study also found that the use of traditional granaries was not popular among the interviewed farmers due to the issue of insecurity in the area. Most farmers were not using insecticides exposing their maize to storage pests' attack. Storage losses caused by leaking roofs made maize to have mould infection rendering it unfit for human consumption. The broken stores exposed maize to rodents' attack making it not safe for human consumption. Due to insecurity, farmers shifted from storing their maize from granaries to their living rooms. However, due to human activity in the living rooms, where the relative humidity is usually high, predisposing the grain to both storage pests and fungal infestation (Dudi, 2014).

In another study in Kenya where Ognakossan *et al*., (2016) investigated maize storage systems and post-harvest losses in six different maize growing Agro-ecological zones among 630 farmers, they found that the proportion of farmers who did not apply any measures to control insects or rodents varied from one Agro-ecological zone to another. All the farmers in the Highland tropical (HLT) zone applied insect control methods to maize stored as cobs, specifically insecticides and indigenous treatments while about half of the farmers in the Moist Transitional (MT) zone did not apply any measures. For rodent control and management, 70% of farmers in all the AEZs except HLT and MT zones applied some form of control measures; only 50% of farmers in HLT zone and less than 25% in the MT zone applied some control measure against rodents during cob storage. Overall, 33% and 26% of the farmers who stored their maize as cobs did not apply any methods against insects and rodents, respectively. This study also found out that in shelled maize grain storage, over 92% of the farmers in Dry Mid-Altitude (DMA), Dry Transitional (DT), HLT, MT and Moist Mid-Altitude (MMA) zones applied some form of protection to counter insects whereas about a third of the farmers in Low Land Tropical (LLT) zone did not apply any methods to control insects. Overall, only 7% of the farmers surveyed across the zones failed to apply any methods to counter insects when the maize was stored as shelled grain. Over 88% of farmers in LLT, MT and MMA applied some form of rodent control methods in shelled maize while 30% of the farmers in DMA zone and HLT did not apply any control methods. Overall, about

15% of farmers who stored maize as grain did not apply any technology to counter rodent infestation.

A study on insects control among farmers in Kenya, Ognakossan, (2017) reported that the use of pesticides was the main method used to control insects and rodents across the country. Synthetic insecticides used included *Actellic Super* dust, *Actellic Gold* dust powder, *Skana Super* grain dust, and *Super Malper* dust. Apart from synthetic insecticides, other methods used were application of cow dung, wood ashes, plant leaves, exposure to sun, mixing with hot pepper, smoking, grain treatment with boiled water, and storage in hermetic plastics bags and metal silos. The hermetic plastic bags used were the Purdue Improved Crop Storage (PICS) triple-layer bags. The rodenticides used included Red Cat powder and Rat Kill (*Brodifacoum* and *Baraki* Pellets). Farmers in all the agroecological zones also kept cats, and used traps and baits for rodent control. Some farmers reported hunting to mitigate rodent attack. Generally, all the farmers interviewed reported that they removed the old maize stocks and cleaned their stores before loading the new harvest.

According to a study by Kang'ethe *et al*., (2017), out of the 280 respondents from Makueni and 261 from Nandi County, 60.7% from Makueni and 72.4% in Nandi dried their maize on canvas while 55.4% from Makueni and 49.0% from Nandi stoked their maize for drying before harvesting. This was reported to increase the risk of fungal infection and aflatoxin contamination. The same study noted that the process of maize shelling in the two areas under study was mainly manual with the maize on cobs being placed in sacks and thrashed as was practiced by 76.8% of the farmers from Makueni and 52.1% from Nandi. This method has been noted to be inappropriate due to the high damage caused to the maize kernel that in turn made it easy for fungal infestation.

On insect control methods, 75.9% and 75.1% in Makueni and Nandi respectively used chemicals to control storage pests on their maize. According to Chan Ben *et al*., (2009), hermetic improved bags and metallic bags are some of the improved storage facilities that are used for the storage of small quantity of cereals by farmers in Vietnam. The

hermetic bags are designed in such a way that they have an inner lining that is impermeable to oxygen which create unfavourable environment for insect attach and fungal growth.

Majority of the respondents in the study by Kang'ethe *et al*., (2017) reported that feeding mouldy maize to animals was linked to reduced milk production and quality, health challenges to the livestock and reduction in weight. The study further reported that 59% of the respondents fed mouldy maize to their livestock while 15% reported that it was utilized in the preparation of the local brews (*changaa* and *busaa*). A good number (54.1%) considered milk obtained from animals fed on mouldy maize to be safe for human consumption of which majority were from Nandi County (75.1%) compared to 24.9% from Makueni County. This was noted to be an indicator of low level of awareness of transmission of aflatoxin and other mycotoxins in the food chain hence the potential effects it poses to the consumers. More than half (52.4%) of the farmers in the same study consumed mouldy maize regardless of the level of moulding. Farmers gave several reasons for this practice of consuming mouldy maize including unavailability of a substitute for the spoiled maize, no great changes in smell and colour, the maize was not bitter and that not all the maize was spoiled. The study reported that most of the farmers in both Makueni and Nandi did not have the necessary knowledge on the risks associated with consuming mouldy maize and most did not understand that it might be contaminated with aflatoxin and fumonisins.

Hence, it was concluded that there was need for awareness creation on aflatoxins and fumonisins contamination of maize and ways of preventing and controlling this contamination. Makueni County lost approximately 7.5% of their maize produce to moulding translating to Kes 1, 667 per household while Nandi County lost 6.8% representing Kes 2, 856 per household each season.

2.3 *Fusarium* species diversity in maize

Different *Fusarium* species have been associated with maize infestation and fumonisin contamination. These species include *F. verticillioides, F. proliferatum, F. nygamai, F. anthophilum, F. dlamini, F. napiforme, F. thapsinum,* and *F. globosum* (Fandohan *et al*., 2003) with *F. verticilliodes* and *F. proliferatum* being the main fumonisin producing species globally. This was also the case with the limited available studies in Africa on *Fusarium* in maize where *F. verticillioides* has been reported as the most prevalent species in maize samples (Atukwase *et al*., 2012; Kedera et al., 1999; Marasas, 1988).

2.3.1 *Fusarium* species diversity globally

In Brazil, a study assessing maize samples from 23 municipalities for two growing seasons between 2008 and 2010 found that *Gibberella fujikuroi* Fusarium complex was isolated in 96% of the samples tested with *G. zeas* being found in 5 of the 27 samples (18%). *G. fujikuroi* had a mean incidence of 58% while the incidence of *G. zeae* ranged from 2% to 6%. Molecular characterization of 104 isolates of *Fusarium Spp* using PCR grouped the isolates into three species of *G. fujikuroi* complex which included; *F. verticillioides* (76%), *F. subglutinans* (4%) and *F. proliferatum* (2%); and *G. zeae* (anamorph of *F. graminearum*) (18%) (Stumpf *et al*., 2013).

Lanza *et al*., (2014) also assessed the prevalence of fumonisin-producing *Fusarium* species in maize in Brazil. The study found that *F. verticilliodes* was the most prevalent species (99%) while *F. proliferatum* was incidental in nature with varying prevalence.

In a study in china on *Fusarium* isolates causing kernel and maize ear root, *F. verticillioides, F. proliferatum* and *F. meridionale* were found to be the most common fungal species from the 116 *Fusarium* species isolates identified (Zhou *et al*., 2018).

A study in Poland spanning two years involving maize kernel of three maize hybrids from 10 locations, Czembor *et al*., (2015) found that 25.24% of the kernels had *Fusarium spp*. with 424 *Fusarium* strains isolated, *F. verticillioides* (272 isolates) and *F.*

temperatum (81 isolates) were found to be the most prevalent *Fusarium* species. The frequency of *F. temperatum* and *F. subglutinans* was positively correlated with the amount of rainfall. On the other hand, the mean temperature in the month of July negatively affected the *Fusarium* spp. frequency.

In another study in Poland, four different *Fusarium* species were found in pre-harvest maize ear rot for the period 2013/2014. The species isolated included *F. verticillioides, F. poae, F. graminearum,* and *F. subglutinans*. From 1985 to a period covering 13 seasons, 11 different *Fusarium* species were identified in maize that consisted of *F. verticillioides, F. poae, F. graminearum, F. subglutinans, F. proliferatum, F. tricinctum, F. equiseti, F. avenaceum, F. cerealis, F. culmorum* and *F. sporotrichioides*. However, the frequency of each species was varied. The study reported that there was a significant increase in frequency of *F. verticillioides* and changes in mycotoxins profile identified over the period (Gromadzka *et al*., 2016).

In a related study by Gromadzka *et al*., (2019) on the causal agents of pre-harvest *Fusarium* maize ear rot in Poland, six different fusarium species were observed from the 42 isolates identified, with 34 of the isolates being *F. temperatum* and five being *F. subglutinans.*

In Spain, *F. verticillioides* was the most prevalent *Fusarium* species in maize kernel followed by *F. proliferatum* (Aguín *et al*., 2014; Ariño *et al*., 2007; Butrón *et al*., 2006; Jurado *et al*., 2006). In the study by Aguin *et al*., (2014), nine different species of *Fusarium* species was reported to have been isolated in maize samples. Samples from all the 24 locations had five species of Fusarium that included *F. verticillioides, F. proliferatum, F. subglutinans sensu lato, F. oxysporum* and *F. poae.* In all the locations, *F. verticillioides* was the most prevalent ranging from 33% to 99% in the different locations. The second most prevalent *Fusarium* species was *F. subglutinans sensu lato* complex consisting of *F. begoniae* and *F. sterilihyphosum* species with a prevalence ranging from 1% to 27% in the different locations. Other species identified were not more than 4% in any of the different environmental locations and consisted of *F.*

proliferatum, F. oxysporum, F. poae, F. solani, F. cerealis, F. culmorum and *F. equiseti*.

In Iran, 41 maize samples were assessed for *Fusarium* species of which *F. verticillioides* was the most prevalent species followed by *F. proliferatum, F. oxysporum, F. culmorum, F. solani, F. equiseti* and *F. poae*. In total, 1008 isolates were identified of which 60.41% were *F. verticilliodes*, 13.39% *F. proliferatum*, 5.64% were *F. culmorum*, F. *solani* made up 4.17% of the total isolates, *F. equiseti* (1.48%), *F. poae* (1.19%) while other species with a low incidence made up the remaining 5.96%. At harvest stage, *F. verticillioides* occurred with a relative density of 30.35% and frequency of 41.46% and this was highest when compared to other stages (Aliakbari *et al*., 2007).

In Serbia Krnjaja *et al*., (2011) analysed *Fusarium* spp. in maize grain samples of two maize hybrids; late maturity (ZP704) and medium early (ZP434) meant for silage. In the study, four *Fusarium* species including *F. verticillioides* in ZP 704 (30.50%) and (28.63%) in ZP434 hybrids, *F. graminearum* in ZP704 (3.00%) to 5.00% in ZP434, *F. proliferatum* 0.13% (ZP434) to 7.00% (ZP704) and *F. subglutinans* 0.13% (ZP434) to 7.00% (ZP704) were identified. The incidence of each of the *Fusarium* species was found to be higher in late maize hybrid (ZP704) than in medium early hybrid (ZP434) ($P < 0.05$).

In Switzerland, *Fusarium* contamination was examined in maize meant for animal feeds. *Fusarium* species varied between region and year. The prevalence of *Fusarium* species varied from 0.4% to 49.7% in maize kernel and that of maize stem pieces ranged from 24.2% to 83.8%. In the maize kernel, 16 *Fusarium* species were isolated, while in the stem cells, 15 different *Fusarium* species were identified. There was a significance difference in the prevalence and composition of *Fusarium* between stem samples and kernel samples and between samples from south and north ($P < 0.05$). As was the case in many countries, *F. verticillioides* (32.9%) was the main species in the samples from the northern region followed by *F. graminearum* (31.3%), *F. proliferatum* (7.3%) and *F. crookwellense* (7.1%). High diversity in the *Fusarium* species in the region was noted (Dorn *et al*., 2009).

Of the 84 maize samples assessed for *Fusarium* species in Germany, *F. Verticillioides* was the main species identified in the year 2006. The other species isolated in higher proportions were *F. graminearum*, and *F. proliferatum*. In the year 2007, *F. verticillioides* was the main species with *F. graminearum, F. cerealis* and *F. subglutinans* being the other species isolated in higher proportions (Goertz *et al*., 2010).

2.3.2 *Fusarium* species diversity in Sub-Saharan Africa

Various studies in SSA have shown that *F. verticillioides* is the dominant species SSA (Tsehaye *et al*., 2017; Rheeder *et al*., 2016; Mohale *et al*., 2013; Shephard *et al*., 2013a; Atukwase *et al*., 2012; Boutigny *et al*., 2012; Chilaka *et al*., 2012a; Phoku *et al*., 2012; Ncube *et a*l., 2011; Mukanga *et al*., 2010; Alakonya *et al*., 2009; Adejumo *et al*., 2007; Afolabi *et al*., 2006; Fandohan *et al*., 2005; Bankole & Mabekoje, 2004; Gamanya & Sibanda, 2001; Kpodo *et al*., 2000). All the samples tested positive for *F. verticilliodes* in the study by (Shephard et al., 2013a), 89.3% (Bankole & Mabekoje, 2004) and 88% (Chilaka et al., 2012a). Other studies where the prevalence of *F. Verticilliodes* was high included Atukwase *et al*., (2012) 61.9%-77.5% and Phoku *et al*., (2012). Other common *Fusarium* species that were identified in maize samples in the different studies in SSA are *F. proliferatum* with a prevalence of 73% (Chilaka *et al*., 2012a), 31% (Fandohan et al., 2005), 18.5% (Phoku et al., 2012) and 22.5% (Tsehaye et al., 2017).

Other *Fusarium* species have been identified in different SSA countries but at low prevalence includes *F. oxysporum* (Tsehaye et al., 2017; Phoku et al., 2012), *F. subglutinans* (Tsehaye *et al*., 2017; Mohale *et al*., 2013; Shephard *et al*., 2013a; Boutigny et al., 2012; Ncube *et al*., 2011; Alakonya *et al*., 2009;) and *F. psuedoanthophilum* (Tsehaye *et al*., 2017), (Table 2.1).

According to a study by Ncube *et al*., (2011) in South Africa, *F. verticillioides* was also found to be the most prevalent *Fusarium* species in maize samples collected from subsistence farmers covering two growing seasons. This was followed by *F. subglutinans* and *F. proliferatum*.

Atukwase *et al*., (2012) found that in Uganda, the *Fusarium* incidence was significantly reduced from the second month of storage to the sixth month of maize storage (77.5% - 31.9%) ($p < 0.05$). Increase in moisture was also significantly associated with *Fusarium* level reduction ($r = -0.68$, $p < 0.01$). Likewise, Fandohan *et al*., (2005) found the incidence of *Fusarium* being significantly higher when maize was stored on a cemented floor in a house, and in a non-ventilated facility as compared to well ventilated storage systems ($p < 0.05$). There was low *Fusarium* incidence in maize stored in well ventilated bamboo granary ($p < 0.05$). Insect damage to the grains was associated with high *Fusarium* incidence with a positive correlation being observed ($r = 0.802$, $p < 0.01$).

Murithi (2014) found that *Fusarium* was the main species isolated from the samples collected from 30 different markets in Kitui, Machakos and Meru counties. This was followed by *Aspergillus* species. Kitui had the highest isolation of *Fusarium spp.* followed by Meru and Machakos respectively. *F. verticillioides, F. proliferatum* and *F. oxysporum* were isolated in all the regions with *F. verticillioides* being the most frequently isolated species while *F. oxysporum* was the least isolated in all the regions.

In a study by Bii *et al*., (2012), *Fusarium* and fumonisin contamination were evaluated in 86 stored maize samples. Maize samples were collected from selected farmers in aflatoxin 'hot' spots of Eastern province in Kibwezi and Kitui districts. *F. verticillioides* was found to be the predominant species isolated at (39.9 %) in the two districts.

A total of 32 *Fusarium* isolates were recovered from 30 samples of the 86 maize grain samples in which six *Fusarium* species were identified as *F. verticillioides* (39.9 %), *F. proliferatum* (15.1 %), *F. lateritium* (12.1 %), *F. anthophilum* (9.0 %), *F. oxysporum* (15.1 %) and *F. solani* (9.0 %).

2.4 Fumonisin levels in maize

Fungal infestation of maize does not automatically cause the production of fumonisins (Fandohan *et al*., 2003). Contamination of maize by fumonisin is dependent on several

factors including host susceptibility and environmental factors, that determine the severity and incidence of mycotoxins contamination (Bii *et al*., 2012).

The level of Fumonisin has been found to vary from country to country and from one region to another in the same country (Hove *et al*., 2016; Mwalwayo & Thole, 2016; Nyangi *et al*., 2016; Mutiga *et al*., 2014; Boutigny *et al*., 2012; Ncube *et al*., 2011; Mukanga *et al*., 2010; Adejumo *et al*., 2007). It also varies with the season and period of the year (McLaren, & Flett, 2017; van Rensburg *et al*., 2015; Boutigny *et al*., 2012; Fandohan *et al*., 2005)

The level of rainfall and humidity has also been shown to influence fumonisin levels (Tsehaye *et al*., 2017; van Rensburg *et a*l., 2017; van Rensburg *et al*., 2015; McLaren *et al*., 2015; Atukwase *et al*., 2012; Mukanga *et al*., 2010). Tsehaye *et al*., 2017 showed a positive significant correlation between high humidity and fumonisin levels ($r = 0.521$, $p = 0.018$). Atukwase *et al*., (2012) found that high moisture content was positively correlated with fumonisin levels ($r = 0.57$, $p < 0.01$) while Mukanga *et al*., (2010) found that rainfall severity was positively correlated with level of fumonisin $r = 0.65$ (p-value < 0.01).

Another environmental factor that has been associated with fumonisin levels is temperature (Tsehaye *et al*., 2017; van Rensburg *et al*., 2017; van Rensburg *et a*l., 2015; Fandohan *et al*., 2005). According to Tsehaye *et al*., 2017, there was a significant positive correlation between fumonisin concentration with temperature recorded in the growing season ($r = 0.533$, $p \leq 0.016$), and temperature recorded for the storage period ($r = 0.518$, $p \leq 0.019$).

Some of the post-harvest maize handling practices has also been associated with fumonisin contamination. According to Hove *et al*., (2016), higher mean fumonisin contamination was observed in maize transported as cobs in Zimbabwe. Mean FB_1 = 401 µg/kg and 263 µg/kg (0.401 ppm and 0.263 ppm), when maize on cobs were transported without polypropylene bags and in polypropylene bags respectively and as

grain (mean FB_1=181 μg/kg [0.181 ppm]). Regarding FB_2, higher contamination was observed in maize transported from the field as grain without polypropylene bags than as grain in polypropylene bags (mean FB_2 =149 μg/kg and <LOD respectively [0.149 ppm and <LOD respectively]).

