ASSESSMENT OF RODENTS' POSTHARVEST LOSSES IN ON-FARM MAIZE STORAGE IN KENYA

KUKOM EDOH OGNAKOSSAN

MASTER OF SCIENCE

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Assessment of Rodents' Postharvest Losses in on-farm Maize Storage in Kenya

Kukom Edoh Ognakossan

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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..

Kukom Edoh Ognakossan

This thesis has been submitted for examination with our approval as university supervisors.

Signature.. Date..

Dr. Daniel Ndaka Sila
JKUAT, Kenya

Signature.. Date..

Dr. Willis O. Owino
JKUAT, Kenya

Signature.. Date..

Dr. Hippolyte Affognon

ICRISAT, Mali

DEDICATION

To my late mother, Paula Ameyovi Gadegbeku

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TABLE OF CONTENTS

DECLARATION ii

DEDICATION iii

ACKNOWLEDGEMENT iv

TABLE OF CONTENTS..vi

LIST OF TABLES..xi

LIST OF FIGURES..xiii

LIST OF APPENDICES..xv

ABBREVIATIONS AND ACRONYMS..xvi

ABSTRACT xvii

CHAPTER ONE 1

INTRODUCTION 1

1.1. Background 1

1.2. Problem Statement..2

1.3. Justification 4

1.4. Objectives 5

1.4.1. General objective 5

1.4.2. Specific objectives 5

1.5. Hypotheses 5

CHAPTER TWO 24

LITERATURE REVIEW 24

2.1. Maize 24

2.1.1. Origin and distribution 24

2.1.2. Importance of maize in Kenya 24

2.2. Postharvest losses 26

2.2.1. Concept of Postharvest Losses 26

2.2.2. Different types of postharvest food losses 26

2.2.3. Importance of grain losses 27

2.2.4. Magnitude of Maize Grain Postharvest Losses in Kenya 28

2.2.5. Factors and causes of maize grain losses 29

2.3. Description of Rodents 36

2.3.1. Distribution and Characteristics of Rodents 36

2.3.2. Feeding Ecology of Commensal Rodents 37

2.3.3. Public Health Concerns of Rodents 38

2.4. Rodent Pest Management Strategies in Storage 38

2.4.1. Preventive Methods 38

2.4.2. Control Measures 39

CHAPTER THREE 41

MATERIALS AND METHODS 41

3.1. Maize Storage Practices and Farmers Assessment of Rodent Postharvest Losses 41

3.1.1. Study Area 41

3.1.2. Sampling and Data Collection 43

3.2. Estimation of the Actual Weight Losses Caused by Rodents in Storage and Identification of Rodents Species Associated to the Losses and their Population Estimate 46

3.2.1. Study Area 46

3.2.2. Estimation of the Actual Weight Losses Caused by Rodents in Storage .. 46

3.2.3. Identification of Rodents Species Associated to the Losses in the Farmer's Stores and their Population Estimation 51

3.3. Influence of Rodents Damages on the Grains Contamination by Storage Moulds and Aflatoxins 54

3.3.1. Samples Preparation 54

3.3.2. Total Moulds Count 55

3.3.3. Determination of Fungal Incidence 55

3.3.4. Aflatoxin Analysis 56

3.4. Data Analysis 57

CHAPTER FOUR **59**

RESULTS **59**

4.1. Maize Storage Practices and Farmers' Assessment of Rodent Postharvest Losses 59

4.1.1. Socio-Demographic Characteristics of Respondents 59

4.1.2. Maize Storage Forms 61

4.1.3. Maize Storage Structures 63

4.1.4. Storage Problems 70

4.1.5. Control of Storage Pests 72

4.1.6. Farmers Training on Grain Storage and Protection Technologies 76

4.1.7. Losses During Maize Storage 77

4.1.8. Factors Affecting Maize Postharvest Losses due to Rodents 80

4.2. Actual Weight Losses and Percentage Damage Grains Caused by Rodents in Storage 83

4.3. Rodents Species Associated with the Losses and their Population Estimation86

4.4. Influence of Rodents Damages on the Grains Contamination by Storage Moulds and Aflatoxins 88

CHAPTER FIVE **91**

DISCUSSION **91**

5.1. On-Farm Maize Storage System 91

5.2. Magnitudes of Farmers' Perceived Weight Losses....................................93

5.3. Factors Affecting Maize Losses..95

5.4. Actual Weight Losses Caused by Rodents in Storage..................................98

5.5. Diversity of Rodents' Species Associated to the Losses in on-Farm Maize Storage..100

5.6. Influence of Rodents Damages on the Grains Contamination by Storage Moulds and Aflatoxins..101

CHAPTER SIX..103

CONCLUSION AND RECOMMENDATIONS..103

6.1. Conclusion..103

6.2. Recommendations..104

REFERENCES..105

APPENDICES..126

LIST OF TABLES

Table 3.1: Characteristics of the maize-specific agro-ecological zones of Kenya....42

Table 3.2: Study Sites (sub-counties) 45

Table 4.1: Socio-demographic characteristics of respondents (n = 630).................60

Table 4.2: End uses of maize harvested by farmers 61

Table 4.3: Proportions of farmers using different forms of maize storage across in the various agro-ecological zones (n = 630) 62

Table 4.4: Storage structures used by farmer to store maize across the agro-ecological zones 65

Table 4.5: Methods used by farmers to protect maize cobs against storage pests (n = 247)...74

Table 4.6: Methods used by farmers to protect shelled maize grain against storage pests (n = 526)...75

Table 4.7: Storage losses incurred by farmers on maize during storage across the agro-ecological zones 79

Table 4.8: Regression of the influence of socio-economic, storage and agro-ecological factors on level of perceived losses due to rodents and the total losses during on-farm maize storage 81

Table 4.9: Actual weight loss due to rodent and percentage damaged grains in cobs and shelled maize storage in the experiment at Mwarakaya ward (Kilifi-south) over end of June to end of September 2015. 85

Table 4.10: Rodents species associated with the losses and their population estimation..86

Table 4.11: Total mould counts, incidence of *Aspergillus* spp, *Fusarium* spp and total aflatoxin level in the rodent damaged grains sample and non-damaged grain sample. 89

LIST OF FIGURES

Figure 2.1: Maize production, importation and exportation in Kenya 25

Figure 2.2: Main maize storage insect pests in Kenya 32

Figure 2.3: Maize cobs infected by fungi. 33

Figure 2.4: Commensal rodents responsible for postharvest losses in East Africa...35

Figure 3.1: Map showing maize specific agro-ecological zones in Kenya...............43

Figure 3.2: Setting up the trial with shelled maize grains in bag and dehusked maize on cobs 48

Figure 3.3: Re-weighing of maize stored for weight losses estimation using weight balance 51

Figure3.4: Different types of traps used in the experiment....................................52

Figure 3.5: Setting of traps – (a) traps set in room, (b) traps set in the granary........54

Figure 3.6: Rodents damaged grains composite sample and non-damaged grains composite sample 55

Figure 4.1: Maize storage structures across agro-ecological zones..........................64

Figure 4.2: Places used by farmers for storage of bagged maize grain. n: sample size 67

Figure 4.3: Storage duration of maize stored as cobs...69

Figure 4.4: Problems encountered by farmers in the storage of maize 71

Figure 4.5: Proportion of farmers who had or had not received training on stored grain and protection technologies in the various agro-ecological zones. n: sample size...76

Figure 4.6: Rodent's damages to the maize stored...84

Figure 4.7: Microbiological analysis on rodents damaged grains and non-damaged grains 90

LIST OF APPENDICES

Appendix i: Questionnaire for Rodent's Losses Assessment Study on Maize During Storage in Kenya 126

ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zone
ANOVA	Analysis Of Variance
ASL	Above Sea Level
CFU	Colony Forming Unit
DM	Dry Matter
DMA	Dry Mid-Altitude
DT	Dry Transitional
FAO	Food and Agricultural Organization
HLT	Highland Tropical
JKUAT	Jomo Kenyatta University of Agriculture and Technology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ISO	International Standards Organization
LLT	Lowland Tropical
m.c	Moisture content
MMA	Moist Transitional zone
MT	Moist Mid-Altitude
ppb	Part Per Billion
SSA	Sub-Saharan Africa