Storage of maize after harvesting has also been shown to be associated with fumonisin levels. Maize stored in traditional structure called *tau* and traditional mud silos had higher levels of fumonisins at 3.4 μg/kg (0.034 ppm) and 3.5 μg/kg (0.035 ppm) respectively compared to maize stored in granaries at 1.61 μg/kg (0.0161 ppm) ($p < 0.05$) after six months of storage (Atukwase *et al*., 2012).

Some maize handling practices have also been shown to influence fumonisin levels. Sorting of maize before storage was associated with low fumonisin levels (Kamala *et al*., 2016; Mutiga *et al*., 2014). According to Mutiga *et al*., (2014) sorting of maize after harvesting reduced fumonisin contamination by 65%. Methods of drying and storage were also shown to influence fumonisin level. In a study by Kamala *et al*., (2016) in Tanzania, the likelihood of contamination was high with respect to drying maize on the bare ground (OR = 3.2; 95% CI = 1.02– 10.01), storing unsorted maize (OR = 3.8; 95% CI = 1.49–9.75) or storing maize without applying insecticides (OR = 2.57; 95% CI = 1.01–6.53) ($P < 0.05$).

Farmers' knowledge of mycotoxins was found to be significantly associated with level of fumonisin contamination. High level of mycotoxins awareness by farmers was associated with low fumonisin contamination levels (Nyangi *et al*., 2016). Variety of maize was also shown to be significantly associated with fumonisin levels where some varieties were more contaminated with fumonisins than others (Mutiga *et al*., 2015).

2.4.1 Fumonisin levels globally

Several studies have been carried out in Brazil on fumonisin contamination in maize. In Minas Gerais region of Brazil, all the 40 maize samples tested were positive for

fumonisins contamination with the level ranging between 230 µg/kg (0.23 ppm) to 6,450 µg/kg (6.45 ppm). Thirty three of these samples had fumonisin levels of more than 1000 µg/kg (1 ppm) (Queiroz *et al*., 2012).

In an assessment of industrial maize-based food products in Sao-Paulo, Brazil, FB_1 levels of more than 30 µg/kg (0.03 ppm) were found in 47 of the 72 samples (Savi *et al*., 2016). In Southern region of Brazil, FB_1 and FB_2 were detected in all the 148 maize samples analyzed while 98.6%, 97.9% and 8.1% of the samples contained FB_3, FB_4 and FB_6 respectively (de Oliveira *et al*., 2011).

In another study in Brazil, FB_1 was detected in 58.6% of the samples, FB_2 in 37.9% of the samples and both FB_1 and FB_2 were detected in 37.9% of the samples. Of the samples, 41.3% had FB_1 and FB_2 that were below the level of detection. The mean level of FB_1 was 0.66 µg/g (0.66 ppm) while that of FB_2 was 0.42 µg/g (0.42 ppm) (Stumpf *et al*., 2013). In a study by Lanza *et al*., (2014), all the 50 analyzed samples in Brazil were positive for fumonisins with the levels ranging from 0.01 to 2.39 µg/g (0.01- 2.39 ppm).

According to a study conducted by Rosa *et al*., (2019) assessing fumonisin production by *Fusarium verticillioides* in Maize grown in different areas of Brazil, most of the samples showed levels of fumonisin B_1 that were considered to be higher than tolerable if destined for human consumption in corn products, with the tolerance limit for fumonisin currently being 1.5 µg/g (1.5 ppm). Approximately 70% of samples from the municipality of Gurupi, presented fumonisin B_1 (FB_1) and 40% of the samples had levels of fumonisin B_2 (FB_2) that were considered higher than tolerable if intended for human consumption. Contamination of grains by fumonisin mycotoxin occurred even in symptomatic or asymptomatic grains.

In china, FB_1 was detected in 47 *F. verticillioides* isolates and 19 *F. proliferatum* isolates out of the 116 different *Fusarium* species isolates. *F. verticillioides* and *F. proliferatum* isolates were reported to result in the production of FB_1 mainly with an average of 263.94 µg/g and 3,632.88 µg/g (263.94 ppm and 3,632.88 ppm) respectively

and a range of 3,170 to 1,566,440 µg/kg (3.17 ppm to 1,566.44 ppm), and 97740 to 11,100,990 µg/kg (97.74 ppm to 11,100.99 ppm) for each gram of dry hyphal weight in that order. These results in China showed that *F. proliferatum* isolates were responsible for production of more fumonisins when compared to *F. verticillioides* (Zhou *et al*., 2018). In Poland, FB_1 was detected in all the samples tested (Czembor *et al*., 2015).

2.4.2 Fumonisin levels in maize in Sub-Saharan Africa

Various studies in SSA reported varying prevalence of fumonisins in maize (Mutiga *et al*., 2014; Shephard *et al*., 2013a; Atukwase *et al*., 2012; Chilaka *et al*., 2012a; van der Westhuizen *et al*., 2010; Alakonya *et al*., 2009; Afolabi *et al*., 2006; Fandohan *et al*., 2006; Sangare-Tigori *et al*., 2006; Fandohan *et al*., 2005; Nikiema *et al*., 2004; Gamanya & Sibanda, 2001; Kpodo *et al*., 2000). The number of fumonisin positive samples in most of the studies were above 50% except in three studies by (Mngqawa *et al*., 2016) where only 47% of the samples from one of the two districts in South Africa were positive, (Nyangi *et al*., 2016) where 35% positive samples were fumonisin positive.

The level of fumonisin varied from one study and country to another with some samples having high levels than recommended. The highest mean fumonisin level of 8,819 µg/kg (8.819 ppm) was observed in the study by Phoku *et al*., (2012). Fumonisin B_1 levels were higher than Fumonisin B_2 and B_3 in studies where the three were differentiated (Murashiki *et al*., 2017; Hove *et al*., 2016; Shephard *et al*., 2013a; Boutigny *et al*., 2012; Kimanya *et al*., 2010; Ngoko *et al*., 2001) [Table 2.4.2.1]. In South Africa, a study of two cultivars of maize from 14 different locations reported an average fumonisin level of 2,542 µg/kg (2.542 ppm) with a maximum fumonisin level of 16,717 µg/kg (16.717 ppm) (Boutigny *et al*., 2012).

The range of fumonisins in Kitui and Machakos in Kenya was reported to be between 20 ng/kg to 550 ng/kg (0.02 µg/kg to 0.55 µg/kg) while all the areas of Meru had fumonisins levels ranging from 1139 ng/kg to 2008 ng/kg (1.139 µg/kg to 2.008 µg/kg) which was above the acceptable limits (Murithi, 2014).

In another study in Kenya, a high level of mean fumonisin contamination was detected in the maize samples from Makueni (1.17 ± 0.085) µg/kg, compared to Kitui (0.912 ± 0.134) µg/kg. Most of the samples exceeded 1 µg/kg the maximum tolerable levels recommended by the European commission (Bii *et al*., 2012).

Table 2.1: Studies on Fusarium and fumonisins in Sub-Saharan Africa

No	Author	Country	Sample Size	Study Design	*Fusarium*	Fumonisin Mean	Fumonisin Range	Positives	Quantification Tech
1	Hove *et al.*, 2016	Zimbabwe	95	cross-sectional	-	FB1=242µg/kg FB2= 120µg/kg FB3= 57 µg/kg	FB1=nd-1106 µg/kg FB2=nd-334 µg/kg FB3=nd-67µg/kg	FB1=95% FB2= 31% FB3=3%	multi-mycotoxin LC-MS/MS method
2	Phoku *et al.*, 2012	South Africa	54	cross-sectional	*F. verticilliodes* (70.3%) *F. oxysporum* (25.9%) *F. proliferatum* (18.5%) *F. sambucinum* (3.7%) *F. poae* (3.7%) *F. graminearum* (3.7%) *F. dimerum* (1.8%)	8,189 µg/kg	101-53863 µg/kg	49 (72%)	HPLC
3	Rensburg *et al*., 2014	South Africa		Control Trial	-	-	-	-	HPLC
4	Westhuizen 2010	South Africa	60	cross-sectional	-	HG-Bizana 0.495 µg/kg HG-Centane 0.665 µg/kg COM0.370	nd-3.975 µg/kg 0.040-1.980 µg/kg 0.005-	25 15 20 (100%)	HPLC

						µg/kg	1.580µg/kg		
5	Nyangi *et al.*, 2016	Tanzania	440	cross-sectional	-	5.15 µg/kg	0.40–46.00 µg/kg	35%	ELISA
6	Adetuniji *et al.*, 2014	Nigeria	70 HF–4, SS–11, NGS–11, SGS–11 and DS–33.	cross-sectional	-	SS= 694.25 ng/g) NGS= 2,979.50ng/g SGS= 2,675.01 ng/g DS= 2,153.71ng/g HF= 6,923ng/g	-	-	HPLC
						B2 114 µg/kg	53- 230 µg/kg	66%	HPLC
7	Boutigny *et al.*, 2012	South Africa	45	cross-sectional	*F. graminearum*, *F. verticillioides* and *F. subglutinans*	B1 =1793ng/g B2= 749 ng/g	FB1=1793-11624ng/g FB2=749-5093ng/g	FB1= 62% FB2= 57%	HPLC
8	Shephard *et al.*, 2013	South Africa	GQ=54 Mouldy= 38	Cross-sectional	*F. verticillioides* in all samples, *F. proliferatum* in 1 sample, *F. subglutinans* and *F. graminearum* sensu lato in 46 samples,	GQ FB1=2,083 µg/kg FB2=927 µg/kg Mouldy FB1 =27.64 µg/kg FB2=35.98 µg/kg	FB1=56 14990µg/kg FB2=38 6444µg/kg Mouldy FB1=514 190100 µg/kg FB2=222 64840µg/kg	– 100% – – 100%	HPLC
9	Rheeder *et al.*, 2016	South Africa	211	cross-sectional	*F. verticillioides* Centane 16% for both	Centane 1997=575 µg/kg 2000=975 µg/kg 2003=	Centane (nd - 7185) (nd - 7965) (nd - 8385)	Centane 38/40 37/41 23/24	HPLC

					1997 & 2000, 2003- Mbizana 2000- 20003- *F. subglutinans* *F. graminearum*	2,150 µg/kg 32% 17% 11%	Mbizana 2000= nd – 6410 µg/kg Mbizana 2000= 950 µg/kg, 2003= 610 µg/kg	Mbizana 2003= nd - 6645 µg/kg Mbizana 40/41 21/36	
10	Mohale *et al*., 2013	Lesotho	40	cross-sectional	*F. verticillioides*, *F. proliferatum* and *F. subglutinans*	-	FB1 2.24 -- 935.7µg/kg, FB2 ranged from nd-10.5 µg/kg FB3 nd- 67.2. µg/kg		HPLC
12	Tsehaye *et al*., 2016	Ethiopia	200	cross-sectional	*F. verticilliodes* species (42%), *F. graminearum* (22.5%), *F. psuedoanthophilum* (13.4%), *F. oxysporum* (7.5%). Other species identified included *F. incarnatum*, *F. brevicatenulatum* and *F. temperatum*, *F. equiseti*, *F.*	348 µg/kg	25-4500 µg/kg	77%	(ELISA) kits (RIDASCREEN®Fumonisin, R-Biopharm AG, Darmstadt, Germany)

					subglutinans, and *F. Larcetarum*.				
13	Mogensen *et al*., 2011	South Africa	400	cross-sectional	-	GQ	0.28-1.1 mg/kg	-	HPLC
					-	BQ	0.03-6.2 µg/kg	-	
14	Murashiki *et al*., 2016	Zimbabwe	388 (Shamva 166, Makoni, 222)	cross-sectional	-	-	Shamva FB1=10.43 µg/kg - 432.32µg/kg Makoni FB1= 13.84 µg/kg - 606.64 µg/kg		EuroProxima™ ELISA kits.
15	Ncube *et al*., 2011	South Africa	261	cross-sectional	*F. verticillioides F. subglutinans* and *F. proliferatum*	-	0-21.8 µg/g	-	Veratox enzyme-linked immunosorbent assay (ELISA) quantitative fumonisin 5/10 test kit (Neogen Corp, Lansing, MI, USA
16	Atukwase *et al*., 2012	Uganda	12	Cross-sectional	*Fusarium* incidence 61.9%-77.5%	-	1.46 - 5.96 µg/kg	12 (100%)	Flouremeter method (vicam method
17	Mukanga 2010	Zambia	114	Cross-sectional	*F. verticillioides* (2 - 21%), *F, graminearum*	-	-192 ppm	-	CD-ELISA (AgraQuant Assay, Romer Labs).
18	Mwalwayo, 2016	Malawi	90	Cross-sectional	-	0.9 µg/kg	nd -7 µg/kg	76	Reveal Accuscan III Reader System (AS 5130,Neogen®Corporation , Lansing, MI, USA (Reveal Q+)
19	Kamala *et al*., 2016	Tanzania	120	Cross-sectional	-	-	49-18273 µg/kg	85%	HPLC

20	Alakonya *et al*.,2009	Kenya	12	Cross-sectional	*F. verticilliodes*, *F. graminearum*, and *F. subglutinans*	-	22 - 1348 µg/kg	100%	ELISA
21	Mutiga *et al*., 2016	Kenya	233	Cross-sectional	-	1.9 ppm	-	87%	ELISA kit
22	Mutiga *et al*., 2014	Kenya	624	Cross-sectional	-	-	Meru central=2,040–>6,000ppb Mwala= 842–4,809ppb Meru north= 2,300–>6,000ppb Meru south= 1,596–>6,000ppb Mwingi= 2,562–>6,000 Kitui= 1,459–>6,000ppb Mbeere= 1,711–>6,000ppb Embu= 1,300–>6,000ppb Machakos= 974–>6,000ppb Kathiani= 1,346–3,679ppb	100%	ELISA kit
23	Mngqawa *et al*., 2015	South Africa	114 District 1=52 District	Cross-sectional	-	-	District1-12 to 8514 µg/kg District2-11–18924 µg/kg	92%	HPLC

			2=62					47%	
24	Rensburg *et al*., 2017	South Africa	6 maize cultivars	Control –trial	-	-	-	-	HPLC
25	Chikala *et al.*, 2012	South Africa	40	Cross-sectional	*F. verticillioides* (88%) and *F. proliferatum* (73%)	455ppb	64 - 1035 ppb	40 (100%)	thin layer chromatography (TLC) and high performance liquid chromatography (HPLC)
26	Kimanya *et al.*, 2010	Tanzania	191	Cross-sectional	-	-	21-3201 µg/kg	131 (69%)	HPLC

2.5 Conceptual Framework

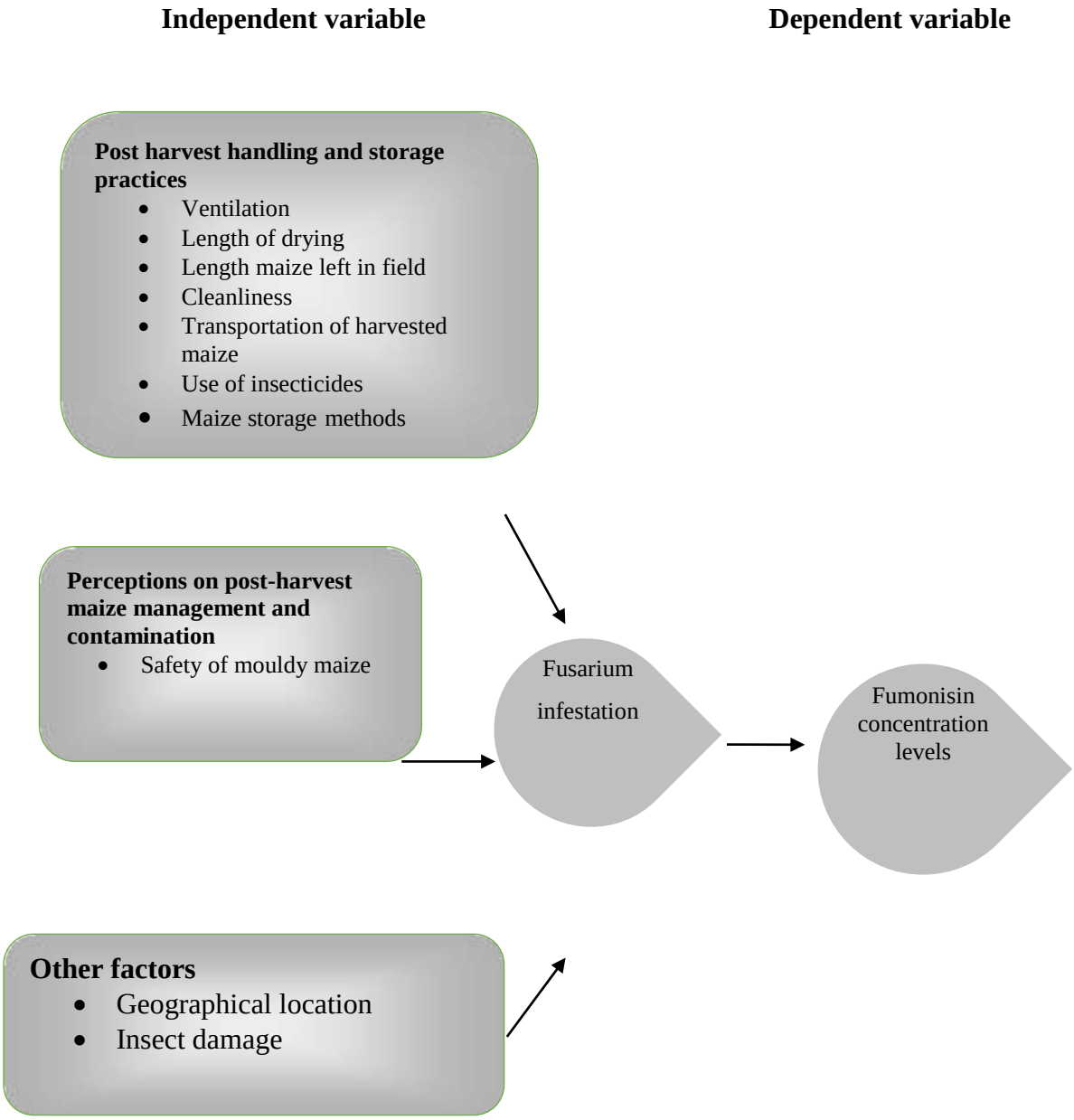


Figure 2.1: Conceptual Framework

Conceptual Framework on the determinants of Fusarium species infestation and Fumonisins production in Maize

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study sites

The study was carried out in Rift Valley (Bomet, Nakuru and Trans-Nzoia Counties) and Lower Eastern regions of Kenya (Makueni, Machakos and Kitui Counties). The Rift Valley region was selected as it is considered the grain basket of Kenya while Lower Eastern region was selected due to the high reported cases of aflatoxin in the region (Daniel *et al*., 2011) hence being considered an aflatoxin "hotspot".

3.1.1 Rift valley region

Bomet County had a total population of 875,689 persons constituting: 434,287 males, 441,379 females and 23 intersex with an annual growth rate of 2.7%. It covers an area of 2,530.9 km^2 with a population density of 346 persons per km^2. The County has 5 sub counties and 25 electoral wards. The average temperatures is 18^{O}C monthly and rainfall ranges between 1100 mm to 1500 mm per annum. Agriculture is the economic activity in most of Bomet County with tea being the major source of income for Bomet residents. The dairy industry is the other major revenue earner contributing a significant household income boosted by a milk factory in Sotik town and several milk cooling plants spread across the County. Maize, which is the County's staple food, is the major food crop grown. Other crops cultivated in the area include beans, Irish potatoes, millet, cabbages, onions, bananas and pineapples (KNBS, 2019).

Trans Nzoia County has an area of 2,495 km^2 and had a population of 990,341 people: 489,107 Male; 501,206 Female; 28 Intersex. Its population density is 397 persons per km^2 (KNBS, 2019). The county headquarters are located in Kitale Town.

Trans Nzoia has 5 sub-counties divided into 25 electoral wards. The county is largely agricultural with large scale and small-scale maize, wheat and dairy farming. This

county is fondly referred to as the grain basket of Kenya for its role in grain production in the country. Trans Nzoia has a cool and temperate climate with average annual temperatures ranging between a minimum of 10°C to a maximum of 27°C. It receives annual precipitation ranging between 1000 and 1200 mm, with the wettest months being experienced between April and October (Trans-Nzoia County Integrated Development Plan, 2018-2022).

Nakuru County is located in the Southeastern part of the former Rift Valley Province and has a population of 2,162,202 persons constituting: 1,077,272 Males; 1,084,835 Females and 95 intersex. The number of households is 616,046, with an average of 3.5 persons per household (KNBS, 2019). The County covers an area of 7,462.4 Km^2 with a population density of 290 persons per km^2. Agriculture is the lifeline of the economy of this County as 70% of the 7,462.4 Km^2 of the county's land is arable and highly productive. It is very much possible for farmers in Nakuru County to have two seasons per years as the county has a bimodal rainfall pattern with a high of 1800 mm and a low of 500 mm. Nakuru County usually has long rains between March, April, May and June, while short rains occur between October and November. The County has 11 sub counties with 55 electoral wards (Nakuru County, 2017).

The study was conducted in ten villages within the three Rift valley counties. The sub counties randomly selected were Sotik Sub County in Bomet, Saboti Sub County in Trans-Nzoia and Rongai Sub County in Nakuru. The villages included Chesambai, Kapchumbe, Kaplombe and Kapolesobe in Sotik Sub County; Chepkaitit, Laboot and Sinendet in Saboti Sub-County and Chepseon, Saptet and Waldai in Rongai Sub-County (Table 3.1).

3.1.2 Lower Eastern region

The prevailing local climate in Lower Eastern (Machakos, Kitui, Makueni) is semi-arid and the landscape is hilly, rising from an altitude of 1,000 to 1,600 meters above sea level. The Counties experience bi-modal rainfall that is erratic and unpredictable, which

ranges between 500 mm to 1,300 mm annually. There are two rainy seasons in this region, the long one starting at the end of March and continues to May, while the short rains season starts at the end of October and lasts till December. Temperatures vary between 18˚C and 29˚C throughout the year (KNBS, 2019).

Machakos County has a population of 1,421928 persons with 402,466 households. Machakos County covers an area of 6,042.7 km^2 with a population density of 235 people per km^2. The population constituted 710,707 male, 711,191 female and 34 Intersex persons. It has 8 Sub-Counties and 41 electoral wards. The Sub-Counties include Machakos town, Masinga, Yatta, Kangundo, Kathiani, Matungulu, Mwala and Mavoko (KNBS, 2019). Approximately 60% of total land area in Machakos is arable. Agriculture is the main activity carried out in most of the Sub-Counties. The main cash crops are coffee, mangoes, citrus, French beans, pineapples, flowers, sorghum and vegetables.

The food crops grown include maize, beans, pigeon peas, green grams, cowpeas and cassava which are cultivated in small scale. (Machakos County Integrated Development Plan II, 2018-2022)

Makueni County covers an area of 8,169.8 km^2 with a population density of 121 persons per km^2. The population is 987,653 people constituting 489,691 males, 497,942 females and 20 intersex people. The number of households is 244,669. It has 6 Sub-counties and 30 electoral wards. The Sub-counties include Makueni, Kaiti, Kilome, Kibwezi East, Kibwezi West, and Mbooni (KNBS, 2019).

The County is largely arid and semi-arid and usually prone to frequent droughts. The lower regions receive rainfall ranging from 250 mm to 400 mm while the high regions receive rainfall ranging from 800mm to 900mm. Population growth has put pressure on land available for agricultural use leading to subdivision of land to uneconomical sizes. The resultant pieces of land are small to hardly support commercialized agriculture. The average farm size is 1.2 Hectares (Makueni County Intergrated Development Plan, 2018-2022)

Kitui County's population is 1,136,187 persons, constituting 549,003 males, 587,151 females and 33 intersex. The number of households is 262,942 and the population density is 37 persons per km^2. It has 8 Sub-counties and 41 electoral wards (KNBS, 2019).

The altitude of the Kitui County ranges between 400 m and 1800 m above sea level. Most parts of the County have an arid and semi-arid climate with rainfall distribution that is erratic and unreliable. However, the highland areas exhibit a sub-humid climate. The lowest annual average temperature is 140 ^{0}C and the highest annual average temperature is 320 ^{0}C (Kitui County Integrated Development Plan , 2018-2022)

In Lower Eastern, the study was conducted in ten villages selected from the three counties. As was the case in Rift valley, one Sub-County was randomly selected from each of the three counties. The included Sub-counties were Machakos town, Mutomo and Makueni for Machakos, Kitui and Makueni Counties respectively. The ten villages included Kithima, Mithini, Nzoweni and Uvalini in Machakos town Sub-County; Kiteta, Uae in Mutomo Sub-County and Kiatine, Kyumu, Kisyungii/kisyogai and Nthangu in Makueni Sub-County (KNBS, 2019).

Map of the Study Areas

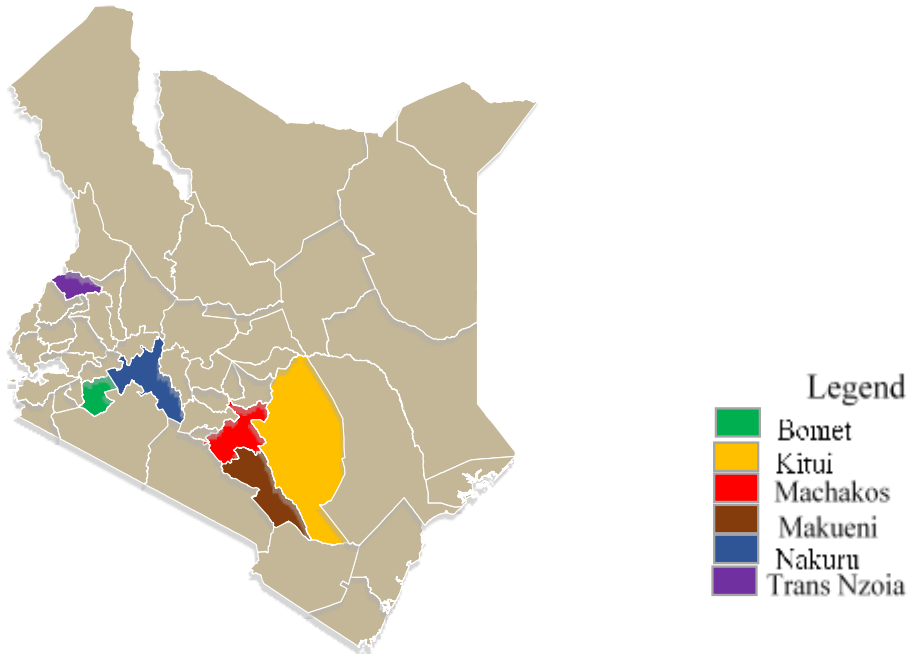


Figure 3.1: Map of the study areas

3.2 Study population

Maize farmers from the two study regions of Rift Valley and Lower Eastern formed the study population. Most households in the two regions practicing small scale farming for their livelihood. Maize was the main food crop grown by the residents, mainly for subsistence in the Lower Eastern region, while for some farmers in Rift Valley, maize farming was also done as an income generating venture.

3.3 Study design

This study adopted a cross-sectional design comparing post-harvest knowledge, perceptions and practices, fusarium diversity and fumonisin contamination levels in the two study regions. The study was also laboratory based with the maize samples from the study areas being analyzed for *Fusarium* species and fumonisin contamination.

3.4 Sample size determination

Previous studies have shown the prevalence of *Fusarium* species infestation in maize to be 42% (Tsehaye *et al*., 2017). This study was purposed to be 90% confident in detecting a 10% percentage point difference in one direction at the 2.5% level of significance and a power of 90%.

(a) Prevalence rate, $\overline{p_0}$ = 42%

(b) Anticipated prevalence, $\overline{p_a}$=29%

(c) Level of significance, α= 2.5%

Z_1-α= 1.96, and Z_1-β=1.282

(d) Power of the test, 1-β= 90%

(e) Alternative hypothesis (one-sided test) sample size, n is given according to Baseman (1978) as;

$$n = \{z_{1-\alpha}\sqrt{[p_0(1-p_0)} + z_{1-\beta}\sqrt{p_a(1-p_a)}\}^2/(p_0-p_a)^2$$

n = 142

To account for non-response rate due to refusal to participate by sampled respondents, this sample size (142) was increased by 10% in each study region to make it **157**.

This translated to 157 X 2 = **314** households in the two regions.

Hence a sample of 157 was required for each study site (**314** Households in the two study regions) to preserve the power of the test to detect the desired difference.

3.5 Eligibility criteria

3.5.1 Inclusion criteria

For the farmers:

- Maize farmers who have lived in the study areas for more than one year before the commencement of this study.
- The respondents were preferably household heads. If the head was not available for the interview, then an adult household member above 18 years of age who was a primary decision maker on household's maize storage practices and consumption was interviewed.
- Farmers who are willing to participate in the interview and ready to give consent.
- For the maize samples:
- Only maize samples meant for human consumption from the farmers own production in the study areas were collected for lab analysis.

3.5.2 Exclusion criteria

For the maize samples:

- Maize grains that was purchased by the farmers

3.6 Sampling technique

Multi-stage sampling approach was used in the study. The two study regions were purposively selected for the study. Rift Valley region counties of Bomet, Trans-Nzoia and Nakuru were selected purposively as they are considered the grain baskets of Kenya while the Lower Eastern region counties of Machakos, Kitui and Makueni were selected due to the high reported cases of aflatoxin in the region (Daniel *et al*., 2011). One Sub-County was randomly selected from each of the six counties included in the study. This was done by writing down the names of the Sub-Counties per county and assigning each

of them a specific number which were then written on different piece of papers, after which the pieces were mixed thoroughly in a bowl and one piece of paper picked. The assigned number of the sub-county selected was used in the study. The sampling frame for the sub counties is indicated in the table below.

Table 3.1: Study locations

	Counties	**Sub counties**
	Rift valley	
1	Nakuru	Nakuru Town East
		Nakuru Town West
		Njoro
		Molo
		Gilgil
		Naivasha
		Kuresoi North
		Kuresoi South
		Rongai
		Subukia
2	Bomet	Sotik.
		Bomet Central.
		Bomet East.
		Chepalungu.
		Konoin
3	Trans-Nzoia	Cherangany
		Kwanza
		Saboti
		Kiminini
		Endebess
	Lower Eastern	
1	Kitui	Kitui Central
		Lower Yatta
		Kitui West
		Kisasi
		Nzambani
		Mutitu
		Mutomo
		Ikutha
		Katulani
		Matinyani

		Mwingi Central
2	Machakos	Mavoko Masinga Yatta Kangundo Kathiani Matungulu Mwala
3	Makueni	Makueni. Kaiti. Kilome. Kibwezi East. Kibwezi West. Nzaui. Kathonzweni. Mbooni East.

Random sampling was also used to select the villages from which the data was collected in each of the sub counties. The list of selected sub counties and villages is presented in the results. The sample size was equally distributed to each of the sub-counties. Households were randomly selected from the village elders' list supplied to the research team [Table 3.1].

3.7 Data collection

3.7.1 Data collection tools

Data from the farmers were collected using an interviewer administered questionnaire. The questionnaire was divided into three sections; section one was on respondents Socio-demographic information, section two on Household maize consumption practices while section three was on the farmers' knowledge, perceptions and practices on maize post-harvest handling and storage. Two questions were used to assess the participants knowledge on post-harvest maize management practices. The first question assessed their knowledge of causes of moulding in maize while the second one assessed their knowledge on practices to minimize moulding maize (Appendix IV).

3.7.2 Data collection process

A total of 12 research assistants were trained in research ethics, and data collection, including questionnaire administration. The assistants were recruited from the study regions in order to ensure that language does not become a barrier in the administration of the questionnaire.

During the data collection, consent was sought from the eligible participants and those who consented were interviewed using the study questionnaire. Approximately ¼ kg (250g) of maize sample of maize harvested from the family land were purchased from each consented household after completion of the questionnaire for laboratory analysis. However, if the household had exhausted their harvested maize, no sample was taken from it. The collected samples were packed in sampling bags and labeled using codes before being transported to the laboratory for analysis.

3.7.3 Isolation and characterization of fungal species

Daniel *et al*., (2012) protocol involving seed disinfection method was used. Briefly, the procedure involved the treatment of maize seeds with 1% sodium hypochlorite (NaOCl) to reduce surface contaminants. Thereafter, the grains were soaked in hydrochloric acid (HCl) for 30 minutes and then soaked in 60ºC hot water for 5-10 minutes. The seeds were then put in lots each of 15g after which each lot was wrapped in 1 to 2 layers of cheesecloth and soaked in sterile distilled water for four hours at room temperature. They were then transferred to a water bath at 60ºC for 5 minutes. From the water bath, they were blotted in a sterile paper in a laminar flow before culture. Culture of disinfected Maize grain was done on Carnation Leaf-piece Agar (CLA). The inoculated CLA plates were incubated for 2-7 days at 27ºC ambient air. The plates were examined daily for fungal growth.

Suspected Fusarium species colonies were sub-cultured on Potato Dextrose Agar (PDA) for purity and sub-sequent morphological and microscopic examination. Identification of

Fusarium species was done according to Leslie & Summerell, (2006) and Kerényi *et al*., (2004) protocol (Plates 1-7).

3.7.4 Sample preparations and determination of fumonisin levels

Maize sample preparation for fumonisin quantification was done using Envilogix Quick Tox Kit as per the manufacturer's instructions. Briefly, a portion of the collected maize samples was ground with a mill and a sample of 20 grams weighed into sample cups. Equal amount of 50% Ethanol was added to each sample and shaken for 2 minutes. One hundred microliters of the extract were diluted with 100 µl of buffer. Quantification of fumonisin was done using Envrologix Quick Tox Kit.

3.8 Data management and analysis

The collected data was entered into MS Excel, cleaned then imported into IBM Statistical Package for Social Sciences (SPSS) version 24.0 for analysis. Descriptive and comparative statistics were used for the analysis. For descriptive analysis, mean and standard deviation or median and interquartile range was used for continuous variable based on whether the variable data was normally distributed or not respectively. For categorical variables, frequency and percentages were used. For knowledge assessment, each correct option was given a score of one. The first question had a total score of 7 while the second question had a total score of 6, giving a total of 13. The knowledge score was categorize into two (Good/poor). Those who score higher than the sample mean score were considered as having good knowledge.

For comparative analysis between the two regions, chi-square test and fisher's exact test were used for categorical data such as gender and level of education of respondents, quality of harvested maize, insect control practices, maize storage practices, and other maize postharvest practices. A two-sample t-test was used to compare the means of continuous variables such as age of respondents, acres of land, quantity of maize taken from storage for consumption, maize that was discoloured, quantity of maize after

shelling and the average maize selling price. A *P-value* of < 0.05 was considered statistically significant.

For the analysis of Fusarium infestation and fumonisin contamination data, descriptive statistics were used to analyze *Fusarium* isolates and Fumonisin contamination levels. This included determination of frequencies and proportions of *Fusarium* species isolated and mean concentration levels of fumonisin toxins. The differences in proportion of *Fusarium* isolated between the two regions were compared using fisher's exact test, while the differences in the level of fumonisins among the two regions and the different counties were assessed using the Mann-Whitney U test and Kruskal-Wallis test respectively. A P-value of < 0.05 was considered statistically significant.

3.9 Ethical considerations

Ethical approval for the study was given by the Institutional Research and Ethics Committee (IREC) of Moi University and Moi Teaching and Referral Hospital (MTRH), Eldoret approval No FAN: IREC 1829 of 2nd March 2017 (Appendix I). Permission was also obtained from respective County Governments through assistance of National Commission of Science, Technology and Innovation (NACOSTI) Research Clearance permit No 14093 issued on 12th May 2017 (Appendix II).

The nature and purpose of the study was explained to each of the study respondent in Kiswahili or local language by the researcher or trained research assistants and their questions and concerns addressed. Consent was obtained from the individual respondent and data was collected from them using an interviewer administered questionnaire (Appendix III).

3.10 Limitations of the study

This study depended on the respondents recall on some aspects hence the limitation of recall bias as the respondent might have forgotten some of the issues. However, to minimize recall bias, the study assessed practices for their most recent harvest. The

study was a descriptive study hence the findings cannot be generalized to the wider population. Despite this, it provides a snapshot of farmers perceptions and practices which might be applicable to related settings in the country. The study, however, provides insights on post-harvest knowledge, perceptions and practices of farmers that might be applicable to many parts of the country.

The study was also carried out during one harvest period and therefore might not represent the general practices through all the seasons of the year since the practices might vary from one season to the next.

CHAPTER FOUR

RESULTS

4.1 Demographic characteristics of the participants

In this study, a sample size of 314 farmers was used hence 100% response rate. The table below shows the counties, sub counties and villages from which the data was gathered from.

4.1.1 Distribution of respondents by Region and County

Table 4.1: Sub counties and villages where data was collected

County	Sub county	Village
Trans-Nzoia	Saboti	Chepkaitit
		Laboot
		Sinendet
Bomet	Sotik	Chesambai
		Kapchumbe
		Kaplombe
		Kapolesobe
Nakuru	Rongai	Chepseon
		Saptet
		Waldai
Total	**3**	**10**
Kitui	Mutomo	Kiteta
		Uae
Makueni	Makueni	Kiatine
		Kisyungii/Kisyogai
		Kyumu
		Nthangu
Machakos	Machakos town	Kithima
		Mithini
		Nzoweni
		Uvalini
Total	**3**	**10**

Out of the 314 respondents in the study, 165 (52.5%) were from the Rift Valley region while 149 (47.5%) were from the Lower Eastern Region. One hundred and eighty four respondents (58.6%) were female while the rest 130 (41.4%) were male.

Among the 165 respondents from Rift valley, 50 (30.3%) were from Bomet County, 65 (39.4%) from Nakuru County and 50 (30.3%) from Trans-Nzoia County. Of the 149 respondents from Lower Eastern Region, 49 (32.9%) were from Kitui County, 50 (33.6%) from Machakos County and the remaining 50 (33.6%) respondents were from Makueni County**.** [Table 4.2].