ABSTRACT

Rodents are one of the major postharvest pests that affect food security by impacting on both food availability and safety. However, knowledge of the impact of rodents in on-farm maize storage systems in Kenya is limited. A survey was conducted in 2014 with a total of 630 farmers spread across the six maize growing agro-ecological zones (AEZs) to assess postharvest losses magnitudes in on-farm maize storage systems in Kenya, and the contribution of rodents to the losses. Experiments were also set in the AEZ identified from the survey study as the main rodents' hot-spot area with 20 farmers from which 10 stored shelled maize grain or dehusked cobs for 3 months to quantify the actual weight losses due to rodents. Ten (10) other farmers allocated their room and granaries for rodent trapping over 4 months to identify rodents species associated with the losses and their population estimate. Additionally, comparison between rodents damaged grains and non-damaged grains were done for total mould count, mould incidence and for total aflatoxin to evaluate the effect of rodents' infestations on the grains contamination by storage moulds. Results showed that insects, rodents and moulds were the main storage problems reported by farmers. Storage losses were highest in the moist transitional and moist mid-altitude zones, and lowest in the dry-transitional zone. Overall, rodents represented the second most important cause of storage losses after insects, and were ranked as the main storage problem in the lowland tropical zone, while insects were the main storage problem in the other AEZs. Where maize was stored on cobs, total storage weight losses (farmer estimation) were 11.1 ± 0.7% with rodents causing up to 43% of these losses. Contrastingly, where maize was stored as shelled loose grain, total losses were 15.5 ± 0.6% with rodents accounting for up to 30%. Regression analysis showed that rodents contributed significantly to total storage losses ($p < 0.0001$), and identified rodent trapping as the main storage practice that significantly ($p = 0.001$) lowered the losses. Together with insecticides, rodent traps were found to significantly decrease total losses. In the set-up experiments, cumulative weight losses over 3 months of storage ranged from 2.2 to 6.9% and from 5.2 to 18.3% in shelled maize grain and dehusked cobs storage, respectively. *Rattus rattus* was the only rodents' species captured during the whole period of trapping in rooms and granaries with a trap success rate varying between 0.62 and 10%. Microbiological analysis showed that total mould count and *Fusarium* spp. incidence were significantly higher in rodent damaged grain samples than in the non-damaged grain samples whereas no significant differences were obtained for *Aspergillus* spp. incidence and total aflatoxin level between the two samples. The findings of this study demonstrated that rodents are significant cause of post-harvest losses in on-farm maize storage in Kenya and also impact on smallholder farmers food safety through their infestation. The results however, suggest that improved awareness and right application of insecticides and trap practices could mitigate losses in on farm-stored maize. Moreover more attention must be paid to hygiene around houses and granaries, construction of rat guards around grain store poles, community rodents trapping programmes and food safety and health issues due to rodents' infestation.

Keywords: Postharvest losses, Rodents, Maize, On-farm storage, Food security, Kenya

CHAPTER ONE

INTRODUCTION

1.1. Background

Maize (*Zea mays* L.) is the staple food for over 90% of the Kenyan population (Laboso & Ng'eny, 1996). For this reason, a large part of harvested maize is stored to guarantee supply between harvest seasons. The bulk of storage takes place in on-farm storage systems. These systems are characterized by traditional storage structures (Nukenine, 2010) that are prone to invasion by agents of stored food losses including insects and rodents (Lathiya *et al.* 2007). In Kenya, earlier works by De Lima (1979a) identified insects and rodents as main causes of postharvest losses in durable crops. The black rat otherwise called roof rat (*Rattus rattus)*, the house mouse (*Mus musculus)* and the Natal multimammate mouse (*Mastomys natalensis*) are responsible for most of the postharvest crop damage caused by rodents in East Africa (Makundi *et al.* 1999). *R. rattus* and *M. musculus* inhabit houses and storage structures whereas *M. natalensis* moves from the fields to frequently invade storage structures at the end of the harvest season due to absence of food in fields (Mdangi *et al.* 2013).

Rodents cause damage to stored food through direct damage, wastage, and contamination (Drummond, 2001) and so affect both grain quantity and quality. Singleton (2003) estimated annual loss of food due to rodents to be equivalent to 11 kg of food per person, which translated to over 77 million metric tons annually, in a world of over 7 billion inhabitants. In India, Cao *et al.* (2002) estimated the overall grain losses due to rodents in the postharvest stage to be 25–30% of which the economic cost amounted to $5 billion in stored food and seed grain annually. Studies in Bangladesh and Myanmar estimated household postharvest losses of stored food due to rodent damage at 2.5% and 17%, respectively (Belmain *et al.*, 2015), and in East Africa, weight losses of 19.3 kg/tonne/year in maize grain stored in traditional open cribs was reported in Tanzania (Mdangi *et al.*, 2013). In Mozambique losses of stored food of 200 to 400 kg/year/dwelling due to rodents were reported by Belmain *et al.* (2003). The grain damage by rodents in stores is often associated with removal of the germ, which causes germination failure when the seeds are used for planting, and the contamination of the grain with faeces, hair and urine which results in poor quality and lower market value (Justice & Bass, 1979). Moreover, rodents are well-known vectors for diseases such as typhoid, paratyphoid, trichinosis, scabies, plague, and hemorrhagic fevers like ebola which are of public health concern (Cao *et al.*, 2002). In Kenya for example, several studies (Ball, 1966; Forrester *et al.*, 1969; de Geus *et al.*, 1977a, b; Halliday *et al.*, 2013) reported leptospirosis human cases due to rodents.

1.2. Problem Statement

Maize (*Z. mays* L.) is by far the most important food crop in Kenya, playing an integral role in national food security (Short *et al.*, 2012). However, after harvest, postharvest losses along the maize value chain amount to 25.9% (APHLIS, 2017) and contribute to food insecurity and low farm incomes in Kenya (Republic of Kenya, 2004). The effect of postharvest food losses on food security is further exacerbated by increasing population, dwindling land resources and adverse impact of climate change threatening sustainable food production.

The actual magnitude of postharvest losses caused by rodents on stored maize in Kenya is largely unknown. Most current and past researches in Kenya on postharvest losses in on-farm maize storage due to storage pests focused on general losses (all losses agents together, no distinction between losses agents) or insects (Komen *et al.,* 2006; Mutambuki & Ngatia, 2006, 2012) whereas specific attention to rodents seem to be minimal. Komen *et al.* (2006) in their study in Trans Nzoia and Uasin Gishu sub-counties, reported general grain losses range of 0 to 50% with highest estimated losses in cribs followed by baskets and lowest estimated losses in grains kept in houses. Mutambuki and Ngatia (2006) in their study in the semi arid area of Kitui sub-county in 2006, recorded average cumulative weight loss of 29.1 and 19.1 % due to insects over 6 months for untreated and treated maize respectively. In Mutambuki and Ngatia (2012) study in the Highlands areas of Bungoma sub-counties, cumulative weight loss due to insects averaged 20.6% and 9.7% for untreated and treated maize respectively over 6 months period. With regard to rodents, existing losses data in Kenya in on-farm maize storage drew back to the period of 1973 to 1976 where De Lima (1979a) reported annual losses of 1.43%, 1.60% and 1.32% respectively for the periods of 1973-74, 1974-75 and 1975-76 and yet were casual studies which did not consider linkage between agro-ecological conditions, storage practices and the socio-economic circumstances of farmers when assessing the losses.

From 1979 till now, no research has been conducted on rodents' issues in grains stores to understand the impact they may have on food security of small scale farmers and design interventions to reduce them although, there are strong evidences that rodents may be of great disturbance in on-farm maize storage systems in Kenya as the storage systems present favourable conditions for their presence and proliferation. On-farm maize storage systems is usually characterized by inadequate facilities and methods for grain storage to control storage pests (Bett & Nguyo, 2007), non-rodent proof traditional grain structures and poor hygiene in stores and houses which make difficult to exclude rodents'. Studies for example in Tanzania (Mdangi *et al.*, 2013) and Bangladesh (Brown *et al.*, 2013) showed that, where farmers use traditional grain storage structures, rodents are a significant problem for the safe storage of commodities leading to significant levels of loss, damage and contamination that contributes to food insecurity, poor nutrition (seed germ removal) and potential disease transmission through rodent urine, faeces and saliva. Additionally, presence of domestic waste, poor hygiene, poor housing structure and improper handling of leftover in rural households offer an environment favourable to the presence and proliferation of commensal rodents (Panti-May *et al.*, 2012). Moreover, rodents infestation can compromise some effective methods to control storage pest insects. For example, hermetic storage plastic bags technologies which have been proven as an effective storage alternative for small-scale farmers to control insects (De Groote *et al.,* 2013; Moussa *et al.,* 2014), can be damaged by rodents (Ndegwa *et al*., 2016) if care is not taken for their control, making these bags ineffective. Treated maize grains with insecticides stored in bags can also be eaten and contaminated by rodents and lead to postharvest losses.

The gap of information on postharvest losses caused by rodents in on-farm maize storage may deny different stakeholders (policy makers, donors, researchers and development agencies) to consider impact rodents can have on grain storage (weight losses and quality losses) in on-farm storage systems and therefore need to be addressed.

1.3. Justification

With maize representing the main staple food for the majority of households in Kenya and one of the principal sources of family income for 70-80% small scale farmers, the impact of eradicating postharvest losses in maize storage is massive. The reduction of postharvest food losses can make a significant contribution towards sustainable food security, and in the recent years, this realization has caused renewed interest in mitigating postharvest losses (Affognon *et al.*, 2015). As a first step, appraising the postharvest system and assessment of the kinds and levels of losses, and the factors associated with them is important. Whereas postharvest losses due to rodents are recognized the world over as a serious problem, only a few studies have assessed the levels of losses that farmers routinely experience in farm stores in Africa (Ratnadass *et al.*, 1991; Belmain *et al.*, 2003; Taylor *et al.*, 2012; Mdangi *et al.*, 2013). In Kenya, apart from the study of De Lima (1979a) which reported the annual weight losses caused by rodents in small holder systems to be 1.45%, no further studies have been undertaken, partly because of the general perception that losses due to rodents are insignificant, and probably also because of the difficulties involved in assessing and preventing such losses. However the on-farm maize storage system presents a high probability for the occurrence of rodents' infestations in stores. Thus given the conducive environment for rodents proliferation in on-farm maize storage system and the significant role postharvest losses reductions could have on the global food security in Kenya, assessing losses due to rodents will help farmers, scientists and policy makers to understand the impact of rodents in maize stores and then determine the importance of investing effort into developing management systems.

1.4. Objectives

1.4.1. General objective

To assess the type and magnitude of postharvest losses caused by rodents during maize storage by small scale farmers in Kenya

1.4.2. Specific objectives

i. To determine storage systems used by farmers with respect to the different maize specific agro-ecological zones (AEZs) in Kenya.

ii. To assess the magnitude of postharvest losses caused by rodents during maize storage by small scale farmers in AEZs and their contribution to the total losses.

iii. To determine the diversity and abundance of rodents species associated with postharvest losses in on-farm maize storage.

iv. To determine the influence of rodents damages on the grains contamination by storage moulds and aflatoxin.

1.5. Hypotheses

- Storage systems used by farmers in Kenya to store maize are not significantly different across the AEZs
- Postharvest losses caused by rodents during maize storage at farm level do not significantly differ across the AEZs and do not contribute significantly to the total losses caused by storage pests.

- Rodents species associated to the losses in on-farm maize storage are not significantly different and their population does not vary with time.
- Rodents' damages on the grains do not significantly influence their contamination by storage moulds and aflatoxins.

CHAPTER TWO

LITERATURE REVIEW

2.1. Maize

2.1.1. Origin and distribution

Maize (*Zea mays* L.) is an annual herbaceous tropical plant of the family of Poaceae, widely grown as a cereal for its grains rich in starch but also as fodder plant. In Indian languages of America, maize literally means "which maintains life" (FAO, 1993). Maize was domesticated in Central Mexico (Matsuoka *et al.*, 2002) between 9,000 and 6,000 years ago (Benz, 2000). However, the ancestral wild form of maize has been hotly debated. The hypothesis of the descent of maize from teosinte on the origin of maize, advanced by Ascherson in 1895 (Mangelsdorf & Reeves, 1939), is the most widely accepted today (Turrent and Serratos –Hernandez, 2004). According to Shephered *et al.* (2010) and Damsteegt and Igwegbe (2005), maize was first introduced into Africa via Ghana and the Sao Tome islands by Portuguese traders in the 16th century and also from the Caribbean, Central and South America. Subsequent introductions have been made from Europe and Asia (McCann, 2001). It is found in a wide range of conditions: 56° north latitude to 40° south latitude, below the level of the sea, the Caspian lowlands, up to 3000 m in the Andes and in semi - arid to arid (Russell & Hallauer, 1980).

2.1.2. Importance of maize in Kenya

In Kenya, maize is the most important staple food and contributes to 65% of staple food calories and 36% of the total caloric intake (Ahmed, 2011). The annual per capita consumption is estimated at 88 kg with around 3 million tons of maize yearly produced over 1.6 million hectares (Short *et al.*, 2012). According to Jayne *et al.* (2001), maize account for roughly 20 percent of gross farm output for the small-scale farming sector and about 70-80% of production is realized by smallholder farmers. From 2003 to 2013, the maize production in Kenya has increased from 2,710,848.00 tonnes to 3,390,941.00 tonnes although these were periods where maize production declined (Fig.2. 1). Average importations increased from 100,132.00 tonnes in 2003 to 258,525.00 tonnes in 2011 while the exportations during that period increased by 8,165.00 tonnes to 10,850.00 tonnes (Fig. 2.1). Moreover in terms of monetary value, the importation increased from 16,039.00 thousands US dollars to 88,757.00 thousands US dollars in 2011 while the exportation increased from 2,690.00 thousands US dollars to 6,567.00 thousands US dollars in the same period (FAO, 2015)

Maize is grown in Kenya for commercial, subsistence or dual purposes. According to Ministry of Agriculture (2010), about 15% of total maize production is sold directly to the National Cereals and Produce Board (NCPB) and large millers. It is also estimated that only 2% of farmers in the smallholder sector account for over 50% of the national marketed supply although almost many farmers grow maize (Short *et al.,* 2012). Moreover, about 57% of smallholder producers are maize insufficient (buying more than they sell), and about 11% are purely subsistence producers (neither buying nor selling maize) (Short *et al.*, 2012).

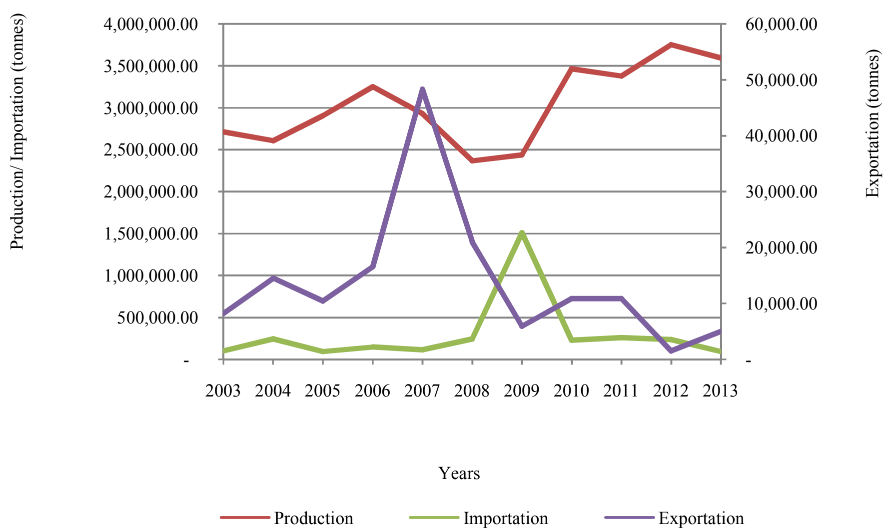

Figure 2.1: Maize production, importation and exportation in Kenya

Source: FAO (2015) (http://www.fao.org/faostat/en/#data)

2.2. Postharvest losses

2.2.1. Concept of Postharvest Losses

According to De Lucia and Assennato (1994), postharvest losses denote a measurable decrease of food in the postharvest system which may be quantitative or qualitative. The postharvest system for its part refers to interconnected activities from the time of harvest through crop processing, marketing and food preparation, to the final decision by the consumer to eat or discard the food (Hodges *et al.*, 2011).

Postharvest losses however, can occur either due to food losses or due to food waste. *Food losses* are a subset of postharvest losses and represent the part of the edible share of food that is available for consumption at either the retail or consumer levels but not consumed for any reason (Hodges *et al.*, 2010). Moreover, food losses occurring at the end of the food chain (retail and final consumption) are rather called "food waste", which relates to retailers' and consumers' behaviour (Parfitt *et al.*, 2010). According to Buzby and Hyman (2012), *food waste* is the subset of food loss representing the loss of edible food due to human action or inaction such as throwing away wilted produce, not consuming available food before its expiry date, or taking serving sizes beyond one's ability to consume.

2.2.2. Different types of postharvest food losses

The postharvest losses can be quantitative and qualitative. However, the quantitative and qualitative losses result in economic losses due to the reduction in the monetary value of the product (Tefera, 2012).

- **Quantitative losses**

Quantitative losses or weight losses can be defined as reduction in weight of edible grain or food available for human consumption which can be quantified and valued, for instance, as a portion of grain eaten by insects, rodents, or lost during spillage or transportation. Appert (1992) reported that the quantitative loss is the kind of losses that can be the most significant for the storage. Moreover weight loss is considered as the standard international measure of grain loss because it is useful in quantifying the national impact of losses and for comparing losses across sites and years (De Lima, 1979b).

According to Hodges *et al.* (2014), weight losses should be normally expressed as loss in dry matter as it should not include any changes in weight due to changes in grain moisture content. Hodges *et al.* (2014) describe two ways to estimate weight losses: i) by collecting and weighing the grain excluded from the system, e.g. grain that is scattered or spilt at harvest, during threshing, transport etc., and ii) by determining what weight of grain remains after a postharvest activity, e.g. after farm storage where pests may have consumed some of the grain. Weight losses may be expressed as an absolute loss which is the actual weight of grain lost (expressed in MT or kilograms) or as a relative loss where the dry weight of grain lost is given as a percentage or proportion of the starting dry weight.

- **Qualitative Losses**

According to Grolleaud (1997), qualitative losses are more difficult to grasp owing to the fact that produce quality is assessed in different ways according to the circumstances considered by the local population and traders concerned. However, they occur due to incidence of insect pest, mites, rodent and birds, or from handling, physical changes or chemical changes in fat, carbohydrates and protein, and by contamination of mycotoxins, pesticide residues, insect fragments, or excreta of rodents and birds and their dead bodies. However, a change in quality is not necessarily a loss until it has resulted in a decline in financial/economic value (Hodges *et al.*, 2014).

2.2.3. Importance of grain losses

According to Hodges *et al.* (2014), the importance of grain postharvest losses resides in the fact that losses of grain quantity (weight losses) and losses of grain quality both deprive the farmers of Sub-Saharan Africa (SSA) of the benefits of their labours and impact on food security. Indeed grain losses do not only imply a loss of food or food shortage but they also imply a loss of all the resources (labour, land, water, fertilizer, insecticide, money etc) that are used to create food (World Bank, 2011). It is estimated that the annual value of weight losses for SSA amounts to about US$4 billion, which exceeds the value of total food aid received by SSA in the decade 1998-2008, equates to the value of cereal imports to SSA in the period 2000-2007, and is equivalent to the annual calorific requirement of at least 48 million people. Yet these values were only based on losses of weight and consequently they are under estimates of the total loss (Hodges *et al.*, 2014).

With the development of agricultural production and marketing in SSA since the 1970s and 1980s, news challenges associated with postharvest losses reduction were generated. Some of these challenges in the case of grains are the introduction of high yielding varieties that are more susceptible to pest damage, additional cropping seasons that result in the need for harvesting and drying when weather is damp or cloudy, increased climate variability, or farmers producing significant surplus produce, which because it is to be marketed rather than consumed by the household, is less well tended (Greeley, 1982). With regard to the impact postharvest losses may have on food availability, their estimations are important to support agricultural policy formulation, identification of opportunities to improve value chains, improvement in food security (by improving the accuracy of cereal supply estimates), and monitoring of loss reduction activities (Hodge *et al.*, 2014).