Table 4.2: Distribution of respondents by Region and County

Region	**County**	**Frequency**	**Percent (%)**
Rift Valley	Bomet	50	30.3
	Nakuru	65	39.4
	Trans-Nzoia	50	30.3
Total		**165**	**100**
Lower Eastern	Kitui	49	32.9
	Machakos	50	33.6
	Makueni	50	33.6
Total		**149**	**100**

4.1.2 Socio-demographic information

The mean age of the respondents was 41.6 years (SD=15.1), with a median of 38 years (IQR= 30-51) while the modal age was 30 years. The youngest respondent was 18 years while the oldest was 94 years [Fig 4.1].

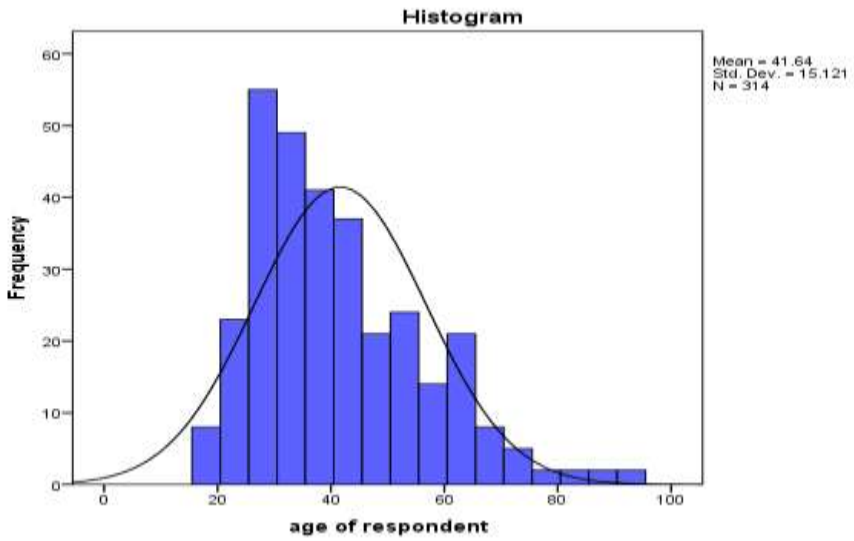


Figure 4.1: Age distribution of the respondents

The median acreage of land owned in the previous year before the study was 2.0 acres (IQR=1-3.6) with a range of 0 to 30 acres and a mean of 2.7 acres (SD=2.8). The median acreage cultivated in the last 12 months was 1.4 acres (IQR=0.5-2.5) with a minimum and a maximum of 0.0 to 15.0 acres respectively and a mean of 1.9 acres (SD=1.9) [Table 4.3].

Table 4.3: Land owned and cultivated in the last 12 months

Region	Statistics	Acres owned in the last 12 months	Acres cultivated in the last 12 months
Rift valley	Mean	2.6	1.9
	Median	2.0	1.5
	Mode	2.0	1.0
	Std. Deviation	2.1	1.6
	Range	12.0	8.0
Lower Eastern	Mean	3.0	1.9
	Median	2.0	1.0
	Mode	1.0	0.5
	Std. Deviation	3.5	2.1
	Range	29.8	15.0

Most participants had attained primary level of education 132 (42.0%) followed by

secondary level education 99 (31.5%), 49 (15.6%) had tertiary level of education while 34 (10.8%) had no formal education.

Full time farming was the main economic activity for 241 (76.8%) of the respondents followed by salaried employment 43 (13.7%), and business 23 (7.3%) while 7 (2.2 %) were involved in other income generating activities.

More than sixty percent, 198 (63.1%) had a monthly income of Kes 5,000 (US$ 50) or below, 64 (20.4%) had a monthly income of between Kes 5,001- 10,000 (US$ 50.01-100), 21 (6.7%) had a monthly income of between Kes 10,001- 15,000 (US$ 100.01-150) while 31 (9.9%) of over Kes 15,000 (US$150). Most, 309 (98.4%) owned the land they lived on and 310 (98.7%) owned the houses they lived in. On the type of houses, 170 (54.1%) respondents lived in semi-permanent houses, 118 (37.6%) lived in permanent houses and 26 (8.3%) lived in temporary houses. Solar panels were the most used lighting source in homes, being used by 123 (39.2%) of the respondents, followed by kerosene 111 (35.4%) and electricity 82 (25.8%). On cooking, 297 (94.6%) used firewood, 33 (10.5%) used charcoal, 21 (6.7%) used cooking gas while 4 (1.3%) used kerosene [Table 4.4].

Table 4.4: Demographic information of the respondents from the study sites

Demographic information	Frequency	Percent (%)
Sex		
Male	130	41.4
Female	184	58.6
Level of education		
None	34	10.8
Primary school	132	42.0
Secondary School	99	31.6
Tertiary	49	15.6
Occupation		
Businessperson	23	7.3
Permanent employment	43	13.7
Full-time farmer	241	76.8
Others	7	2.2
Monthly Income		
0-Ksh 5,000	198	63.1
Ksh 5,001- 10,000	64	20.4
Ksh 10,001- 15,000	21	6.6
Over Ksh 15,000	31	9.9
House ownership		
From family	1	0.3
Rented	3	1.0
Self-owned	310	98.7
Ownership of land they live on		
Yes	309	98.4
No	5	1.6
Type of house		
Permanent	118	37.6
Semi-permanent	170	54.1
Temporary	26	8.3
Lighting source *		
Solar panel	123	39.2
Kerosene	111	35.4
Electricity	82	25.8
Source of cooking energy *		
Firewood	297	94.6
Charcoal	33	10.5
Cooking gas	21	6.7
Kerosene	4	1.3

*Some farmers were using more than one source of lighting and cooking gas.

4.1.3 Quantity of maize harvested from the study sites

The median quantity of maize harvested after shelling was 6.5 bags (585 kg) (IQR=2-19) per household. Most farmers harvested 1 bag (90 Kg) of maize while the farmer who had a lot of maize after threshing had 270 bags (24, 300 kg) per household. There was no significance mean differences for Rift valley (M=17.18 bags, SD= 20.99) and Lower Eastern (M = 12.74 bags, SD = 33.99) regions t (276) = 1.333, p value = 0.184.

The median amount of maize put aside before shelling as a result of rotting was 20 kg (IQR=0-90) per household. The maximum amount was 900 kg. There was a significant difference in the maize put aside before shelling due to rotting for Rift Valley (M = 107.88, SD = 131.70) and Lower Eastern region (M = 31.96, SD = 103.45) regions; t (306.25) = 5.707, p value < 0.001 [Table 4.5].

Table 4.5: Quantity of maize put aside after shelling due to spoilage

	Region				
	Rift Valley	**Lower Eastern**	**t**	**df**	**p-value**
Quantity of maize after shelling					
Mean	17.18 (SD=20.99)	12.74 (SD= 33.99)	1.333,	276	0.184.
Median	10.00 (IQR=5.0-23.5)	2.00 (IQR=1.0-6.5)			
Quantity of maize put aside because of rotting, mouldy before shelling					
Mean	107.9 (SD=131.7)	33.0 (SD= 103.5)	5.707	306.25	< 0.001
Median	90.00 (IQR=16.0-135.0)	0 (IQR=0-10.0)			

4.2 Participants knowledge, perceptions and practices on maize post-harvest and storage

4.2.1 Participants perception on mouldy maize

Mouldy maize was reported to be disposed by 98 (31.2%) respondents while 36 (11.5%) respondents used it to feed their cows, 19 (6.1%) used it as poultry feed, 7 (2.2%) consumed it, 2 (0.6%) sold it and 2 (0.6%) used it for brewing. Eleven (3.5%) of the respondents thought that mouldy maize is safe for human consumption with a

significantly higher proportion being from LE (6.0%) compared to RV (1.2%) (P value=0.02). among the participants, 74 (23.6%) perceived mouldy maize safe for animal consumption, with a higher proportion being from RV (36.4%) compared to LE (9.4%) (P value<0.001).

Among the respondents, 87 (27.7%) thought milk from cows fed on mouldy maize was safe, with a high proportion being from RV (37.0% compared to 17.4% in LE (P Value=0.002). Twelve participants (3.8%) thought it is safe to mix wet and dry maize during storage and 7 (2.2%) considered it safe to consume good looking but wet and smelly maize. Some, 47 (15.0%) considered it safe to sell mouldy maize to local brewers, With A high proportion being from RV (24.8%) compared to LE (4.0%), (P value<0.001). [Table 4.6].

Table 4.6: Participants perception on mouldy maize

Participants attitudes						
		Region				
Participants attitude on mouldy maize	Total (n=314)	Rift valley (n=165)	Lower Eastern (n=149)	df	χ^2	P value
Mouldy maize is safe for human consumption	11 (3.5%)	2 (1.2%)	9 (6.0%)	1	5.399	<0.020
Mouldy maize is safe for animal consumption	74 (23.6%)	60 (36.4%)	14 (9.4%)	1	31.611	<0.001
Consuming milk from cow fed on mouldy maize is safe	87 (27.7%)	61 (37.0%)	26 (17.4%)	1	14.894	<0.001
It is safe to mix wet and dry maize for storage	12 (3.8%)	1 (0.6%)	11 (7.4%)	1	9.782	<0.002
It is safe for human to consume good looking but wet /bad smelling maize	7 (2.2%)	3 (1.8%)	4 (2.7%)	1		0.712
It is safe to sell mouldy maize to local brewers	47 (15.0%)	41 (24.8%)	6 (4.0%)	1	26.670	<0.001

Participants from LE were 5.2 timely more likely to believe that it is safe to consume mouldy maize (OR=5.24, 95% CI 1.11 to 24.65, P value=.036), 82% less likely to

believe that mold maize can be fed to animals (OR=0.18, CI 0.10 to 0.34, P-value<0.001), 64% less likely to believe that consuming milk from cow fed on mouldy maize is safe (OR=0.36, CI .21 to .61, P -value <0.001), 13 times more likely to believe that it is safe to mix dry and wet maize for storage (OR=13.07, CI=1.68 to 102.53, P-value = 0.014), and 87% less likely to believe that it is safe to sell moldy maize to local brewer (OR=0.13, CI=0.05 to 0.31, P-Value <0.001) [Table 4.7].

Table 4.7: Univariate analysis of farmers perceptions on moldy maize based on region.

Participants' attitudes on mouldy maize	OR	95% CI	P value
Safe to consume moldy maize	5.24	1.11 to 24.65	0.036
Mold maize fed to animals	0.18	0.10 to 0.34	<0.001
Consuming milk from cow fed on mouldy maize is safe	0.36	0.21 to 0.61	<0.001
Safe to mix dry and wet maize for storage	13.07	1.67 to 102.53	0.014
It is safe for human to consume good-looking but wet/bad smelling maize	1.49	0.33 to 6.77	0.606
It is safe to sell moldy maize to local brewer	0.13	0.05 to 0.31	<0.001

*Rift valley was used as the reference group.

4.2.2 Factors attributable to maize grains spoilage

Of the respondents, 98 (31.2%) thought that poor soil condition contributes to maize grains spoilage. Higher proportions 88.5%, 89.8%, 91.4%, and 82.2% thought that bad weather, wetness of the piles of the harvested maize, dampness of the storage place, and harvesting maize earlier than usual respectively were the main reasons for maize spoilage. A small proportion (16.9%) thought that drying maize longer than usual leads to maize spoilage. There were significant differences in farmers who thought that poor soils, wet weather, and wetness in maize pile, dampness in storage place and insect and

pests in the storage place between Rift valley and Lower Eastern with the proportion of farmers who thought that these factors cause spoilage of maize grains being higher among Rift valley respondents than that of Lower Eastern (P< 0.05). [Table 4.8].

Table 4.8: Factors attributable to maize spoilage

Factors attributable to maize spoilage						
		Region				p value
Factors attributable to maize grains spoilage	Total (n=314)	Rift valley (n=165)	Lower Eastern (n=149)	χ^2	df	
Poor soil	98 (31.2%)	60 (36.4%)	38 (25.5%)	4.301	1	0.038
Dampness in storage place	287 (91.4%)	159 (96.4%)	128 (85.9%)	10.8951		0.001
Wetness in piles of harvested maize	282 (89.8%)	155 (93.9%)	127 (85.2%)	6.482	1	0.011
Harvesting maize earlier than usual	258 (82.2%)	141 (85.5%)	117 (78.5%)	2.569	1	0.109
Wet weather during harvest	278 (88.5%)	153 (92.7%)	125 (83.9%)	6.020	1	0.014
Insects/pests in storage place	159 (50.6%)	101 (61.2%)	58 (38.9%)	15.5571		<0.001
Drying maize longer than average	53 (16.9%)	29 (17.6%)	24 (16.1%)	0.120	1	0.729

4.2.3 Knowledge and perceptions on minimizing mould infestation

Up to 186 (59.2%) of the respondents thought that spreading chemicals over the grains prior to storage would reduce mould growth with the proportion being significantly higher in Rift Valley than in Lower Eastern [110 (66.7%) vs 76 (51.0%), p value= 0.005]. Two hundred and ninety three (93.3%) thought that storage of completely dry maize only would reduce mould formation. There were smaller proportions of participants who thought that storage of maize in storage plastic bags 70 (22.3%), plastic containers 39 (12.4%), metallic silos 96 (30.6%), and clay pots 107 (34.1%) would help minimize mould growth.

There was a significantly higher proportion of respondents from Lower Eastern than Rift

valley who thought that maize storage in plastic bags and containers would minimize mould infestation (p value < 0.001) [Table 4.9].

Table 4.9: Knowledge and perceptions on minimizing mould infestation

Maize storage and preservation practices		Region				
	Total (n=314)	**Rift valley (n=165)**	**Lower Eastern (n=149)**	χ^2	df	**P value**
Spreading chemical over the grains prior to storage	186 (59.2%)	110 (66.7%)	76 (51.0%)	7.952	1	0.005
Storage of completely dry maize only	293 (93.3%)	158 (95.8%)	135 (90.6%)	3.332	1	0.068
Grain storage in a plastic bag	70 (22.3%)	21 (12.7%)	49 (32.9%)	18.367	1	<0.001
Grain storage in a plastic container	39 (12.4%)	4 (2.4%)	35 (23.5%)	31.941	1	<0.001
Grain storage in a metallic silo	96 (30.6%)	46 (27.9%)	50 (33.6%)	1.189	1	0.275
Grain storage in a clay pot	107 (34.1%)	48 (29.1%)	59 (39.6%)	4.09	2	0.100

To minimize mould infestation in maize, LE farmers were 48% less likely to spread insecticides over the grains prior to storage (OR=0.52, CI=.33 to .82, P-value=.005), 3.4 times more likely to store the maize grain in a plastic bag (OR=3.36, CI=1.90 to 5.95, P-value<0.001), and 60% more likely to store the maize grains in a clay pot (OR=1.60, CI=1.00 to 2.56, P-value=0.051). [Table 4.10]

Table 4.10: Binary regression model of practices to minimize mould infestations of maize based on study region.

Practices to minimize mould infestations of maize in the study sites.	OR	95% CI of OR	Wald value	P
Spreading insecticides over the grains prior to storage	0.521	0.33 to 0.82	0.005	
Storage of completely dry maize only	0.427	0.17 to 1.09	0.075	
Grain storage in a plastic bag	3.36	1.90 to 5.95	<0.001	
Grain storage in a plastic container	12.36	4.27 to 35.74	<0.001	
Grain storage in a metallic silo	1.307	0.81 to 2.11	0.276	
Grain storage in a clay pot	1.60	1.00 to 2.56	0.051	

*Rift valley was used as the reference group.

Knowledge on causes and methods of minimizing molding

The sample mean knowledge score was 9.6 (SD=1.8). Those who score above 9 were considered as having high level of knowledge. More than half 193 (61.5%) were considered as having high level of knowledge on causes and methods of minimizing moulding while 121 (38.5%) were considered to have low level of knowledge. More farmers from Rift Valley, 134 (81.2%) had good level of knowledge compared to 59 (39.6%) in LE, and the regional difference was statistically significant (P-value<0.001) [Table 4.11]

Table 4.11: Participant's Knowledge on causes and methods of minimizing molding

Knowledge on causes and methods of minimizing moulding	Total	Rift Valley	Lower Eastern	X^2	df	P-value
Poor	121 (38.5%)	31 (18.8%)	90 (60.4%)	57.247	1	<0.001
Good	193 (61.5%)	134 (81.2%)	59 (39.6%)			

4.2.4 Insect control methods of the stored maize

Chemicals were the most widely used method of insect control by 222 (70.7%) of the farmers, while 102 (32.5%) used sun drying, and 25 (8.0%) used ash. Some of these farmers, however, used more than one insect control method. On chemicals used, 108 (48.6%) of the respondents used *Actellic* Super, 99 (44.6%) used *Actellic* dust, 6 (2.7%) used *Skana* Super while 2 (0.6%) used *Malathion* dust.

Agroz bags were used by 22 (7.0%) of the farmers. *Actellic* dust was used by many farmers from Lower Eastern compared to those from Rift Valley while *Actellic* super was used by a high proportion of farmers from Rift valley. The differences were statistically significant [X^2 (3) = 29.622, p value <0.001) (Table 4.3.4). [Table4.12]

Table 4.12: Insect control measures in the study sites

Insect control measures		**Region**				
	Total (n=314)	**Rift valley (n=165)**	**Lower Eastern (n=149)**	df	χ^2	**P value**
Use of chemical	222 (70.7%)	117 (70.9%)	105 (70.5%)	1	0.007	0.932
Sun drying/airing	102 (32.5%)	68 (41.2%)	34 (22.8%)	1	12.078	<0.001
Ash	25 (8.0%)	1 (0.6%)	24 (16.1%)	1	25.674	<0.001
None	3 (1.0%)	2 (0.6%)	1 (0.3%			0.224*
Chemical used (n=222)		(n=117)	(n=105)			
Actellic dust	99 (44.6%)	33 (28.2%)	66 (62.9%)	3	29.622	<0.001
Actellic Super	108 (48.6%)	77 (65.8%)	31 (29.5%)	3	53.645	<0.001
Skana super	6 (2.7%)	6 (5.1%)	0 (0.0%)			<0.031*
Malathion dust	2 (0.6%)	1 (0.9%)	1 (1.0%)			1.0*

* Results are for fisher's exact test

* Farmers had the option of selecting more than one option

Farmers from LE were 58% less likely to use sun drying as an insect control measure (OR=0.42, CI= 0.26 to 0.69, P-value=.001) and 31.5 times more likely to use ash as an insect control measure (OR=31.49, CI=4.20 to 235.92, P-value=0.001). [Table 4.13]

Table 4.13: Binary regression of insect control measure based on region.

Insect control measures used in the study sites	OR	95% CI	P value
Use insecticides	0.98	0.60 to 1.59	.932
Sun-drying/airing	0.42	0.26 to 0.69	.001
Ash	31.49	4.20 to 235.92	.001

*Rift valley was used as the reference group.

4.2.5 Other post-harvest maize storage practices

The mean number of days the maize was kept on cobs was 33 days after harvest (IQR=14-30) with a range of 0 to 150 days. The differences in mean number of days the maize was kept on cobs in Rift Valley (M= 37.82, SD= 37.15) and Lower Eastern (M= 27.30, SD= 20.23) was statistically significant; t (258.53) = 3.157, p value = 0.001. The median number of days of drying the maize before storage was 7 days (IQR=3-14). The mean of number of days the maize was dried for Rift Valley (M= 7.02, SD= 6.51) and Lower Eastern (M= 13.00, SD= 11.42) region was statistically significant; t (229.82) = -5.62, p value <0.001.

Nearly half, 152 (48.4%) of the farmers interviewed kept the maize on cobs at home in a separate room after harvesting while 148 (47.1%) left the maize in the field without covering after harvesting with more farmer from Lower Eastern leaving their maize on cobs in the field without covering compared to those from Rift Valley [88 (59.1%) vs 60 (36.4%) [X^2] (1) = 16.187, *P value* < 0.001].

Only eleven respondents (3.5%) took maize to commercial storage facilities with the rest storing them at home. The practice of consuming and selling the maize while still green was practiced by 104 (33.1%) of the respondents with a high proportion of respondents from Lower Eastern practicing it compared to those from Rift Valley [71 (47.7%) vs 33 (20.0%) [X^2 (1) = 27.025, *P* value < 0.001].

All farmers interviewed used sun drying and airing to dry their maize. Maize stored as de-husked cobs was practiced by 108 (34.4%) respondents while 52 (16.6%) stored the maize in husks and 307 (97.8%) stored it as grains. Most, 306 (97.5%) of the respondents reported that their grains were dry last season while 7 (2.2%) reported that it was not dry. For those who reported that their grains were not dry, they said that it was due to poor weather, consumption of maize while green, poor seed quality, and short drying season. Majority, 309 (98.4%) reported that their storage facilities were cleaned before storing the new maize grains in them [Table 4.14].

Table 4.14: Other Post-harvest maize storage practices

Post-harvest maize storage practices		Region				
	Total (n=314)	Rift valley (n=165)	Lower Eastern (n=149)	χ^2	Df	*P value*
Postharvest maize cob management methods						
Leave maize pile in the field without covering	148 (47.1%)	60 (36.4%)	88 (59.1%)	16.1871		<0.001
Bring home and pile in a separate room	152 (48.4%)	102 (61.8%)	50 (33.6%)	25.0391		<0.001
Leave maize pile in the field covered	106 (33.8%)	24 (14.5%)	82 (55.0%)	57.3971		<0.001
Dry off the ground on tarpaulin	125 (39.8%)	28 (17.0%)	97 (65.1%)	75.6971		<0.001
Consume and sell as green maize	104 (33.1%)	33 (20.0%)	71 (47.7%)	27.0251		<0.001
Take to commercial storage facility	11 (3.5%)	3 (1.8%)	8 (5.4%)	2.920	1	0.087
Method of drying						
Sun drying	314 (100.0%)	165 (100.0%)	149 (100.0%)			
Cleans storage facility of all previous year remnants prior to storing	309 (98.4%)	165 (100.0%)	144 (96.6%)			<0.023*
Frequency of storing maize on de-husked cobs						
Never	206 (65.6%)	117 (70.9%)	89 (59.7%)			<0.037*
Always	108 (34.4%)	48 (29.1%)	60 (40.3%)			
Frequency of storing maize as grains						
Never	7 (2.2%)	7 (4.2%)	0 (0.0%)			<0.011*
Always	307 (97.8%)	158 (95.8%)	149 (100.0%)			
Frequency of storing maize in the husk						
Never	262 (83.4%)	134 (81.2%)	128 (85.9%)			0.264*
Always	52 (16.6%)	31 (18.8%)	21 (14.1%)			
Agrees that own grains were dry last season						
Yes	306 (97.5%)	161 (97.6%)	145 (97.3%)			0.884*
No	7 (2.2%)	4 (2.4%)	3 (2.0%)			

*Results are for Fischer's exact test

Farmers from LE were 2.5 times more likely to leave maize pile in the field without covering (OR=2.53, CI=1.60 to 3.98, P-value=0.001), 7.2 times more likely to leave maize pile in the field covered (OR=7.19, CI=4.19 to 12.34, P-value<0.001), 69% less likely to bring home and pile in a separate room (OR=0.31, CI=0.20 to 0.50, P-value<0.001, 9.1 times more likely to dry their maize off the ground on tarpaulin (OR=9.13, CI=5.38 to 15.47, P-value<0.001), 3.6 times more likely to consume and sell maize as green maize (OR=3.64, CI=2.21 to 6.00, P-value<0.001) and 64% more likely to store maize on dehusked cobs (OR=1.64, CI=1.03 to 2.63, P-value=0.038). [Table 4.15]

Table 4.15: Univariate analysis of Post-harvest maize storage practices in LE compared to RV

Postharvest maize storage practice	OR	95% CI	P value
Postharvest maize cob management method			
Leave maize pile in the field without covering	2.53	1.60 to 3.98	0.001
Leave maize pile in the field covered	7.19	4.19 to 12.34	<0.001
Bring home and pile in a separate room	0.31	0.20 to 0.50	<0.001
Dry off the ground on tarpaulin	9.13	5.38 to 15.47	<0.001
Consume and sell as green maize	3.64	2.21 to 6.00	<0.001
Take to commercial storage facility	3.06	0.80 to 11.77	0.103
Cleans storage facility of all previous year remnants prior to storing	1	-	-
Frequency of storing maize on dehusked cobs	1.64	1.03 to 2.63	0.038
Frequency of storing maize in the husk	0.71	0.39 to 1.30	0.265
Never stored maize as grains	1	-	-
Agrees that own grains were dry last season	1.21	0.27 to 5.49	0.806

*Rift valley was used as the reference group.

One hundred and twenty respondents (38.2%) reported that they knew their maize grains were dry when they were hard to chew, 95 (30.3%) by listening to the grains sound when they drop it to the ground and measuring its weight, 49 (15.6%) knew that the maize grains were dry by touching them, 17 (5.4%) by observing change in colour, and 16 (5.1%) knew that the grains were dry when self-shelling happened when the maize cobs are threshed. Other methods used to know when the maize grains were dry included observation during shelling as reported by 8 (2.5%) respondents, storage in store for one week as reported by 4 (1.3%), after sun drying 2 (0.6%) and during milling as was reported by 2 (0.6%) of the respondents. For the 7 (2.2%) respondents who reported that their grains were not dry, they gave the following reasons: 3 said it was due to inadequate sunlight, 1 each said it was due to poor spreading of maize, short drying time, poor seed quality and consumed all the maize while still green.

4.2.6 Maize disposal practices

Among the farmers interviewed, 95 (30.3%) had taken maize from their storage for sale one month before the study. The interquartile range of the maize sold was 720 kgs (360, 1462.5) with the minimum amount being 90 kgs while the maximum amount was 12,600 kgs. There was a significant difference in mean quantity of maize sold between Rift Valley (900 kgs) and Lower Eastern (315 kgs) (p value < 0.001). The quality of maize sold by the respondents was reported to be good by 86 (96.6%), poor by 2 (3.1%) and fair by 1 (1.1%) respondent.

The average selling price of a bag of maize was ksh 2,698.54 with the minimum price being ksh 1,000 while the maximum price was ksh 7,500. The median and modal selling price was Ksh 2,500.

There was a significant difference between the mean maize selling prices per bag between Rift valley and Lower Eastern (Kes 2,532.00 verses Kes 3,531.50 respectively, p value = 0.045). Businessmen were the largest buyers (69) 74.2% followed by local consumers 15 (16.1%). Other buyers were schools and local cereal traders. Fourteen

farmers (14.7%) of those who sold maize had mouldy maize in their sale with the quantity of mouldy maize ranging from 2 kgs to 270 kg with a median of 22.5 kg (IQR=2-28.1) [Table 4.16].

Table 4.16: Maize disposal practices in the study sites

Maize disposal practices					
		Region		df	
	Total (n=314)	Rift valley (n=165)	Lower Eastern (n=149)		P value
Participants who took maize from storage for sale in the month of harvest	95 (30.3%)	82 (49.7%)	13 (8.7%)		<0.001
Average selling price	2,602.92	2451	3,362.50		0.045
Median selling price	2500	2400	3250		
Quality of grains sold (n=95)					
Poor	3 (3.1%)	3 (3.7%)	0 (0.0%)	1	1.00
Fair	1 (1.1%)	1 (1.2%)	0 (0.0%)	1	1.00
Good	91 (95.8%)	78 (95.1%)	13 (100.0%)	1	0.416
Buyer of the largest sale in the month (n=93)					
Business people	69 (74.2%)	56 (71.8%)	13 (86.7%)	1	0.017
Cereals dealer	6 (6.5%)	6 (7.7%)	0 (0.0%)	1	0.592
Local consumer	15 (16.1%)	13 (16.7%)	2 (13.3%)	1	1.00
School	3 (3.2%)	3 (3.8%)	0 (0.0%)	1	1.00
Participants who had discolored, damaged or mouldy maize in their sale	14 (14.7%)	12 (14.6%)	2 (15.4%)	1	1.00

The farmers from LE were 87% less likely to have taken maize from storage for sale in the month of harvest (0.130, CI= 0.07 to 0.24, P-value<0.001). [Table 4.17]

Table 4.17: Binary regression model of maize disposal practices based on study regions.

Practices to minimize mould infestations of maize in the study sites.	OR	95% CI of OR	Wald P value
Participants who took maize from storage for sale in the month of Harvest	0.13	0.07 to 0.24	<0.001
Quantity sold	0.99	0.99 to 1.00	.037
Maize selling price	1.00	-	0.05

*Rift valley was used as the reference group.

4.3 Household maize consumption practices

More than half 196 (62.4%) of the respondents' households consumed more than 30 kg of maize in 30 days while 118 (37.6%) consumed less than 30 kg in 30 days. Of the consumed maize, 178 (56.7%) of respondents reported that all of it was from their own production, 75 (23.9%) reported that some of it was from their own production while 61 (19.4%) reported having bought all of the consumed maize by the household. There was a statistically significant difference in quantity of maize consumed from own production in the two regions with more farmers from Rift Valley consuming maize from their own production as compared to those from Lower Eastern Regions [X^2 (2) = 55.709, p < 0.001]. This was also the case with the quantity of maize purchased where more farmers from Lower Eastern purchased maize for consumption compared to those from Rift Valley (X^2 (3) = 20.727, p <0.001). [Table 4.18]

Table 4.18: Household maize consumption practices by region

Household consumption in the last 30 days						
		Region				
Consumption (Kg)	Total =314)	(nRift valley (n= 165)	Lower Eastern (n=149)	X^2	Df	P value
≤ 30 kg	118 (37.6%)	56 (33.9%)	62 (41.6%)	20.727	3	<0.001
Over 30 kg	196 (62.4%)	109 (66.1%)	87 (58.4%)			
Quantity of the consumed maize from own production cosumed						
All	178 (56.7%)	125 (75.8%)	53 (35.6%)	55.709	2	<0.001
Some	75 (23.9%)	28 (17.0%)	47 (31.5%)			
None	61 (19.4%)	12 (7.3%)	49 (32.9%)			

The farmers from LE were 4 times more likely to have half of the maize they consumed from their own production (OR=3.96, CI=2.24 to 6.98, P-value<0.001), and 9.6 times more likely to have none of the maize they consumed from their own production (OR=9.63, CI=4.74 to 19.56, P-value<0.001) [Table 4.19].

Table 4.19: Univariate analysis of household maize consumption per region

Household maize consumption practices by region	OR	95% CI	P value
Quantity of consumed maize from own production			
All	Ref		
Half	3.96	2.24 to 6.98	<0.001
None	9.63	4.74 to 19.56	<0.001
Household consumption in the last 30 days			
Over 15 Gorogoros (30 kgs)	.721	.46 to 1.14	0.162

*Rift valley was used as the reference group.

The median number of days the maize stayed in storage was 90 days (IQR=45-150). The mean difference in the number of days the maize lasted in storage for Rift Valley (M = 140.04, SD = 76.73) and Lower Eastern (M = 71.24, SD = 51.69) regions was

statistically significant; t (219.82) = 7.981, p value < 0.001.

The quantity of maize taken from storage for human consumption in the month of the study ranged from 0 to 1,350 kg with a mean of 47.27 kg (SD=120.8) and median of 30 kg (IQR=10-40). Of this maize, only 4 (1.3%) of the respondents reported that it was of bad quality. The quantity of discoloured maize consumed ranged from 0 - 90 kg with a mean of 3.6 kg (SD=11.5). There was significant difference in the means of discoloured or damaged maize consumed for Rift Valley (M = 4.62 kg, SD = 13.86) and Lower Eastern (M = 1.94 kg, SD = 5.96) regions; t (215.37) = 2.110, p = 0.036.

Table 4.20: Days maize lasted in storge and quantity of maize discoloured

	Total	Rift Valley	Lower Eastern	t	df	P value
Days maize lasted in storage	90 (IQR=45-150), days.	140.0 (76.7)	71.2 (51.7)	219.8	7.98	<0.001
Quantity of discolored maize consumed	3.6 (11.5)	4.62 (13.86)	1.94 (5.96)	215.37	2.11	0.036

4.4 Fusarium and other species isolated from the maize

Of the 314 farmers, only 243 (77.4%) provided maize samples, of which 131 (79.4%) were from RV while 112 (75.2%) were from LE. Out of the 131 samples of maize from RV and 112 maize samples from LE, 78 (59.5%) and 95 (84.8%) had fungi species detected in them respectively [Table 4.21].

Table 4.21: Fungal species isolated in the study sites

Region	**Total Samples**	**Samples With Fungal Species**
Rift Valley	131	78 (59.5%)
Lower Eastern	112	95 (84.8%)
Total	**243**	**173 (71.2%)**

Among samples with fungi species, *Aspergillus spp* was the main fungi isolated in the

samples accounting for 87 (50.3%), followed by *Fusarium* 52 (30.1%), *Rhizopus* 42 (24.3%), *Penicillium* 40 (23.1%) and *yeast* 31 (17.9%) in that order.

Other species identified included *Mucorales*, *Acremonium*, *Cladosporium* and non-sporulating fungal species. Lower Eastern Region had a higher proportion of *Fusarium spp* (and Aspergillus) infestation compared to Rift Valley Region and the difference was statistically significant (P < 0.001) [Table 4.2].

Table 4.22: Species diversity of fungi isolated from maize in the study sites

	Region			
Variable	**Rift Valley**	**Lower Eastern**	**Total**	**Fisher's Exact test P-value**
Fungal species	**n = 78**	**n = 95**	**n = 173**	
Aspergillus	23 (29.5%)	64 (67.4%)	87 (50.3%)	<0.001
Fusarium	11 (14.1%)	41 (43.2%)	52 (30.1%)	<0.001
Rhizopus	20 (25.6%)	22 (23.2%)	42 (24.3%)	0.725
Penicillium	18 (23.1%)	22 (23.2%)	40 (23.1%)	>0.999
Yeast	19 (24.4%)	12 (12.6%)	31 (17.9%)	0.049
Mucorales	2 (2.6%)	2 (2.1%)	4 (2.3%)	0.999
Acremonium	5 (6.4%)	0 (0.0%)	5 (2.9%)	0.017
Cladosporium	0 (0.0%)	2 (2.1%)	2 (1.2%)	0.502
Non-sporulating	3 (3.8%)	0 (0.0%)	3 (1.7%)	0.090

*Some of the samples had more than fungi species isolated.

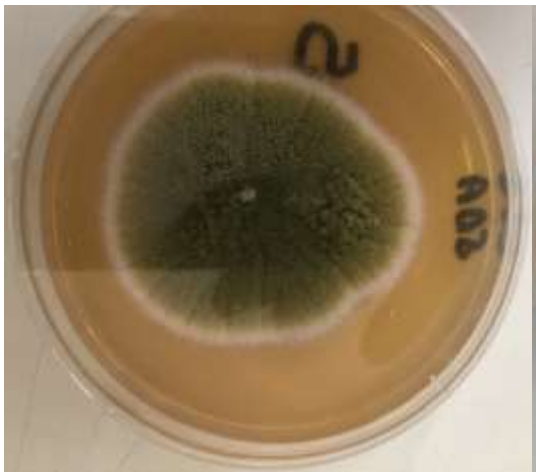
Among the *Fusarium* species, *F verticilliodes* was the most predominant species accounting for 42 (80.8%). Other Fusarium species isolated in the study areas were *F. andiyazi* 9 (17.3%) and *F. temperatum* 1 (1.9%). The proportion of *F. verticillioides* was higher in Lower Eastern compared to Rift valley (p = 0.025) [Table 4.23].

Table 4.23: Fusarium species isolated from the samples

	Region			
Fusarium species	**Rift Valley (N=11)**	**Lower Eastern (N=41)**	**Total (N=52)**	**Fisher's Exact test P-value**
Fusarium verticilliodes	6 (54.5%)	36 (87.8%)	42 (80.8%)	0.025
Fusarium andiyazi	5 (45.5%)	4 (9.8%)	9 (17.3%)	0.014
Fusarium temperatum	0 (0.0%)	1 (2.4%)	1 (1.9%)	>0.999

Plate 4.1 **Plate 4.2**

Plate 4.1 and 4.2: Maize kernel infested with Aspergillus and Fusarium species



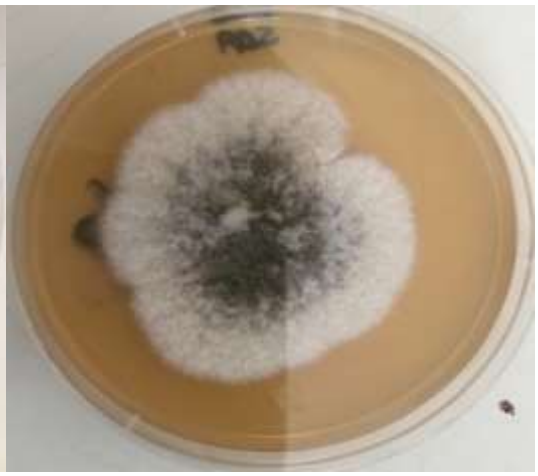


Plate 4.3: Aspergillus spp **Plate 4.4: Fusarium spp.**

Plates 4.3 and 4.4: Aspergillus and Fusarium species isolated from maize

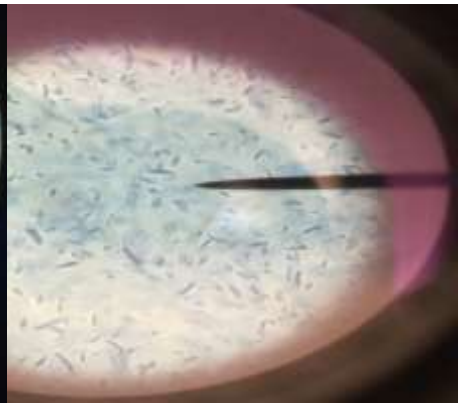


Plate 4.5 **Plate 4.6**

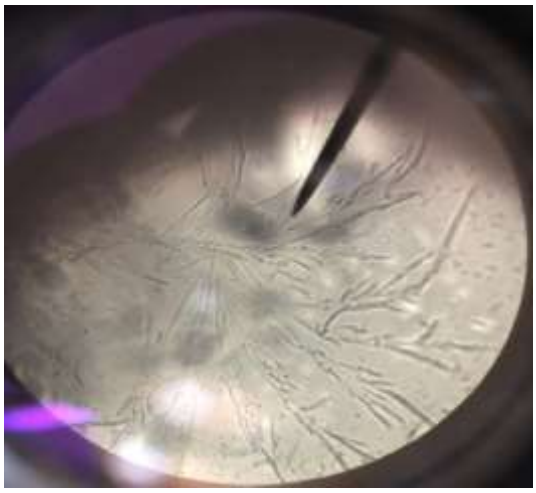


Plate 4.7

Plates 4.5.4.7: Microscopic features of the fusarium species isolated

Plates 5, 6 and 7 shows the curved macroconia and spindle shaped microconidia typical of fusarium species.