2.2.4. Magnitude of Maize Grain Postharvest Losses in Kenya

Overall, magnitude of postharvest losses data in maize in Kenya are exclusively on physical losses at storage, and insect infestation being the most loss agent reported (De Lima, 1979; Komen *et al.,* 2006; Mutambuki & Ngatia, 2006, 2012). The postharvest losses due to rodents are largely unknown. Moreover, no study has quantified quality losses which are often associated with loss of market and nutritional value (Affognon *et al.*, 2015). In 1979, De Lima (1979) reported average annual loss estimate of 4.54% due to insects and 1.45% due to rodents from a survey of losses in five provinces (Wester, Nyanza, Rift Valley, Central and Eastern) of Kenya over the period of 1973 to 1976. In Komen *et al*. (2006) study in Trans Nzoia and Uasin Gishu sub-counties, general grain losses (without distinction between loss agents) estimate range from 0 to 50% with highest estimated losses in cribs followed by baskets and lowest estimated losses in grains kept in houses. Mutambuki and Ngatia (2006) in their study in the semi arid area of Kitui sub-county in 2006, recorded average cumulative weight loss of 29.1 and 19.1 % attributed to insects over 6 months for untreated and treated maize respectively. In Mutambuki and Ngatia (2012) study in the Highlands areas of Bungoma sub-counties, cumulative weight loss due to insects averaged 20.6% and 9.7% for untreated and treated maize respectively over 6 months period. When postharvest losses estimates of the African Postharvest Losses Information System (APHLIS), a multi-stakeholder monitoring system that dates to 2009, are considered, overall postharvest losses along maize value chain ranged from 18.0% to 25.9% over the period of 2007 to 2013 (APHLIS, 2017).

2.2.5. Factors and causes of maize grain losses

A. Physical factors

Temperature

Temperature plays a very important role in the conservation of products because it has a strong influence on the rate of respiration of the grain stored and the parasitic organisms, as well as the relative humidity, the water content of stored products and finally the development of storage pests. Temperatures of 20-35°C prevailing mostly in tropical and subtropical climates offer pests as well as fungi, ideal living conditions when the relative humidity is also quite high (Gwinner *et al.*, 1996). Some moulds can grow very slowly in grain at temperatures below freezing of water, but at temperatures of 54.5°C their growth is stopped (Saul and Harris, 1976). Low temperatures are commonly used to manage stored-product insects. Few species can achieve a population increase < 18°C but *Sitophilus granaries* is one of the exceptions, as it can reproduce at temperatures down to 15°C (Beckett *et al.*, 2007). Between 1 and 5°C, depending upon acclimation and the species, stored product insects are unable to move and reproduce. Temperatures < 0°C will kill insects; the lower the temperature, the faster the insects will succumb to cold injury (Beckett *et al.*, 2007). Moreover the minimum temperature for successful disinfestations of insects in stored grains is 50°C (Wright *et al.*, 2002).

Moisture content and relative humidity

Moisture content of stored product comes in several ways in the degradation process. Indeed, the thermodynamic activity of water affects the intensity and speed of chemical reactions (oxidation, Maillard reaction), enzyme reactions, the development and physiology of the microorganisms and changes the most physical properties (rheological, mechanical) (Multon, 1982). Depending on the relative humidity, the stored product releases moisture in the air (drying) or absorb water (wetting) until it reaches a state of equilibrium (Gwinner *et al.*, 1996). The recommended maximum storage moisture content is often defined as the equilibrium moisture content at a relative humidity of 65-70% below which the development of micro- organisms and the enzymatic activity are stopped. For maize, the maximum recommended moisture content for long-term storage is 13% (Cruz *et al.*, 1988). In the Kenya quality standard specification for imported maize, maximum moisture content requirement is 13.5% (NCPB, 2017)

B. Engineering and mechanical factors

Engineering and mechanical factors that affect postharvest losses include types and efficiency of harvesting tools, equipment and machines; primary processing equipment and machines; drying and storage structures; type and efficiency of non-farm transport (Meija, 2003; Folayan, 2013).

C. Socio-economic factors

The socio-economic factors include financial status of the farm household, farming system and storage; and marketing system (Meija, 2003). Indeed farmers strategies to cope with storage losses is highly influenced credit constraints (including high cost of capital), risk aversion, lack of modern storage technology, and unreliable information about grain prices (Kadjo *et al.*, 2013). All these factors influence farmers' decision to adopt technologies or to invest in better storage options to reduce postharvest losses.

D. Biological factors

Insects

Among stored grains pests, insects are the most predominant in the tropic and cause the great losses and deterioration to food grain (Mejia, 2003). Damage caused by insects can result in financial loss, starvation and poisoning risks related to the consumption of spoiled or treated food with pesticides. The origin of the infestation of stored grain is variable. It may begin at the field level for certain insects, or may occur along the chain of postharvest taken by the food, or may be in warehouses.

The main insects that infest stored products belong to the families of Coleopteran (damage caused by larvae and adults) and Lepidoptera (damage caused only by the larvae) (Fleurat-Lessard, 1988; Gwinner *et al.*, 1996). The first insects that colonize stored grain pests are called primary. They are able to attack the grain in good condition and larval development takes place inside the seed usually. Populations of secondary pests only develop once the grain is damaged. They feed primarily on seeds and have a wider range of foods as primary pests. On stored maize in sub-Saharan Africa, primary pests such as the maize weevil (*S. zeamais*), the larger grain borer, (*Prostephanus truncatus*) and Angoumois grain (*Sitotroga cerealella*) are by far the biggest destroyers (Golob, 2009). In Kenya, the larger grain borer and the maize weevil are the main storage insect pests in maize storage (Bett & Nguyo, 2007; De Groote, 2013; Nganga *et al.*, 2016) (Fig. 2.2).

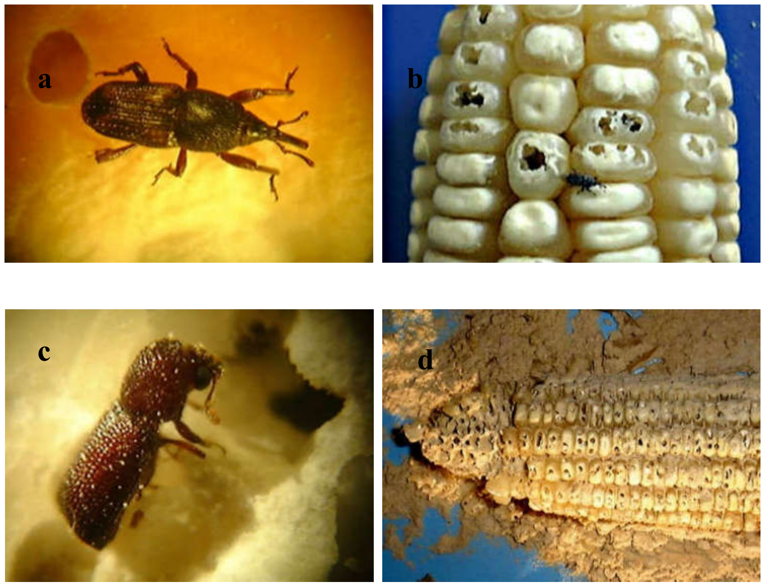

Figure 2.2: Main maize storage insect pests in Kenya

(a) maize weevil (*S. zeamais*), (b) maize cob damaged by maize weevils, (c) larger grain borer (*P. truncatus*) and (d) maize cob damaged by larger grain borers. Source: Savidan (2002)

Fungi and mycotoxins

Fungi are the most important micro-organisms that can cause or contribute to the deterioration of stored products through the reduction of nutritional value of grain, grain discoloration, deterioration of grain quality and reduction of germination (Fig. 2.3.) (FAO, 1998). *Fusarium*, *Aspergillus* and *Penicillium* species have been identified as the most important types of fungi that infest stored maize and produce mycotoxins which are harmful to both human beings and animals (Sweeney *et al.*, 2000; Bennet & Klich, 2003; Ngoko *et al.*, 2008; Wild & Gong, 2010).

Mycotoxins are toxics secondary metabolites produced by filamentous fungi. They are an important problem for international regulation because of their toxicity and carcinogenic effect on humans and animals (Ceballos, 2007). In postharvest, poor storage conditions such as high humidity, the presence of fungi in pre-harvest, the presence of insects on stored grain can all contribute to further fungal growth and mycotoxin accumulation in maize (Sinha, 1994). Out of the more than 400 mycotoxins known, the most important in terms of commercial impact and risk to human and animal health are aflatoxins, fumonisins, ochratoxins, deoxynivalenol, zearalenone, trichothecenes and patulin (Bennet & Klich, 2003). However aflatoxins are by far the most important mycotoxins (Reddy *et al.*, 2010). In the Kenya quality standard specification for imported maize, maximum total aflatoxin requirement is 10 ppb (NCPB, 2017).

Figure 2.3: Maize cobs infected by fungi.

Source: Kibe (2015)

Rodents

In a number of countries, the damage caused by rodents equals or exceeds those caused by insect pests (Gwinner *et al.*, 1996). Among rodents, pests which really affect storage are rats and mice (family of Muridae). The most common species are the black rat or roof rat (*R. rattus*), the Norway rat (*Rattus norvegicus*), the natal multimammate mouse (*M. natalensis*) and the house mouse (*M. musculus*) (Cruz *et al.*, 1988, Makundi *et al.*, 1999). According to Makundi *et al.* (1999), *R. rattus*, *M. musculus* and *M. natalensis* are responsible for most of the postharvest crop damage caused by rodents in East Africa. These species (Fig. 2.4) which generally live in close association with people are commonly known as "commensal rodents" (Fall, 2011). Rodents not only cause physical damage and crop loss but also contaminate the environment, crop products and finished food with allergens (Hollander *et al.*, 1997), human and animal microbial pathogens (Daniels *et al.*, 2003; Meerburg & Kijlstra, 2007), toxigenic fungi (Stejskal *et al.*, 2005) and physical contaminants, such as hairs, urine and faeces (droppings, faecal pellets) (Frantz & Davis, 1991).

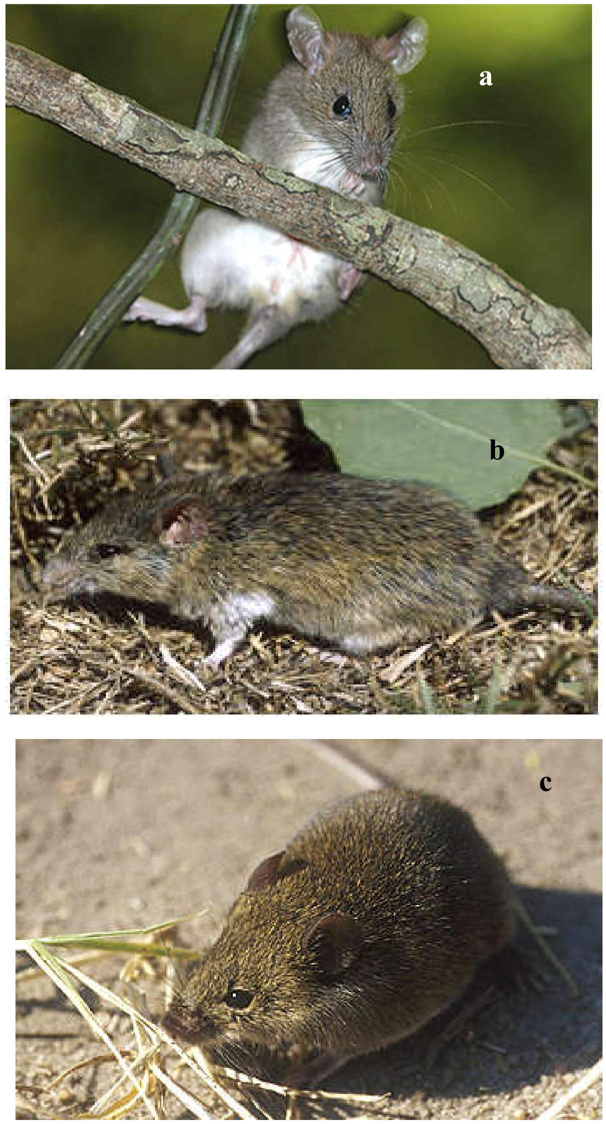

Figure 2.4: Commensal rodents responsible for postharvest losses in East Africa

(a) *R. rattus*, (b) *M. natalensis* and (c) *M. musculus*

Sources: (**a**) http://archive.fieldmuseum.org/tanzania/species.asp?ID=567

(**b**) http://archive.fieldmuseum.org/tanzania/species.asp?ID=541

(**c**) http://archive.fieldmuseum.org/tanzania/species.asp?ID=548

2.3. Description of Rodents

2.3.1. Distribution and Characteristics of Rodents

Rodents are the largest and one of the most interesting groups of mammals in the world. Over 40% of mammal species are in the order Rodentia with more than 2000 species encompassing a staggering diversity of form and behaviour (Kay and Hoekstra, 2008). They are found in vast numbers on all continents other than Antarctica and in all habitats (from arid deserts to arctic tundra), except the ocean. In East Africa, it was estimated that rodents account for 28% of the total mammalian fauna (Habtamu & Bekele, 2008). Despite the large number of rodents in the world, less than 100 species are serious pests worldwide, damaging crops, stored commodities and structures and spreading disease to humans and livestock (Fall, 2011). Common rodents include mice, rats, squirrels, porcupines, beavers, guinea pigs, and hamsters.

According to Fall (2011), the most prominent anatomical features of commensal rodents are their long, sparsely haired tails and their continuously growing incisors. Teeth are worn continuously by gnawing and are used for investigating food and other materials. *R. rattus* is characterized by relatively large ears and a tail that is nearly always longer than the body. The tail length measures 19 cm or longer and individuals head and body length are between 16 and 22 cm with a range mass of 70 to 300 g (Gillespie & Myers, 2004). A sexual dimorphism is observed between males and females. Males are longer and heavier than females. Individuals present also several colours forms. Colours may be grey-brown on the back with either a similarly-coloured or creamish-white belly, or it may be black all over (CABI, 2016). *M. musculus* is characterized by a range length of 65 to 95 mm with a long tail of 60-105 mm. Individuals range mass varies between 12 to 30 g. Their fur ranges in colour from light brown to black, and they generally have white or buffy bellys (Gillespie & Myers, 2004). Moreover it is also reported that individuals tend to have darker fur when living closely with humans (Gillespie & Myers, 2004). *M. natalensis* is characterized by a head-body length of around 145 mm with a tail length of around

156 mm. An adult individual can weigh between 56 to 70 g. The fur is moderately long and soft to the touch, the dorsal colour buffy-grey suffused with black hairs; underparts vary from white to dark-grey, suffused with black hairs (Mills & Hes, 1997).

Generally, young rats or mice are born fully dependent on the mother, but mature in about 3 weeks and can breed in another 3 weeks. Litter sizes for commensal rats and mice average about 4-8 and breeding may occur throughout the year (Fall, 2011).

Rats and mice are excellent climbers. This coupled with their abilities to jump and to squeeze through small openings makes them difficult to exclude from structures. Their senses of hearing, smell, and taste are well developed, but like most other nocturnal mammals, their vision is poor. They have long, sensitive whiskers called vibrissae, used in navigating runways or burrow systems. They detect sounds at frequencies well above the range of human hearing (Fall, 2011).

2.3.2. Feeding Ecology of Commensal Rodents

Rodents have very wide range of diet and food is one of the most important dimensions of niche. Generally, many rodents are opportunistic feeders, capable of changing their feeding habits depending on the availability of food from season to season (Taitt, 1981; Leirs, 1994; Happold, 2001). According to Futuyma (2005) most rodents consume all sorts of plant materials, primarily seeds, leaves, stems, flowers and roots. In the wild, brown rats eat snails, insects, crustaceans and freshwater shellfish. Commensal rats (*R. norvegicus* and *R. rattus*) utilize garbage for food and rubbish piles for shelter (Schroder & Hulse, 1979). Mice are omnivorous; they eat anything, but their favorite foods are cereals (Tobin & Fall, 2004).

Rodents readily learn to reject or avoid unpalatable foods or those containing toxins, which presents a problem for the development of bait materials for effective delivery of rodenticides (Tobin & Fall, 2004). Also because of the large space or diastema behind their incisors, rodents can use their front teeth to investigate or nibble unfamiliar materials without actually taking them inside their mouths (Tobin & Fall, 2004).

2.3.3. Public Health Concerns of Rodents

A part from directs damages to the produces, food contamination by rodents rose food safety and public health concerns related to foodborne pathogens transmission by rodents. According to Brooks and Fielder (2006), rodents that frequent food stores and live in close association with humans in many parts of the tropics and subtropics in developing countries are known to be the reservoirs and vectors of several human diseases. Rodents can transmit about 60 types of diseases to humans, and are carriers of diseases that affect both humans and domestic livestock (Parshad, 1999). Salmonella organisms are spread through the droppings of all the commensal rodents, house mice and rats (Brooks & Fielder, 2006). Black rats are associated with transmission of bubonic plague, whereas brown rats are associated with spreading the Weil’s disease, cryptosporidiosis, viral hemorrhagic fever (VHF), Q fever and Hantavirus pulmonary syndrome (Mills & Childs, 2001). Lassa fever has been spread by the urine and faeces of the multimammate rat in parts of West Africa (Brooks & Fielder, 2006). House mice transmit the lymphocytic chloriomeningitis arenaviruse (Mills & Childs, 2001), which cause aseptic meningitis (Roebroek *et al.*, 1994).

2.4. Rodent Pest Management Strategies in Storage

Rodent's pest management strategies consist mainly of combination of a variety of preventive and control methods, appropriate to specific situations.

2.4.1. Preventive Methods

According to Gwinner *et al.* (1996), the most essential factors for the occurrence of rodents are: sufficient supplies of food, protected places in which they can build burrows and nests, hiding places access to produce. However the control of these factors through the application of storage hygiene and technical measures as part of an integrated control programme can help to minimize rodents' problems in storage. Storage hygiene and technical measures recommended consists to:

- keep the store absolutely clean. Remove any spilt grain immediately as it attracts rodents
- store bags in tidy stacks set up on pallets, ensuring that there is a space of 1 m all round the stack
- store any empty or old bags and fumigation sheets on pallets, and if possible in separate stores
- keep the store free of rubbish in order not to provide the animals with any places to hide or nest
- keep the areas surrounding the store free of tall weeds so as not to give the animals any cover
- keep the area in the vicinity of the store free of any stagnant water and ensure that rainwater is drained away, as it can be used as source of drinking water
- apply rodent proof on the poles of granaries
- repair any damage to the store immediately

2.4.2. Control Measures

Control measures are a basic requirement in keeping rodents damage down to a minimum. According to Gwinner *et al.* (1996), before applying control measures, the following questions must be answered in order to achieve the greatest possible success with measures to combat rodents: (1) What species of rodent are causing damage to the produce?, (2) What is the approximate degree of infestation (loss estimation)?, (3) What is the extent of the infestation? If necessary, work must be performed in conjunction with neighbours. (4)Where exactly are the rodents particularly active?, (5) Where are the runs, burrows and nests? In what condition are the stores and the surroundings?