4.5 Fumonisin levels

Due to financial constraints, only 200 (82.3%) samples were tested for fumonisins, including 99 (75.6%) samples from Rift Valley and 101 (90.2%) from Lower Eastern. More samples from LE were purposively tested for fumonisin than the number tested from RV as many sample from LE had fusarium species identified compared to those from RV.

Of the 200 samples tested, 133 (66.5%) had fumonisin that was below the level of detection (<LOD), 63 (31.5%) had fumonisin levels ranging from 0.1 ppm to 4.0 ppm while 4 (2.0%) had levels that were greater than 4.0 ppm. Lower Eastern Region had higher proportion of samples with detectable fumonisin levels when compared to Rift Valley Region (55.4% vs 11.1%, $P < 0.05$) [Table 4.24].

Table 4.24: Fumonisin contamination levels per region

Fumonisin levels	Total (n=200)	Rift Valley (n=99)	Lower Eastern (N=101)	Fishers exact test P value
< LOD	133 (66.5%)	88 (88.9%)	45 (44.5%)	<0.001
0.1- 4.0	62 (31.0%)	10 (10.1%)	52 (51.5%)	<0.001
>4.0	5 (2.5%)	1 (1.0%)	4 (4.0%)	<0.001
Total	**200**	**99**	**101**	

The median fumonisin levels for Rift Valley and Lower Easter Regions was 0.66 ppm and 0.62 ppm respectively. There was no statistically significant difference in the fumonisin levels distribution between the two regions (z = -0.542, p = 0.588) [Figure 4.2].

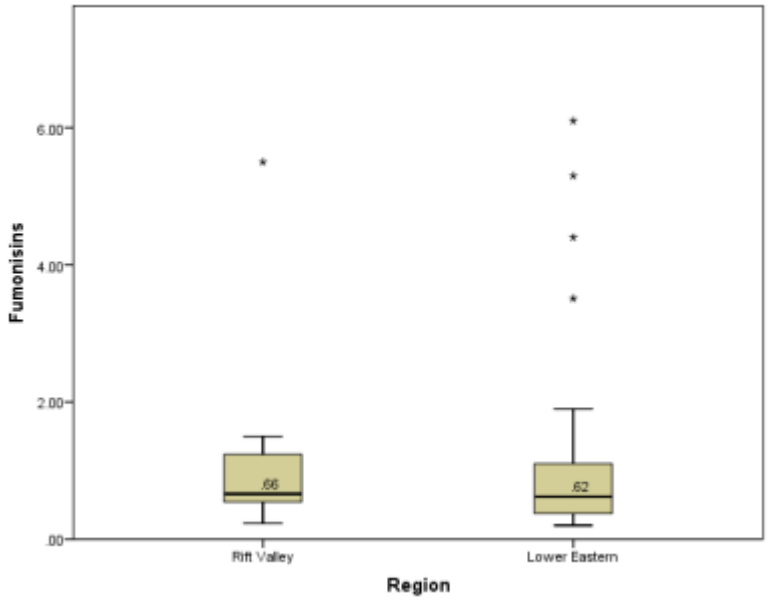


Figure 4.2: Distribution of Fumonisin levels between the two regions

The distribution of fumonisins per county did not show any significant differences [Table 4.25].

Table 4.25: Fumonisin contamination levels per county

	Fumonisins levels			
County	**<LOD**	**0.1- 4.0 ppm**	**> 4.0 ppm**	**Total**
Bomet	35 (83.3%)	7 (16.7%)	0 (0)	42 (100%)
Kitui	19 (46.3)	20 (48.8%)	2 (4.9%)	41 (100%)
Machakos	13 (44.8%)	16 (55.2%)	0 (0)	29 (100%)
Makueni	13 (41.9%)	16 (51.6%)	2 (6.%)	31 (100%)
Nakuru	27 (100%)	0 (0)	0 (0)	27 (100%)
Trans Nzoia	26 (86.7%)	3 (10.%)	1 (3.3%)	30 (100%)

A Kruskal-Wallis test showed that there was no statistically significant difference in fumonisin levels between the different counties, $\chi^2(4) = 3.397$, P -value = 0.494 [Fig 4.3].

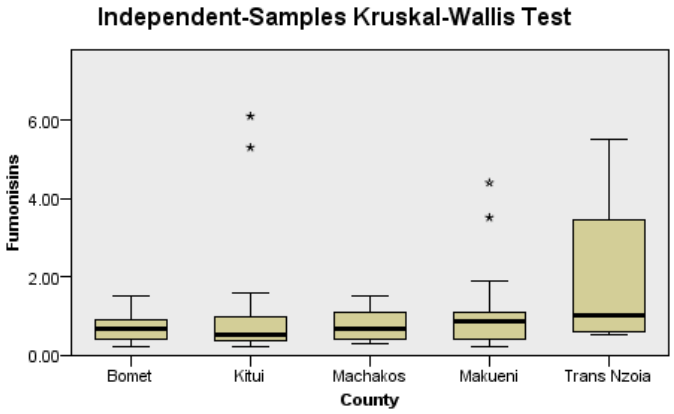


Figure 4.3: Distribution of Fumonisin Contamination per county

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Demographic information

Slightly more than half of the respondents were female (58.6%), a likely indicator of more female involvement in farming. However, this might also have been due to family roles where more females stay at home while males go out for work considering that the data collection was done mostly during weekdays. Most of the respondents depended on farming as their main source of livelihood and majority were low-income earners. In addition, most of the respondents in the study sites were small scale farmers and owned small pieces of land on which they lived and practiced farming. Most respondents interviewed had attained either primary or secondary level of education with only a few individuals having attained tertiary education level. According to Onemolease, *et al*., (2001) low education level has the ability of negatively impacting on farmers post-harvest practices and act as a barrier to their awareness of the consequences of maize contamination.

5.1.2 Knowledge and perceptions on mould infestation and its associated practices

Fungal infestation of maize was common in the regions under study with 173 (55.1%) maize samples of the 314 analyzed having fungi. The two main fungal species identified were *Aspergillus* and *Fusarium spp*. These two are known to produce aflatoxin and fumonisin mycotoxins respectively. This was also the case in the AfloSTOP survey where 25% of farmers in north Rift and Meru reported that some maize became mouldy while in storage in the last 12 months, whereas 20% of Makueni farmers reported the same.

Mould infestation was a serious problem in maize among the farmers surveyed in the AfloSTOP study, 54% had mould problems within the first month, that raised the question of their postharvest practices (AflaSTOP & IFPRI, 2013). In the current study, 3.5% of the respondents believed that mouldy maize was good for human consumption, 23.6% believed the maize was safe for animal consumption while 15.0% believed it was safe to sell it to be used for brewing. This was also the case in AfloSTOP survey where most farmers reported to feed mouldy maize to their livestock while a good number mixed bad maize with good ones before consuming it (AflaSTOP & IFPRI, 2013).

Losses can result from contaminated grain or rejection of products due to mould. Mycotoxins can restrict maize trade and limit income of smallholder farmers because of food safety concerns (Suleiman & Kurt, 2015; Suleiman *et al*., 2013).

Some respondents in this study consumed mouldy maize while others mixed it with good looking maize and sold it. In Ghana, it was reported that majority of the people interviewed believed that consumption of contaminated maize has no health effects due to rigorous cooking process of maize based foods (Akowuah *et al*., 2015).

Kang'ethe *et al*., (2017) reported that some of the farmers fed mouldy maize to livestock, as was the case in this study. If the maize is contaminated with fumonisins or aflatoxins, the mycotoxins can be passed on in the food chain leading to mycotoxins in milk hence exposure to those consuming it. According to Kang'ethe *et al*., (2017) a high proportion of milk samples from Nandi and Makueni were contaminated with aflatoxin M_1. They further reported that a good number of farmers used mouldy maize for brewing local brews commonly known as *Busaa* and *Chang'aa* as was the case in this study where 15% of the farmers sold it to the brewers.

Local brews made from contaminated mouldy maize have been found to contain fumonisins as was the case in Kenya (Kirui *et al*., 2014; Mbugua & Gathumbi, 2004), Botswana (Nkwe *et al*., 2005) and South Africa (Shephard *et al*., 2005).

5.1.3 Maize storage practices by farmers

5.1.3.1 Quantity of maize grown in the study sites

The land under maize cultivation was higher in Rift valley compared to Eastern Region. . A survey by AflaSTOP & IFPRI, (2013) showed that farmers in north Rift grow maize as their main crop, while eastern farmers seemed to diversify their crops hence depending less on maize farming. Most farmers in Rift Valley region only grew maize compared to farmers who did so in Makueni and Meru.

Most of the farmers in this study exhaust their maize from their storage by the fourth quarter of the year with only 39.3% having maize in their stores by the next harvest. This is likely to be due to the fact that the maize produced by the farmers was not adequate to last until the next season. It could also be due to farmers selling most of the maize hence not able to have enough maize to last them to the next harvesting season. Similar findings were found by Thamaga-Chitja *et al*. (2004) in Northern Kwazulu-Natal, South Africa where the average length the maize lasted in storage ranged from 5.6 months to 8.6 months showing that the maize is exhausted before the next harvest. In the case where the maize was exhausted before the next harvest, farmers bought maize to cater for the deficits as was the case in this study. This highlights the inadequacy in production that can lead to food insecurity and over dependence on maize both for food security and economic purposes.

5.1.3.2 Post-harvest maize management practices by the farmers

Post-harvest maize management practices that include drying, cleaning and storage among others are important and key along the maize value chain. Most respondents in this study stored their maize in their houses in a separate room. According to the findings by Thamaga-Chitja *et al*., (2004) in South Africa, the traditional practice was to leave the maize to dry in the field before harvesting. Different maize storage methods were applied with traditional silos being the most widely used storage method.

According to Potter & Hotchkiss, (1995) 75% to 85% of national storage of maize in Africa is on-farm storage by small-scale farmers and traders. The study reports that with such storage practices being highly ineffective, the resultant effects are losses associated with mould growth, contamination by mycotoxins such as aflatoxins and fumonisins, insect infestation as well as spoilage. According to Addo *et al*., (2002), most small-Scale farmers in Africa utilized varied maize storage practices including the use of open storage, woven baskets, thatched structures, raised platforms, polyethylene or polypropylene bags and jute bags. Most small-scale farmers dry their maize either when the maize is still in the field or when in storage. Kaaya & Kyamuhangire, (2006) reported that delays in drying of the maize in the field could cause losses during the storage period.

The lack of awareness or poor knowledge of good post-harvest practices and technologies by farmers has been pointed out as one of the challenges to be overcome if a meaningful reduction of postharvest losses is to be achieved (Abass *et al*., 2014; Kitinoja *et al*., 2011).

However, Kaminski & Christiaensen, (2014) reported that training of farmers on grain storage and protection technologies did not necessarily result in lower storage losses either arising from rodents or other loss agents since the farmers who received training incurred similar magnitudes of postharvest losses when compared to those farmers who did not receive the training. This observation suggests that farmers probably did not apply the knowledge acquired during the training, a behavior that could be related to the non-availability of the technologies proposed, lack of economic incentives to store and better protect food, non-cost effectiveness of technologies or the training and other interventions being too narrow or short-lived to pay off.

A large percentage of food products are lost during post-harvest practices in SSA (FAO, 2011). Hence there is need to invest in better post-harvest practices to reduce the losses. A cost-benefit analysis needs to be carried out to highlight the importance of such mitigation measures. Hence the need to provide evidence of the effects of post-harvest

losses and the quantities involved (Affognon *et al*., 2015). The reduction of postharvest food losses can make a significant contribution towards sustainable food security, and in recent years, this realization has caused renewed interest in mitigating postharvest losses.

The practice of leaving maize in the field after harvesting, sometimes uncovered was reported by majority of the farmers. This was also the case in Ghana where farmers heaped and left the maize in the field after harvesting (Akowuah *et al*., 2015). According to Hell and Mutegi (2011), leaving the harvested crop in the field prior to storage promotes fungal growth and insect infestation. Udoh *et al*., (2000) also reported that this is a common practice in Africa and is often due to labour constraints and the need to let the crop dry completely prior to harvest.

According to a study by Mwangi *et al*., (2017) the reduction of grain loss was associated with drying and cleaning the storage facility before storage, early pest control and storage periods shorter than two months. These findings provide important reasons for appraising current off-farm storage techniques with a view to taking possible actions for improvements.

Thirty three percent (33%) of the respondents in this study consumed and sold maize while still green. This practice might be greatly contributing to food insecurity. With large quantities of maize consumed while still green, the harvests are greatly reduced. This practice is rampant in Kenya with media reports in the country highlighting its effects of reducing the final dry maize output hence impacting negatively on food security with stakeholders requiring the government to come up with a policy to regulate the practice (Netya, 2017). In this study, this practice was more common in lower Eastern region compared to Rift Valley and this might partly explain why lower Eastern is more food insecure compared to Rift Valley.

The method of maize grain storage has been shown to influence *Fusarium spp* infestations of maize (Atukwase *et al*., 2012). As was the case in this study, a study in

Tanzania found that most farmers cleaned their storage facilities and cleared it of old maize grain stock before loading them with new maize grains stock (Kamala *et al*., 2016). This was also the practice by majority of the farmers in Guatamala where 98% of the farmers reported to clean their maize storage facility before storing freshly harvested stock (Mendoza *et al*., 2017).

As was the case in this study, Kang'ethe *et al*., (2017) also reported that most of the farmers in their study stored their maize in their homes in polypropylene bags. Such kind of bags have been shown to result in increase in moisture which favours fungal growth and mycotoxins contamination including fumonisins (Mutegi *et al*., 2013).

Traditional methods have been reported that farmers use to check whether maize grains are dry enough for storage including biting, listening for the sound produced when the grains were dropped and use of finger pressing technique (Mendoza *et al*., 2017; Kamala *et al*., 2016; Akowuah *et al*., 2015). As was the case in this study, the AflaSTOP survey reported that the most common way to check the grain for dryness in north Rift and Makueni was to drop the grain and ensure that there was a cracking sound as was practiced by over one-third of farmers in north Rift and over half of farmers in Makueni. AflaSTOP & IFPRI, (2013) reported that in Meru, the most common way to check the grain for dryness was to shake the grain.

Similar findings were reported by Kamala *et al*., (2016) in Tanzania where the farmers tested for grain dryness by biting or listening to the sound produced by the maize grains when dropped to the ground. In Ghana, the farmers were also reported to check for maize dryness using their teeth by biting (Akowuah *et al*., 2015). These and other traditional practices were also used by farmers in Guatamala where farmers used finger nail test (32%), mouth test (16.9%), and a combination of sound and visual observation (45.4%) to test if the maize was dry enough for storage (Mendoza *et al*., 2017). Such traditional practices are not accurate and might lead to maize being stored while still having high moisture content hence making it susceptible to fungal growth and a likelihood of fumonisin and aflatoxin contamination (Hell *et al*., 2008).

Some Postharvest practices have been reported to play a critical role in the maize contamination with fumonisins and aflatoxins. In the study by Kamala *et al*., (2016), storing maize without addition of insecticides and drying the maize on bare grounds were found to be significantly associated with fumonisin and aflatoxin contamination. In this study, drying maize on open ground was not common and most farmers dried their maize on a tarpaulin before storage. Most farmers dried the maize for 7 days with the range of drying being between 3 days to 7 days.

The current study findings are similar to what was found in the AflaSTOP & IFPRI, (2013) survey where the median farmer in both Rift Valley and lower eastern regions dried maize cobs for seven days per season. Almost all farmers in north Rift dry their maize grains after shelling the cobs on a tarpaulin. This shows that farmers clearly know the importance of avoiding contact with the ground. The most common drying method was to dry maize grains on a canvas/tarpaulin or plastic sheets (78%) as was the case in this study, unfortunately the method of drying depended on the weather conditions.

5.1.3.3 Maize storage and insect control measures

A number of studies have reported that insect attack contributes greatly to maize grains loss. According to Midega *et al*., (2016) insect pests, notably maize weevil and grain borer, contributed to approximately 40% grains loss. The farmers in the study areas practiced some form of insect control with the use of chemicals being the most widely used method by (70.7%) of the farmers. *Actellic* Super and *Actellic* dust were the main chemicals used for insect control. Similar practices were reported in a survey in Eastern and Rift Valley where 75% to 80% of the farmers treated their maize with chemicals before storage (AflaSTOP & IFPRI, 2013).

Unlike in this study, Midega *et al*., (2016) reported that aeration/sun-drying were the main insect mitigation practices in western Kenya as was reported to be practiced by 88.8% of the study participants. However, in this study, sun drying was also practiced, being the second most common insect control method as was reported by 32.5% of the

respondents.

In Uganda, Atukwase *et al*., (2012) reported that insect damage was observed to be high in maize stored in unshelled form during the first two months of storage; however, after four months, the insect damage was higher in shelled maize compared to the unshelled ones. Similar findings were reported in the study by Midega *et al*., (2016) where insect attack was reported to be high in shelled maize when compared to unshelled maize. Addition of chemicals kept the insect damage to 25% during the first four months after harvest, however by the sixth month the damage increased up to 80% in the maize where chemical had been added. The damage was found to be more in maize stored as grains than those stored as unshelled maize. The same study also found out that a number of farmers (7.6%) used ash (a traditional insect control methods) for insect damage prevention. However, according to Atukwase *et al*., (2012), the effectiveness of such methods needs to be evaluated further.

5.1.4 Characteristics of *Fusarium* species in the study sites

Aspergillus and *Fusarium* species were the main fungal species isolated from the maize samples in this study. As was the case in this study, Kangethe *et al*., (2017) also found co-occurrence of *Aspergillus* and *Fusarium* species in a study carried out in Nandi and Makueni Counties with the incidence of *Aspergillus* being higher than that of *Fusarium* species.

Fusarium verticillioides was the main *Fusarium* species isolated from the samples tested in this study. This was also the case in other studies conducted in Kenya where *F. verticillioides* was the predominant species. In a study by Kedera *et al*., (1999), *F. verticillioides* formerly known as *F. morniliforme* was found to be the dominant *Fusarium species* isolated in 60% of the samples. In other surveys, *F. verticillioides* was also found to be the main species representing 82% of the isolates from maize (Kedera *et al*., 1994) and 14% in maize from stalls and roadside traders in western and central Kenya (MacDonald & Chapman, 1997).