Thus correct planning of control measures can only be performed once these questions have been answered. Generally rodent control measures include non-chemical methods such as traps and cats and chemical methods such as chronic poisons and acute poisons (Gwinner *et al.*, 1996).

Traps

The traps must be placed along walls, on runs or in other places frequented by the rodents. Traps must be controlled daily and any dead animals must be removed and the traps cleaned.

Cats

Cats can make a contribution towards rodent control. However, cats themselves may become a hygiene problem in stores if care is not taken.

Chronic poisons

They have properties of a delayed action. The rodents will die without feeling pain. They will thus not become suspicious of the poisoned bait and no bait aversion will ensue. Prebaiting is therefore not necessary. Poisoned animals normally die in their nests or hiding places. The bodies of dead rodents are therefore not usually found during the course of treatment.

Acute poisons

Acute poisons have a rapid effect due to their high toxicity, meaning that poisoned rodents die immediately. In control campaigns using these poisons, the bodies of dead rodents can be found in and around the store. These must be collected and burned.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Maize Storage Practices and Farmers Assessment of Rodent Postharvest Losses

3.1.1. Study Area

The study was carried out within the six maize growing AEZs of Kenya (Fig. 3.1) which are located in Central, Coast, Eastern, Nyanza, Rift valley and Western regions of the country (Ong'amo *et al.*, 2006). These AEZs are highland tropics zone (HLT), moist transitional zone (MT), moist mid-altitude zone (MMA), dry mid-altitude zone (DMA), dry transitional zone (DT) and the lowland tropical zone (LLT). The weather characteristics of the six zones are described in the Table 3.1. The highest potential areas are MT followed by HLT zones, which together, represent 64% of the total production area and account for approximately 80% of Kenya's maize production. The other zones make up about 30% of the total maize area but produce only 15% of Kenya's maize. The remaining 6% of the maize area which contributes 5% of the production is located in the 0-0.5% maize intensity zone. LLT and DT zones are regarded as the lowest potential areas. DMA and MMA zones are considered as medium potential areas (De Groote, 2002).

Table 3.1: Characteristics of the maize-specific agro-ecological zones of Kenya

Agro-ecological zones	Altitude (m ASL[g])	Average total seasonal rainfall (mm)	Daily temperature (°C)	
			Min.	Max.
LLT [a]	<800	<1000	20.0	29.4
DMA [b]	700-1300	<600	16.1	27.9
DT [c]	1100-1800	<600	14.0	25.3
HLT [d]	>1600	>400	10.0	23.0
MT [e]	1200-2000	>500	13.4	23.3
MMA [f]	1100-1500	>500	15.9	28.3

[a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone, [g] Above sea level

Source: Hassan *et al.* (1998)

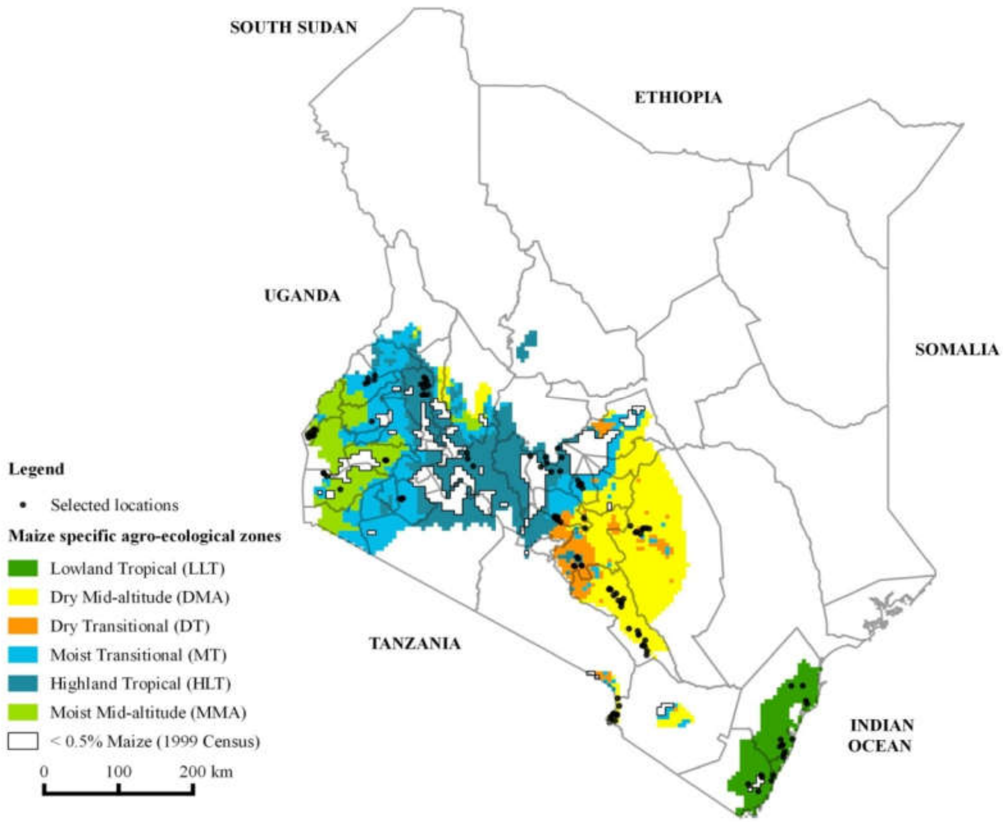

Figure 3.1: Map showing maize specific agro-ecological zones in Kenya

3.1.2. Sampling and Data Collection

A total of 630 out of a possible 2.97 million small-scale maize farmers (COMPETE 2010), were interviewed using a structured questionnaire following a 6 x 3 x 35 design (Six AEZs; three sub-counties in each AEZ and 35 respondents per sub-county). According to Krejcie and Morgan (1970), for a population size beyond 1,000,000 a minimum sample size of 400 based on a 0.95 confidence level and a margin of error of 0.05 is regarded as adequate. To identify individual respondents, combinations of random and purposive sampling techniques were employed. Three sub-counties were selected randomly in each AEZ, and 35 maize farmers were purposively selected from each of the sub-counties to give a sample size of 105 respondents per AEZ (Table 3.2). Purposive sampling of farmers was applied so as to include only those farmers who harvested maize in 2013 and had subsequently stored part of it. In each household visited, the person who was primarily involved in farming of maize was deliberately identified and interviewed. To achieve this, before commencing the interview, the household head was identified and asked whether he/she was primarily involved in the farming of maize. If the household head was primarily involved, the interview proceeded, otherwise he/she was requested to redirect accordingly.

Interviews were conducted by trained enumerators in the national language (Kiswahili) in the presence of a trained local interpreter. Data on demographic and socio-economic characteristics of farmers, maize production, consumption, and storage practices, importance of different maize storage pests, estimate of losses incurred during storage, and coping strategies for the losses were collected. Before estimation of losses, the concept of postharvest losses was explained, and the respondents were trained on how to use the proportional piling method (Watson 1994; Sharp 2007) to give a quantitative estimate of losses. In using this method, farmers were asked to select out from 100 dried beans the part corresponding to the losses they experienced for each type of storage pest reported as cause of losses in their stores. Separate estimates were obtained for the long rain crop season (L_{LR}) and the short rain crop season (L_{SR}). In the case where farmers harvested and stored maize during only one crop season, the annual losses were directly equivalent to the losses reported for the one season whereas in the cases where farmers harvested and stored maize during the long and short rain crop seasons, annual losses were calculated using the expression:

$$L(\%) = (L_{LR}Q_{LR} + L_{SR}Q_{SR}) * 100/(Q_{LR} + Q_{SR}),$$

where L (%) is the annual losses, L_{LR} is proportion of maize lost during storage of the long rain harvest, L_{SR} is proportion of maize lost during storage of the short rain harvest, Q_{LR} is the quantity of maize (kg) stored from the harvest of the long rain season, and Q_{SR} is the quantity of maize (kg) stored from the harvest of the short rain season.

Table 3.2: Study Sites (sub-counties)

Agro-ecological zones	Sub-counties surveyed	Provinces	County	No. of farmers surveyed
Lowland tropical	Malindi	Coast	Kilifi	35
	Kilifi-south	Coast	Kilifi	35
	Matuga	Coast	Kwale	35
Dry mid-altitude	Taveta	Coast	Taita-Taveta	35
	Kibwezi east	Eastern	Makueni	35
	Mwingi west	Eastern	Kitui	35
Dry-transitional	Gatanga	Central	Kiambu	35
	Machakos	Eastern	Machakos	35
	Makueni	Eastern	Makueni	35
Highlands	Kieni	Central	Nyeri	35
	Rongai	Rift valley	Nakuru	35
	Moiben	Rift valley	Uasin Gishu	35
Moist transitional	Sotik	Rift valley	Bomet	35
	Kirinyaga central	Central	Kirinyaga	35
	Kimilili	Western	Bungoma	35
Moist mid-altitude	Mbita	Nyanza	Homabay	35
	Budalangi	Nyanza	Bussia	35
	Nyando	Nyanza	Kisumu	35
Total				**630**

3.2. Estimation of the Actual Weight Losses Caused by Rodents in Storage and Identification of Rodents Species Associated to the Losses and their Population Estimate

3.2.1. Study Area

The losses quantification study, identification of the rodents' species and estimation of their population were performed in the LLT zone as the survey study results showed that this zone was the main hot-spot area for rodents' postharvest problems. In the LLT zone, all the studies were conducted in the Mwarakaya ward (3°49.17'S; 039°41.498'E) located in the Kilifi-south sub-county, one of the counties covered by the survey study (section 3.1). Mwarakaya ward is characterized by two maize cropping seasons. The long rain cropping season starts from April and ends in July whereas the short rain cropping season starts from September to end in December. Harvest for the long rain season covers the period of end July to end August whereas harvest for the short rain season covers the whole month of January.

3.2.2. Estimation of the Actual Weight Losses Caused by Rodents in Storage

Research approach

Trial on the losses quantification was carried out in two villages (Mbuyuni & Kinzugu) with 10 farmers selected from each village with the help of the Agricultural Officers of the Mwarakaya ward. The selection of the farmers was based on their report of encountering rodent's problems during storage. In each village, farmers were divided in two groups of 5 based on maize storage form (cobs storage & shelled maize grain storage). Farmers in each group of maize storage form constituted a replicate in the trial.

Procurement and treatment of maize samples

One hundred and ten (110) kg of shelled maize grain or dehusked maize cobs were purchased from a group of farmers in the area for the trial. The shelled maize purchased was a mix of two hybrid varieties (Pwani hybrid 4 & Drylands hybrid 4) whereas maize cobs purchased were a mix of two local varieties (Mdzihana & Kanjerenjere). The shelled maize grain purchased was cleaned and had a negligible amount of insects damaged grains. Rodents damaged grains were excluded. The shelled maize grain was later treated with Actellic Super dust (pirimiphos-methyl 1.6% w/w + permethrin 0.3% w/w) two weeks before the set-up of the trial. The insecticide was applied to minimize insects infestation during the course of the experiment. For the maize cobs, only cobs which did not present any visible insects or rodents damages were selected during the purchase. The maize cobs used for the experiment were not treated with the insecticide.

Experimental set up for assessing losses due to rodents

All the farmers involved in the trial stored each 10 kg of either shelled maize grain or cobs according to the group in which they were assigned to. Shelled maize grain was bagged in 50 kg polypropylene bag tied with rope and then placed on a mat in order to collect the spilled grains from the bags in the case of rodents' attacks (Fig. 3.2a). For the maize cobs, cobs were counted and total weight measured with weighing balance (Ashton Meyers, USA, Max 5 kg, d = 1 g) and placed on a plastic sheet mat (Fig. 3.2b, c). The bagged maize grains or the cobs on the mat were stored for 3 months (End of June to end of September 2015) in the farmers dwelling at their usual maize storage places. Some farmers thus had their maize stored in the sitting room while others in their bed rooms, kitchens or granaries as the maize storage places differed from one farmer to another. The granary in which maize was stored was characterized by wooden platform with a wall made of mud constructed above the fire place in the kitchen. This type of granary was the most predominant in the area. All the farmers involved in the study promised not to disturb the maize stored for the experiment and also to keep it safe from poultry and domestic animals.

Figure 3.2: Setting up the trial with shelled maize grains in bag and dehusked maize on cobs (a) bagged shelled maize grains put on mat, (b) cobs put on mat and stored in the granary and (c) cobs put on mat stored in a room

Sampling and estimation of losses

Baseline sampling was done during the initial trial installation and subsequent samplings were done at one month interval. For baseline sampling, 200 g of shelled maize grain or 6 randomly selected cobs were taken before filling bags or putting cobs on the mat to determine insects' damage level and the dry matter content of the maize at the beginning of the storage. Monthly sampling concerned only storages that have got rodents' attacks. After sampling, sides of the bags damaged by rodents were sealed with rope and the bags closed as the way they were before sampling.

Samples needed for rodents' damages assessment, were collected through a targeted sampling method. Targeted sampling was used as rodent's infestations were not randomly distributed through the bag or the cobs stored on the mat and were specifically located at the periphery of the bags in the case of shelled maize grains. Moreover, there was strong evidence that rodents were more interested with spill over from damaged bags and loose grains from the cobs on the mat. The loose grains on the mat came from rodents feeding activity on the cobs. In such situation where rodents' infestations are localised, application of random sampling method for rodents damaged grains in the bags or for the cobs stored on the mat may lead to a total missing of damaged grains collection during sampling. Therefore, sampling for rodent damaged grains in the case of shelled maize grains consisted first to collect spilt grains on the mat and second to take a total of 100 g of grains from the bag around the areas of the bags damaged by rodents Grains taken from the bag were then added to the ones collected on the mat. In the case of cobs storage, the loose grains and any damaged cob were collected.

With regard to samples needed for dry matter determination, living insects count and insects damaged grains level, 200 g composite sample of shelled maize grain drawn from three separate positions (top, middle and bottom) in the bags or 6 randomly selected cobs from the lot of cobs on the mat were used. The composite sample obtained with shelled maize grains was subdivided into two 100 g sub-samples. One sub-sample was used for the dry matter content determination whereas the other one was used for live insect counts and insects damaged grains. In the case of maize cobs, two sub-samples of 3 cobs each were made. Each sub-sample was shelled and one was used for dry matter content determination whereas the second one was used for live insects count and insect damaged grains.

Dry matter content determination

The dry moisture content of the maize was obtained by subtracting the moisture content from 100. The moisture content was determined by the oven drying method according to the method of the International Standards Organization (ISO, 1980). Three separate subsamples of about 10 g of maize grains were ground, transferred to a metal container, weighed and dried in an oven for 2 h at 130°C. The moisture content (m.c) was determined with the following formula: m.c (%) = $100[(W_i-W_d)/W_i]$, where W_i = initial weight and W_d = dry weight.

Live adult insect counts and damage

The sub-sample allocated to live adult insects count and damage was first sieved through a set of sieves to separate and count any live adult insects with the main focus being on *Prostephanus truncatus* or *Sitophilus zeamais*. The sieved grains were later sorted into insect damaged and undamaged grains.

Rodents' damaged grains

For the shelled maize grains, 100 g sub-sample was drawn from each sample to count the number of grains damaged or undamaged by rodents. For the cobs samples, damaged cobs collected were shelled and added to the loose grains and a sub-sample of 100 g was thereafter taken to count the number of grains damaged or undamaged by rodents.

Actual weight losses due to rodents

Actual weight losses estimation was done every month and involved only storage attacked by rodents as storages which were not attacked have zero losses. Losses estimation was done on dry weight basis (Hodges *et al.*, 2014). This was done so as not to include any changes in weight of the shelled maize grains or cobs stored due to changes in grain moisture content. The losses were measured by reweighing monthly the amount of the shelled maize grains or cobs stored using weighing scale (Ashton Meyers, USA, Max 5 kg, d = 1 g) to determine weight loss from the original amount stored which was then expressed as cumulative weight losses (Fig. 3.3). The weight of grains spilled out from damaged bags or loose grains from the maize cobs on the mat were also included in the weights recorded every month. The weights measured were converted to dry weight using the dry matter contents determined. The following formula was used for the calculation of the cumulative weight losses in shelled maize grain storage and cobs storage at each sampling date:

$$\mathrm{CWgtL_i}(\%) = (\mathrm{Wgt_0} \times \mathrm{DM_0} - \mathrm{Wgt_i} \times \mathrm{DM_i}) \times 100/(\mathrm{Wgt_0} \times \mathrm{DM_0}),$$

where $CWgtL_i$ (%) is the cumulative weight losses after i month of storage with i = 1, 2 or 3 months of storage, Wgt_0 is the original weight of shelled maize grains or cobs stored, DM_0 is the dry matter content of the shelled maize grains or cobs at the beginning of the storage, Wgt_i is the weight of the shelled maize grain or cobs after i month of storage and DM_i is the dry matter content of the shelled maize grains or cobs after i month of storage.

Figure 3.3: Re-weighing of maize stored for weight losses estimation using weight balance

3.2.3. Identification of Rodents Species Associated to the Losses in the Farmer's Stores and their Population Estimation

To identify species associated with the losses in the farmers store and estimate their populations', trapping was done monthly over four months (August-November 2015) with a group of 10 farmers distributed in two villages (Bokini and Pingilikani) located in the Mwarakaya ward. These two villages were different from the villages in which actual weight loss estimation experiment was set. Three types of traps such as the Snap trap (Wooden Victor® snap traps, Woodstream Corp., Lititz, PA, USA), the Sherman live trap (H. B. Sherman's Traps, Inc., Tallahassee, FL, USA.) and the locally-made trap used by farmers were used (Fig. 3.4).