Fusarium verticillioides has also been shown to be the most common *Fusarium* species in most parts of Africa. In Ethiopia, *F. verticillioides* was shown to be the most commonly isolated *Fusarium* species associated with maize kernels (42%) (Tsehaye *et al*., 2017). Shephard *et al*., (2013_b) also reported high *F. verticillioides* prevalence in South Africa where all samples analysed tested positive for *F. verticillioides*. Phoku *et al*., (2012) also reported 70.3% of the samples analysed in South Africa were positive for *F. verticillioides* as was 88% of the samples analysed by Chilaka *et al*., (2012b). This was also the case in Nigeria where 70% of the samples analysed by Adejumo *et al*., (2007) and 89.3%of those analysed by Bankole & Mabekoje, (2004) were positive for the fungi. *Fusarium verticillioides* prevalence was 65.9% in Ghana (Kpodo *et al*., 2000) and 61.9%-77.5% in Uganda (Atukwase *et al*., 2012) .

Fusarium verticillioides has also been reported to be the most common *Fusarium* species in other regions of the world. It was shown to be the most dominant species in Spain (Aguín *et al*., 2014). de Oliveira *et al*., (2011) found *F. verticillioides* to be the predominant *Fusarium* species with a proportion of 96% in maize collected from the different parts of Brazil. The dominance of *F. verticillioides* confirms what has been reported in other studies in many different regions (Stumpf *et al*., 2013; Ono *et al*., 1999). This species has been shown to be the main producer of fumonisin followed by *F. proliferatum* (Marasas, 2001). Although several other *Fusarium* species have been shown to cause fumonisin contamination, *F. verticillioides* has been shown to be the main cause, especially in tropical and sub-tropical regions of the world (Picot *et al*., 2010; Logrieco *et al*., 2002).

There are many instances where *F. verticillioides* and *F. proliferatum* have been reported to occur together as was the case in southern Europe (Logrieco *et al*., 2002), Iran (Rahjoo *et al*., 2008) and Italy (Covarelli *et al*., 2012). However, there are places where other *Fusarium* species have been found to dominate. A study in Kosovo found *F. subglutinans* to be the most prevalent *Fusarium* species with a prevalence of 73% and 54% while *F. verticillioides* was the second most prevalent species at 14% and 32% in 2009 and 2010 respectively (Shala-Mayrhofer *et al*., 2013). This was also the case in

Canada where *F. subglutinans* was the main species isolated from maize (Tamburic-Ilincic & Schaafsma, 2009).

Since *Fusarium verticillioides* has been shown to be the main species associated with fumonisin contamination. It's presence in this study is a strong pointer of maize contamination with fumonisin in the study areas.

5.1.5 Fumonisin contamination levels

Most (31.0%) of the samples tested had fumonisin levels within the range of 0.1-4.0 ppm. Codex Alimentarius has set the maximum limit for fumonisins in raw maize grain at 4 ppm and 2 ppm (4000 µg/kg and 2000 µg/kg) in maize flour and maize meal respectively (Standard, 2015).

However, the Europe commission has set the limit levels of 1 ppm (1000 µg/kg) in maize or maize-based products for human consumption (European Commission, 2007). The United States Food and Drug Administration (FDA) recommends an allowed FB_1 level of 4 ppm for whole dry milled maize products meant for human consumption 2 ppm in de-germed dried milled maize (US Food Drug Administration, 2001). A considerable number of samples, 21 (10.5%) in this study had levels exceeding the set limits of European Commission and 5 samples (2.5%) exceeded all the internationally set limits. Unfortunately, most Sub-Saharan countries do not have their set standards as was noted by (Marasas, 2001), something which might be contributing to unregulated consumption of contaminated maize.

Kedera *et al*., (1999) did preliminary survey involving maize from western Kenya and reported that 47% of the 197 maize kernel samples had fumonisin B_1 of levels above 100 ng/g (0.1 ppm) with 5% having FB_1 levels of more than 1000 ng/g (1 ppm). In this study, (67) 33.5% of the samples had levels of fumonisins of 0.1-6.0 ppm while one sample had fumonisin of more than 6.0 ppm. Hence, the proportion of samples with more than 0.1 ppm fumonisin levels in this study was higher than that reported in by

Kedera *et al*., (1999).

In Ethiopia, the concentration of fumonisin in maize was found to range from 25 μg/kg to 4500 μg/kg (mean: 348 μg/kg and median: 258 μg/kg) (0.025 ppm to 4.5 ppm (mean: 0.348 ppm and median 0.258 ppm) (Tsehaye *et al*., 2017). A study in Vietnam found 90% of samples analyzed to have fumonisin concentrations of less than 4 ppm with 3.1% having fumonisin levels of over 12 ppm (Phuong *et al*., 2015).

Several studies have shown differences in the levels of fumonisins over different regions and within the same region and this was associated with different agronomic, biological, abiotic and existing environmental factors (Munkvold, 2003). This confirms the need for continuous surveillance to better understand these factors.

Susceptibility of maize to aflatoxin and fumonisin contamination has been reported in many African Countries (Murashiki *et al*., 2017; Tsehaye *et al*., 2017; Nyangi *et al*., 2016; van Rensburg *et al*., 2015; Atukwase *et al*., 2012; Bii *et al*., 2012; Kimanya *et al*., 2008). However, most studies in Kenya have focused more on aflatoxin with little focus placed on fumonisins and other mycotoxins including ochratoxin, deoxynivalenol (DON), nivalenol, zearalenone and ochratoxin A that are also known to be of public health importance.

Exposure to fumonisin has been reported in many countries with varying levels of fumonisin being detected in humans. Many parts of the developing world rely on maize and maize-based foods as a major staple food in their diet, and these populations can be chronically exposed to high levels of fumonisins. Exposure to FB_1 in Tanzania was reported to be within the range of 0.78 - 141.97 μg/kg bw/ day (Kimanya *et al*., 2008). Another study by Kimanya showed that infants were exposed to fumonisins through maize based foods with levels ranging from 0.003 μg/kg bw/day to 28.838 μg/kg bw/day (median; 0.48 μg/kg bw/day) with 26 of the 131 infants being exposed to levels above the permitted levels of 2 μg/kg bw (Kimanya *et al*., 2010). Similarly, human exposure was shown to be 0.195, 0.085 and 0.1 μg/kg ug/kg bw/day for Spanish toddlers, children

and adults respectively (Cano Sancho, 2013) and 0.063 μg/kg bw/day in Brazilian populations (Bordin et al., 2014).

Fumonisin B_1 has been detected in the urine of exclusively breastfed infants, hence it is likely that human breast milk might be a source of exposure in children (WHO, 2018). Magoha *et al*., (2014) reported mother's milk contamination with fumonisin with 58 of the 143 milk samples from mothers containing FB_1 in the range of 6.6 to 471.1 ng/ml (0.0066 to 0.4711 ppm) in Tanzania. This exposes the neonates to FB_1 with some of them being exposed to fumonisin levels that was higher than the internationally recommended levels.

In many countries of sub-Saharan Africa, maize and its products are consumed on a daily basis. It follows that people might be continuously getting exposed to a high level of fumonisins. In South Africa, Phoku *et al*., (2012) found the level of FB_1 in urine to be more than that contained in porridge consumed by the study participants. This was linked to other foods consumed by these participants that might have been contaminated by fumonisins.

Maize being the staple food in Kenya, it is likely that people are exposed to fumonisins through the maize-based food consumed as studies have shown. High levels of fumonisin were reported in local maize-based brew in Kenya (Kirui *et al*., 2014) hence a high risk of exposure to humans.

Fumonisin exposure has also been associated with poor growth or growth impairment in children (Shirima *et al*., 2014), high incidences of oesophageal cancer (FAO/WHO, 2002; Chu & Li, 1994; Sydenham *et al*., 1990), and neural tube defects in foetuses (Missmer *et al*., 2005; Marasas *et al*., 2004).

Exposure to fumonisins in animals has also been associated with porcine pulmonary edema (PPE) syndrome in pigs (Haschek *et al*., 2001), Equine Leucoencephalomalacia (ELEM) in horses, and experimentally, liver cancer in rats (Marasas *et al*., 1984).

With the shown prevalence of fumonisins in maize which is a staple food in many countries, especially in sub-Saharan Africa, there is likelihood that people are exposed to high levels of fumonisin in maize and its products that they consume on a daily basis. This puts them at risk of diseases and conditions associated with fumonisins. Infant and children exposure to fumonisins have been associated with growth retardation and impairment as was shown in Tanzania (Chen *et al*., 2018; Shirima *et al*., 2015; Kimanya *et al*., 2010).

Studies from different regions have shown consumption of fumonisin contaminated food to be associated with oesophageal cancer as was the case in South Africa (Rheeder et al., 1992; Marasas, 1988, 1982; Marasas *et al*., 1981) Iran (Shephard *et al*., 2000) and Northern Italy (Franceschi *et al*., 1990). Studies in China showed an increased incidence of liver cancer in people who consumed fumonisin contaminated maize (Li *et al*., 2001; Chu & Li, 1994). Fumonisin has been classified to be carcinogenic in class 2B group by WHO (IARC, 2011). Apart from cancer, fumonisin contamination has been associated with neural tube defects in fetuses (Marasas *et al*., 2004; Hendricks, 1999; Placinta *et al*., 1999).

The contamination of maize with fumonisin has been shown to depend on environmental factors, post-harvest handling practices and the maize breed variety, and the interaction of some or all these factors (Santiago *et al*., 2015; Mutiga *et al*., 2015). Maize variety has also been shown to be significantly associated with fumonisin contamination where some varieties are more susceptible than others.

High temperatures and warm regions have been linked to high levels *F. verticillioides* infestation and of fumonisin contamination in tropical Ethiopia (Tsehaye *et al*., 2017) as was also the case in Zambia (Schjøth *et al*., 2009) and humid regions as was the case in Uganda, (Atukwase *et al*., 2009) and Zimbabwe (Gamanya & Sibanda, 2001). High moisture content (Atukwase *et al*., 2012), high humidity (Tsehaye *et al*., 2017) and high rainfall (Mukanga *et al*., 2010) have also been shown to be positively correlated with fumonisin levels.

Some post-harvest practices have been reported to be associated with fumonisin contamination. Higher mean contamination was found in maize transported as cobs and when maize on cobs were transported without polypropylene bags (Hove *et al*., 2016). The way the maize is stored after harvesting was also shown to be associated with fumonisin levels. Maize stored in traditional structure was shown to have higher levels of fumonisins compared to maize stored in granaries (1.61 mg/kg) (1.61 ppm) ($p < 0.05$) after six months of storage in Uganda (Atukwase *et al*., 2012).

Maize stored in poorly ventilated structured was associated with a significant increase in fumonisin contamination level (Fandohan *et al*., 2005). Drying the maize on bare ground, storing unsorted maize and storing maize without the application of insecticides was also associated with high fumonisin levels (Kamala *et al*., 2016). Damage of maize grains by insects (Fandohan *et al*., 2005) or during shelling (Fandohan *et al*., 2006) were also shown to be associated with high fumonisin contamination.

5.2 Conclusion

Majority of the individuals interviewed in this study were small-scale farmers. Leaving maize in the field after harvesting was a common practice among these farmers. Use of chemicals was the main pest control measure employed. A good number were also using sun drying as a pest control method.

Farmers' post-harvest perceptions and practices have the potential of affecting the quality of maize with poor post-harvest practices such as storing of maize before they are fully dry, storage of maize before sorting them and improper storage methods. This exposes the maize grains to infestation by *Fusarium* fungi infestation and subsequent fumonisin contamination that might result in adverse health effects to the consumers.

Fusarium verticillioides is the most prevalent Fusarium species isolated in the study sites. This is the main fumonisin producing fungi. Contamination of maize with fumonisin is both a public health threat and poses much risk to food safety and security

in the country.

A considerable number of samples, 21 (10.5%) had fumonisin levels exceeding the set limits of European Commission and 5 samples (2.5%) exceeded all the internationally set limits. Lower Eastern region had more samples with detectable level of fumonisin compared to Rift Valley region. Maize being a staple food in the study regions, fumonisin contamination in these regions therefore pose a significant public health threat as well as food safety and security in the Country.

5.3 Recommendations

From the findings of this study, the following recommendations are made;

5.3.1 Policy recommendations

i. Continuous farmer education and extension services should be carried out by both the County and National governments to educate the farmers on the causes of mycotoxins contamination and the available prevention measures in order to influence the knowledge and attitudes on their current knowledge.
ii. The County and National governments should train farmers in Rift Valley and Lower Eastern on proper post-harvest maize management practices to help them curb the challenge of contamination of maize grains with fumonisin producing fungi.
iii. There is need for public health intervention at both County and National governments to the challenge of fumonisin contamination of maize through increased awareness creation with regards to the public health impacts of consuming fumonisin contaminated maize and maize products.
iv. There is need for the development of local standards and protocols for monitoring of fumonisin and other mycotoxins contamination in maize. This should be done by the line ministries of Health and Agriculture at both County and National Government. Besides, the national government should use the

available data to develop evidence based fumonisin prevention and management policies and strategies.

v. Fumonisin having been reported to be carcinogenic, there is an urgent need for continuous monitoring of maize and formulation of policies to prevent contamination by the National government line ministries of Health and Agriculture.

5.3.2 Recommendations for further research

i. *Fusarium spp* and fumonisin surveillance studies should be conducted in all maize producing regions of the country in order to understand the true extent of the fumonisin contamination of maize in the country.

ii. There is need for inferential studies to determine the association of poor post-harvest maize management practices and fusarium species and fumonisin contamination in Kenya.

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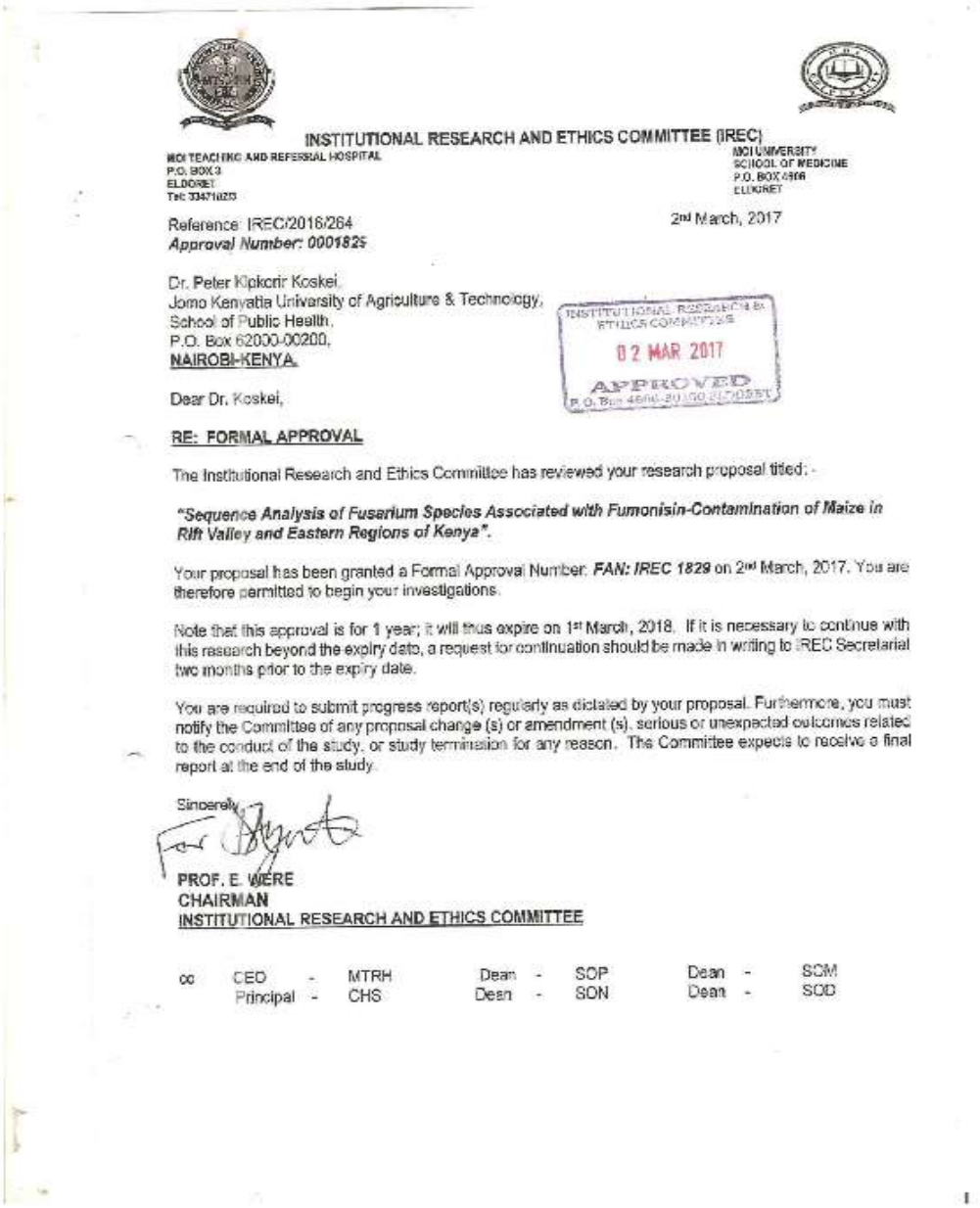
APPENDICES

Appendix I: IREC Ethics Approval



INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471020

MOI UNIVERSITY
SCHOOL OF MEDICINE
P.O. BOX 4606
ELDORET

Reference: IREC/2016/264
Approval Number: 0001829

2nd March, 2017

Dr. Peter Kipkorir Koskei,
Jomo Kenyatta University of Agriculture & Technology,
School of Public Health,
P.O. Box 62000-00200,
NAIROBI-KENYA.

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
02 MAR 2017
APPROVED
P.O. Box 4606-30100 ELDORET

Dear Dr. Koskei,

RE: FORMAL APPROVAL

The Institutional Research and Ethics Committee has reviewed your research proposal titled: -

"Sequence Analysis of Fusarium Species Associated with Fumonisin-Contamination of Maize in Rift Valley and Eastern Regions of Kenya".

Your proposal has been granted a Formal Approval Number: ***FAN: IREC 1829*** on 2nd March, 2017. You are therefore permitted to begin your investigations.

Note that this approval is for 1 year; it will thus expire on 1st March, 2018. If it is necessary to continue with this research beyond the expiry date, a request for continuation should be made in writing to IREC Secretarial two months prior to the expiry date.

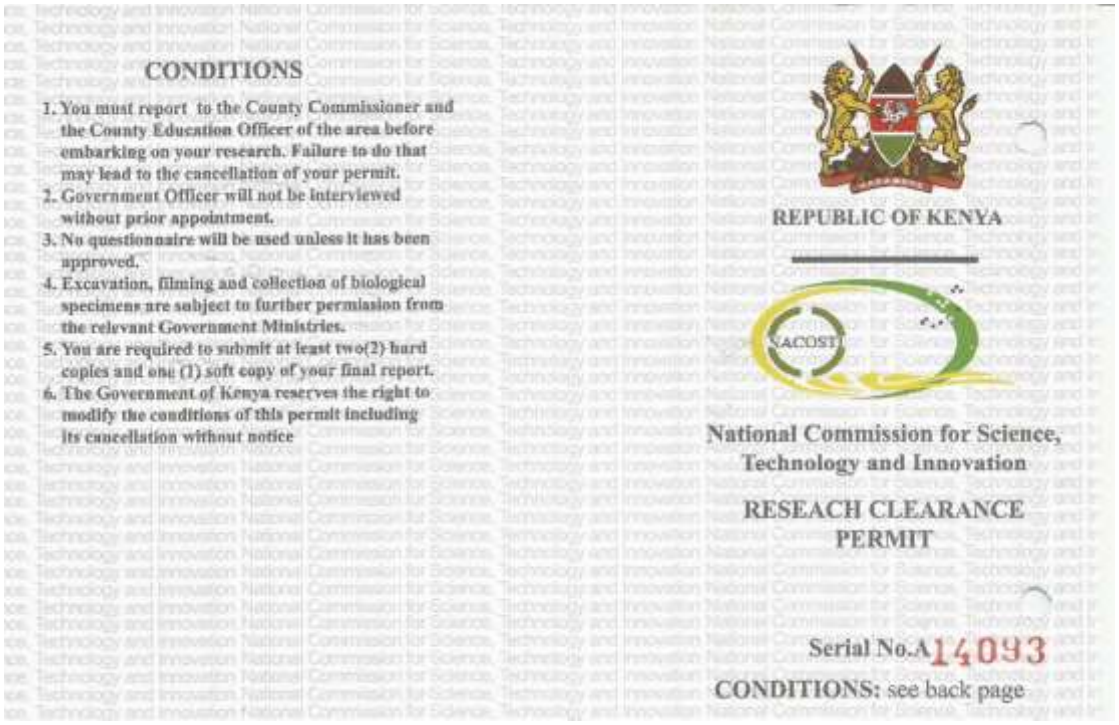
You are required to submit progress report(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change (s) or amendment (s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc CEO - MTRH Dean - SOP Dean - SCM
Principal - CHS Dean - SON Dean - SOD

Appendix II: NACOSTI research clearance permit



CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit.
2. Government Officer will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one (1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

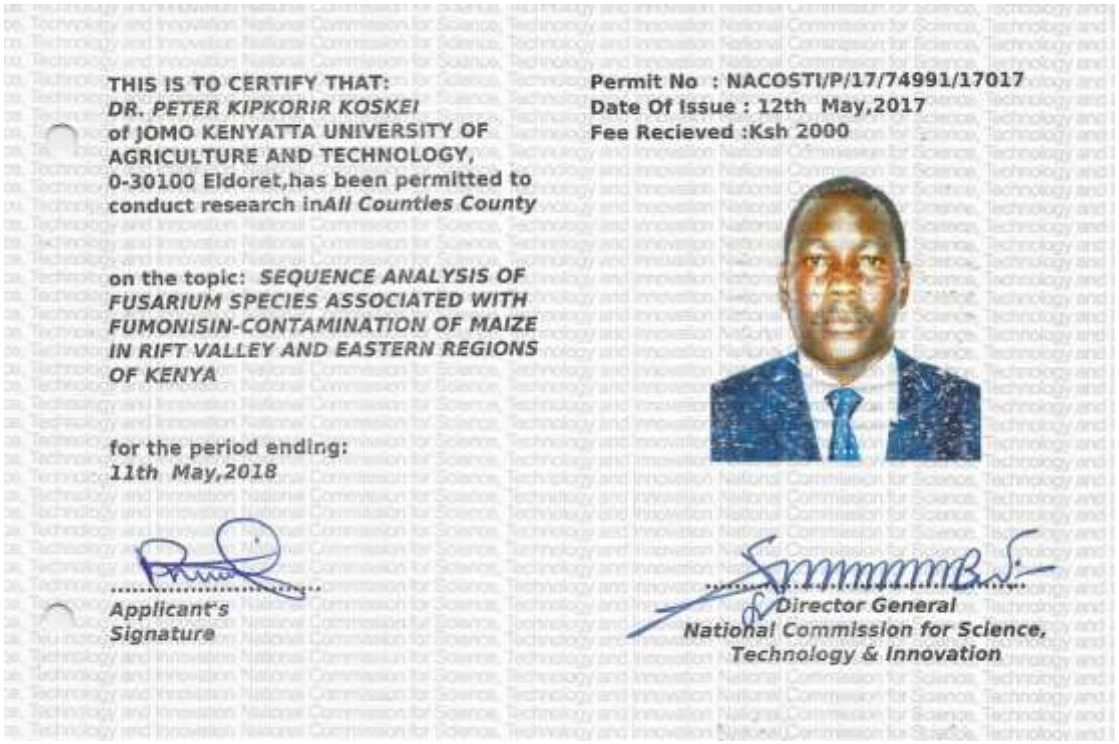
REPUBLIC OF KENYA

National Commission for Science, Technology and Innovation

RESEACH CLEARANCE PERMIT

Serial No.A14093

CONDITIONS: see back page



THIS IS TO CERTIFY THAT:
DR. PETER KIPKORIR KOSKEI
of JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, 0-30100 Eldoret,has been permitted to conduct research in*All Counties County*

on the topic: *SEQUENCE ANALYSIS OF FUSARIUM SPECIES ASSOCIATED WITH FUMONISIN-CONTAMINATION OF MAIZE IN RIFT VALLEY AND EASTERN REGIONS OF KENYA*

for the period ending:
11th May,2018

.....
Applicant's Signature

Permit No : NACOSTI/P/17/74991/17017
Date Of Issue : 12th May,2017
Fee Recieved :Ksh 2000

.....
Director General
National Commission for Science, Technology & Innovation

Appendix III: Consent Form

ASSESSMENT OF MAIZE STORAGE PRACTICES

You are requested to participate in a research study on assessment of the maize storage practices. This is a study conducted by a PhD student of Jomo Kenyatta University of Agriculture and Technology – Institute of Tropical Medicine (ITROMID).

The purpose of this study is to assess the types of maize storage methods being practiced by farmers that will ultimately influence the quality of maize consumed in the community.

Procedures of the study

If you agree to participate in this study, you will be taken through a pre-designed questionnaire.

Voluntary nature of participation

Participation in this study is voluntary. You shall not be penalized if you do not participate in the study, your decision will be respected.

Confidentiality of the information

Information given in this study will be treated as confidential and will only be used for the purpose of this study. Your names will not be used on the questionnaire and subsequent reports.

Benefits associated with participating in the study

The study findings will help to inform policy makers in the Ministries of Health, and Agriculture on how to address food insecurity. There is, however, no direct benefits to individual respondents.

Participant's consent

I have read and understood the information above and by signing below, I consent to participate in the study

Participant's name..... signature..... Date.....

Name of the staff obtaining the consent..... signature.....……

Date.....

CONSENT FORM/FOMU YA RIDHAA (Kiswahili Translation)

Unaombwa kushiriki katika utafiti wa kutathmini njia za kuhifadhi mahindi. Utafiti huu unafanywa na mwanafunzi wa masomo ya shahada ya PhD katika Chuo Kikuu cha Jomo Kenyatta- Instutute of Tropical Medicine (ITROMID).

Lengo la utafiti huu ni kuthamini aina ya njia za kuhifadhi mahindi ambazo wakulima hutumia na hatimaye kuathiri ubora wa mahindi yanayotumika.

Utaratibu wa utafiti.

Ukikubali kushiriki katika utafiti huu, kuna maswali utaombwa kuyajibu.

Hiari ya kushiriki

Ushiriki wako katika huu utafiti ni wa hiari. Kukataa kushiriki katika utafiti huu haitakuwa na madhara yoyote na uamuzi wako utaheshimiwa kamwe.

Usiri wa maelezo/Ujumbe

Ujumbe utakao tupatia utakuwa siri na utatumika kwa madhumuni ya utafiti huu pekee. Majina ya watu hayatatumika popote katika utafiti huu.

Faida ya kushiriki katika utafiti

Matokeo ya utafiti huu yatasaidia watengeneza sera katika Wizara za Afya na Kilimo jinsi ya kushughulikia ubora wa kuifadhi nafaka na kadhalika uhaba wa chakula.

Ridhaa ya mshiriki

Nimesoma na kuelewa maelezo hapo juu na kwa kuweka sahihi hapa chini, nakubali kushiriki katika utafiti huu.

Jina la mshiriki..... Sahihi..... Tarehe.....

Jina la shahidi ..... Sahihi.....……Tarehe.....

Appendix IV: Questionnaire

QUESTIONNAIRE SURVEY TOOL

Questionnaire No: .....

Date Administered: .....

Place: ……...

Region: ……

County: ……

Village: ……

INSTRUCTIONS TO THE RESEARCH ASSISTANTS

Please indicate by putting a tick (√) in the space(s) provided or filling in the blank space(s) the information you get from the respondents as appropriate. Do not write the respondent's name.

PART I: SOCIO-DEMOGRAPHIC INFORMATION

1. Age (In Years) ……
2. Gender

   Male

   Female

What is the highest level of formal education attained?

3. None
4. Primary

   Secondary

   Tertiary

5. Occupation

   Full time farmer

   Business man/Business woman

   Employed

   Others (Please specify).....

6. Did you produce any maize in the last one year?

   Yes

   No

7. How many acres of land did you own in the last 12 months? ……
8. How many acres of land did you cultivate in the last 12 months? …….

PART II: HOUSEHOLD MAIZE CONSUMPTION

9. Over the past 30 days what was your household's total consumption of maize?

   1–5 Gorogoros

   5-10 Gorogoros

   11-15 Gorogoros

   Over 15 Gorogoros

10. How much of the consumed maize was from own production?

    None

    Some

    All

11. How much of consumed maize was purchased?

    None

    Half

    All

12. Do you believe that:

	Yes	No
a) It is safe for humans to consume mouldy maize?		
b) It is safe for animals to consume mouldy maize?		
c) It is safe to consume milk from the cow that was fed with mouldy maize?		

d) It is safe to mix dry maize with wet maize for storage?
e) It is safe for humans to consume maize that looks

   good but is wet or smells bad

f) It is safe to sell mouldy maize to local brewers

13. During this month, how much maize was taken from storage for home consumption? ……
14. In your opinion, what was the quality of the grain taken from storage that was consumed? …….
15. Of consumed maize, how much was discolored, damaged or mouldy in the last month?……...
16. What did you do with the discolored, damaged, mouldy grain taken to be consumed? …….

PART III: KNOWLEDGE, ATTITUDES AND PRACTICES ON MAIZE POSTHARVEST AND STORAGE

17. Do you use any of the following insect storage control measures?

a) Chemical
b) Insect
c) Ash
d) Airing
e) None
f) Other (please specify) ……

18. If chemical use, which chemical did you use (apply)?

a) Actellic dust
b) Actellic supper

c) Malathion dust
d) Skana super
e) Blue cross
f) Spider dust
g) Other (please specify) ……

19. What quantity of maize in cobs (90 kg bags) was put aside before shelling as a result of rotting, moulds, discoloured grains? …….
20. How many bags did you have immediately after shelling maize from main harvest? ……
21. After the previous harvest, which month did you put maize in storage?

    …….

22. For how many months did the stored maize stayed in the storage?

    ……..

23. At what month did you take the first batch of maize out from storage?

    ……...

24. At what month did you take the last batch of maize out from storage?
25. Over the last two seasons, did you follow the following post-harvest maize cob management methods?

a) Leave at piles in the field and not cover it with anything
b) Leave at piles in the field and cover the piles
c) Bring home and pile up in separate room
d) Take to commercial storage facility
e) Consume and sell as green maize
f) Dry off the ground (on tarpaulin)

26. How long did you keep the maize on the cob? ……..
27. After shelling, how long did you dry the grain? ……
28. What method did you use for drying the grain? ……
29. How often do you store maize in the following conditions?

    Dehusked cobs ……

    In the husk ……..

    As grain …….

30. In your opinion, how do you know if the grain is dry enough?

    …….

31. Do you agree that your grain was dry enough last season?

    Yes

    No

32. If, in your opinion, your grain wasn't dry enough last season, why wasn't it?

    …….

33. Prior to placing maize into storage facility, do you clean the storage facility of old maize and remnants from last storage?

    Yes

    No

34. During that month, how much maize was taken from storage to be sold?

    ……

35. In your opinion, what was the quality of the grain taken from storage that was sold?

    ……...

36. What was the average price that you received for sold grain during that month?

    ……

37. Who was the buyer for the largest sale in the month? ……..

38. Of the sold maize, how much was discolored, damaged or mouldy in [month]?

    ……

39. Do you think that the following factors cause the maize grain to go mouldy/discolor?

	Yes	No
a) Poor soil condition where maize is grown		
b) Wet weather during harvest		
c) Wetness in the piles of harvested maize		
d) Dampness in storage place		
e) Harvesting maize earlier than usual		
f) Insects/pests in storage place		
g) Drying the maize longer than average		

40. Do you think that mould formation and growth of mould can be minimized by the use of the following storage techniques?

	Yes	No
a) Spreading chemical over the grain before storage		
b) Storing only completely dry grain		
c) Storing grain in a plastic bag		
d) Storing grain in a plastic container		

e) Storing grain in a metal silo

f) Storing grain in a clay pot

PART IV. SOCIO-ECONOMIC CHARACTERISTICS

41. Source of family income

a) Salaried job b) farmer c) merchant d) Pension e) Other, specify……

42. How many of the following items do you own?

Type of livestock	**Number**
Cattle	
Sheep	
Goats	
Chicken	
Bicycle	
Radio	
TV	
Other, specify	

43. Monthly income (Give approximate amount) Kes

a) 0-5,000 b) 5,001-10,000 c) 10,001-15,000 d) over 15,000

44. Do you own the land you live on? A) Yes b) No

45. Residence/house

a) Self owned b) Rented c) Other, specify……..

18. Type of house

a) Permanent b) Semi-permanent c) Temporary

46. Source of fuel for lighting

a) Electricity b) Solar panels c) Kerosene d) Other, specify…….

47. Source of fuel for cooking

a) Firewood b) Gas c) Charcoal d) Kerosene e) Other, (specify)…….

Appendix V: Storage Structures in the Study Regions

Appendix VI: Abstracts of this work's Publications

Koskei, P., Bii, C. C., Musotsi, P., & Muturi Karanja, S. (2020). Postharvest storage practices of maize in rift valley and lower eastern regions of Kenya: a cross-sectional study. *International journal of microbiology*, *2020*.

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International Journal of Microbiology
Volume 2020, Article ID 6109214, 10 pages
https://doi.org/10.1155/2020/6109214

Hindawi

Research Article

Postharvest Storage Practices of Maize in Rift Valley and Lower Eastern Regions of Kenya: A Cross-Sectional Study

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An assessment of local farmers' knowledge, attitude, and practices on postharvest maize storage and management was carried out with a view of understanding its role in maize contamination with mycotoxins and postharvest losses in Rift Valley and Lower Eastern Regions of Kenya among 165 and 149 farmers, respectively. Differences between the two regions were analyzed using the Chi-square test, Fisher exact test, and two-sample *t*-test. The median quantity of maize harvested by farmers in the two regions after shelling was 585 kg. A median of 20 kg of maize was put aside as a result of rotting before shelling, and there was a significant mean difference in maize set aside as a result of rotting between the two regions (107.88 kg vs. 31.96 kg; t (306.25) = 5.707, P value

Koskei, P., Bii, C., Musotsi, P., & Karanja, S. (2020). Presence of Fusarium Species and Fumonisin Contamination of Maize in Sub-Saharan Africa: A Systematic Review. *African Journal of Education, Science and Technology*, *5*(4), 132-146.

Presence of Fusarium Species and Fumonisin Contamination of Maize in Sub-Saharan Africa: A Systematic Review

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Abstract

Fumonisin is the second most commonly isolated mycotoxin in maize, produced mainly by Fusarium verticillioides. Fumonisins are associated with health effects in humans and animals. We reviewed the available literature on fumonisin contamination of maize in Sub-Saharan Africa (SSA) and the Fusarium species linked to the contamination. We searched for articles in Science Direct, PUBMED, and Google Scholar databases in June 2018 and updated in August 2018. We employed narrative synthesis in data synthesis. Out of the 2,156 records obtained from the search, 39 met the inclusion criteria. Of the included studies, 37 were cross-sectional studies, while two were controlled trials. Fourteen of the included studies were based on South Africa. The Fusarium species predominantly responsible for fumonisin production was Fusarium verticillioides. Other notable Fusarium species included F. proliferatum and F. graminaerum. In 13 studies, all samples tested positive for fumonisins. The levels of Fumonisin varied from one country to another and region to another in the same country. With maize fumonisin contamination reported in several SSA countries, there is a higher risk of human exposure and hence, health effects on individuals.

Keywords: *Fusarium;* fumonisins*; maize;* Sub-Saharan Africa

INTRODUCTION

Fusarium is a genus of fungi with species that produce mycotoxins with the ability to cause toxicity in animals, plants and humans (Abbas *et al*., 2013). *Fusarium* species can infect plants during different development stages. They cause diseases in plants such as seed rot,

Koskei, P., Karanja, S., Mashedi, O., Tetsuhiro, M., Tohru, G., Takashi, Y., & Bii, C. (2020). Isolation and Characterization of Fusarium Species and Fumonisins Contamination in Maize from Lower Eastern and Rift Valley Regions of Kenya. *African Journal of Education, Science and Technology, 6*(1), 19-28.

Isolation and Characterization of *Fusarium* Species and Fumonisins Contamination in Maize from Lower Eastern and Rift Valley Regions of Kenya

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Abstract

Maize serves as a staple food in many Sub-Sahara African (SSA) Countries. It is mostly susceptible to mycotoxins including aflatoxin and fumonisin contamination. Fumonisins are produced by the Fusarium species, predominantly Fusarium verticillioides. Fumonisins' health hazards are documented in many parts of the world. However, few studies exist on fumonisin contamination in maize locally. The presence of Fusarium species and the associated fumonisin contamination of maize grown in Rift Valley and Lower Eastern regions of Kenya were assessed. Maize samples were collected from randomly selected households in three Counties from each of the two regions. Isolation and characterization of Fusarium species was done using Daniel et al., (2011) protocol. Envrologix Quick Tox Kit was used to quantify fumonisin levels. Aspergillus species was the most prevalent fungi species isolated (50.3%) followed by Fusarium species (39.3%) with F. verticillioides accounting for 80.8% of all Fusarium spp. Of the 200 samples analyzed, 133 (65.5%) had fumonisin levels below the level of detection (< 0.1 ppm), 63 (31.5%) had fumonisin level of between 0.1 ppm- 4.0 ppm and 4 (2.0%) sample had fumonisin levels of more than 4.0 ppm. Lower Eastern Region had higher proportion of samples with detectable fumonisin levels compared to Rift Valley Region (55.4% vs 11.1%). In conclusion Fusarium verticillioides commonly