Figure 3.4: Different types of traps used in the experiment

In each village two places (granary and room) were selected to set traps. The Snap traps and Sherman live traps were provided by Kenya Museum. In the Bokini village, traps were set in the granary of 3 farmers and in the room of 2 farmers whereas in the Pingilikani village, traps were set in the granary of 2 farmers and in the room of 3 farmers. In each room and granary selected, 3 Snap traps, 2 Sherman traps and 3 locally-made traps were set for a total of four consecutive nights (Fig. 3.5). A mixture of peanut butter and white oats were used for the Sherman and snap traps while for the locally-made traps cassava pieces dipped in peanut butter were used. Traps were checked and re-baited every morning. For every individual rodent caught, the age (adult or juvenile), head-body length, tail length, left hind foot length, and the weight were recorded. Trapped rodents individuals were identified to species level using the Kingdon field guide to African mammals (Kingdon, 1997), the East African mammals (Kingdon, 1984) and the small mammals of Tanzania (Stanley and Banasiak, 2008) guides. Digital photos and specimens samples were taken to compare with the small mammal collection at the National Museums of Kenya, Nairobi. However, the rodents' species of key interests during the study were *R. rattus*, *M. musculus* and *M. natalensis*. The estimation of the rodents' population was based on the relative estimates of abundance which is an alternative approach to the estimation of the actual population size of rodents (Aplin *et al.*, 2003). Seber (1973) defined the relative abundance as an abundance measurement that is relative to the sampling effort, showing the number of individuals with regard to a measurement different from the surface or volume. Some examples of measurements are the number of individuals trapped with regard to the number of traps or set nets or the number of animals observed during a period of time (Cavia *et al.*, 2012). Moreover, relative estimates of abundance methods are far more cost effective than the actual estimates of the population size which are more laborious and costly (Aplin *et al.*, 2003). Trap success which is one of the simplest measures of relative abundance (Aplin *et al.*, 2003) was used. The trap success was calculated as described by Aplin *et al.* (2003).

Trap success (%) = Number of rodents captured*100/Trap nights, where trap night is the total number of traps set for n consecutive night. Corrected trap night was not used as no case of "null traps" (traps that have been triggered without making a capture) was observed. In this study total trap night per month was calculated as: 10 farmers * 4 nights *(3 snap traps + 2 sherman traps +3 locally-made traps). So total trap nights per month = 320 nights.

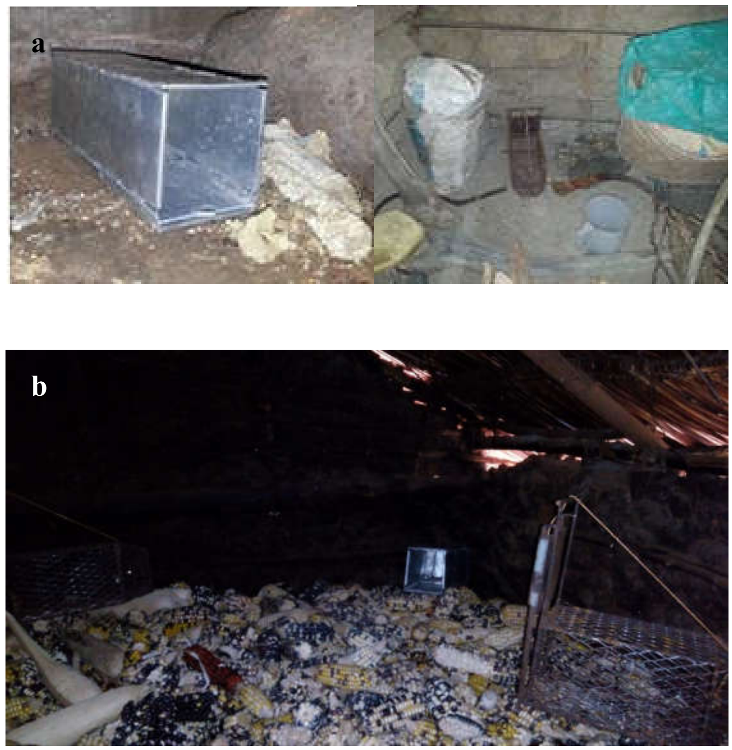

Figure 3.5: Setting of traps – (a) traps set in room, (b) traps set in the granary

3.3. Influence of Rodents Damages on the Grains Contamination by Storage Moulds and Aflatoxins

3.3.1. Samples Preparation

Mould contamination analysis was done with two composite samples (grains undamaged and damaged by rodents) (Fig. 3.6) made from the spilt grains (shelled maize grain storage and loose grains from cobs) collected at the end of the actual losses estimation experiment in order to evaluate the influence of rodents damage on the grain contamination by moulds and aflatoxin. One composite sample was obtained either in mixing the undamaged grains kernels of both cobs spilt shelled maize or in mixing the rodents damaged grains kernels of both cobs and spilt shelled maize.

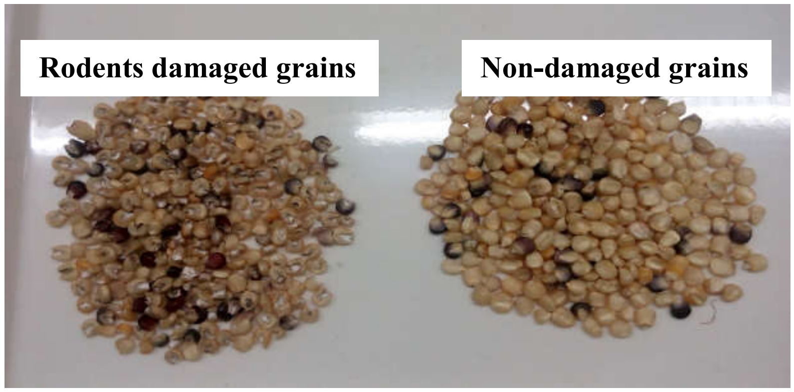

Figure 3.6: Rodents damaged grains composite sample and non-damaged grains composite sample

3.3.2. Total Moulds Count

Total moulds count was performed using the surface plating method (Pitt & Hocking, 2009). Three replicates of 10 g of grains from each sample (grains undamaged and damaged by rodents) were thoroughly mixed with 90 ml 0.1% peptone water solution and serial dilutions were prepared up to 10^{-3}. 0.1 ml aliquots of each dilution were transferred to Petri dishes containing Sabouraud Dextrose Agar (SDA). The Petri dishes were incubated at 25°C under 12:12-hour light and dark regime for 4 days. Colonies developing on plates were counted at the end of the incubation period and recorded as Colony Forming Units per gram (CFU/g).

3.3.3. Determination of Fungal Incidence

Three replicates of 21 grains of each sample (63 grains per sample) were surface disinfested in 3% sodium hypochlorite solution for 2 min and rinsed twice in distilled water. Seven grains were then plated per Petri dishes (7 grains per Petri dish) containing Czapek Dox Agar (CDA) to which 1 g chloramphenicol per litre had been added. The Petri dishes were incubated at 25°C under 12:12-hour light and dark regime for four days. After the incubation, the number of grain infected were recorded and categorized per colour characteristic of the fungi present on the grains. Pure sub-cultures based on the fungi colour characteristics were made and incubated for 5 days for the genera identification. The fungi genera identification was made with preparation of slides for microscopic examination of their morphological structures using the key of Pitt and Hocking (2009). After identification, the percentage of grains infected by each fungus genera was thereafter calculated to determine their incidence on maize grains.

3.3.4. Aflatoxin Analysis

Samples preparation and extraction

Aflatoxin analysis was done on the rodent damaged grains sample and the undamaged grains sample. For each sample, 10 sub-samples of 5 g each were obtained after grinding of the grains and sieving through a 20 mesh sieve. The ground samples were vigorously shaken in 25 ml of 70% methanol for 3 minutes using a mechanical shaker. The extracts were filtered through a Whatman #1 filter and the filtrates were collected for analysis.

ELISA *analysis*

Extracts were assayed for total aflatoxin using Veratox® Total Aflatoxin ELISA (Enzyme Linked Immunosorbent Assay) Kit (Veratox®, Neogen Corporation, Lansing, MI, USA, Product 8030). A 100 µl conjugate was added to red-marked mixing well using 12-channel pipettor, then 100 µl of controls and extracts were added unto it. From the red-marked mixing well, 100µl was obtained and transferred to the antibody-coated wells, mixed three times and incubated for 2 minutes. Contents were then dumped into a waste container and the antibody-coated wells were washed 5 times with sterile distilled water. Excess water was tapped out on an absorbent paper towel. Next, 100 µl Substrate from reagent boat was transferred to antibody-coated wells; mixed thoroughly and incubated for 3 minutes. Lastly, 100 µl Red Stop solution was added to antibody-coated wells and mixed thoroughly. Results were interpreted using micro-plate ELISA reader. The results obtained were multiplied by the dilution factor. All sub-samples extracts were run in duplicates and the detection limit was 1.4 ppb.

3.4. Data Analysis

Qualitative data (maize storage forms, storage places and structures, storage duration, methods used by farmers to protect stored maize, and training on postharvest) were summarized as contingency tables or graphs. Differences between categories within AEZs as well as the overall sample were determined using the Chi-square test followed by pairwise comparisons using "chisq.multcomp" function with Bonferroni *p*-values adjustment in the RVAideMemoire package (Hervé, 2014) in R 3.2.5. Prior to analysis, data on losses and the proportions of harvested maize taken for various uses (percentage) were tested for normality using the Shapiro-Wilk test. The data were found to be not normally distributed and were arcsine square root (x/100)-transformed and then subjected to analysis of variance (ANOVA) in SPSS version 20. Means were separated using Duncan's Multiple Range Test at 95% confidence level.

To identify the factors associated with the losses, relationships between reported magnitudes of losses, storage practices, storage bio-physical environment, as well the socio-demographic characteristics of the farmers were established using regression analysis. This was performed in STATA 12 (StataCorp LP, TX, USA). A model was fitted with the explanatory variables grouped in four categories: (i) the respondents socioeconomic characteristics (gender, age, experience in maize farming and education level), (ii) the storage practices and management characteristics (maize storage forms, storage structures, use of chemicals, cat, trap and training on grain storage protection), (iii) the storage seasons (long rain season, short rain season or both), and (iv) the AEZs. In addition to these variables, presence or absence of rodents in storage was considered for the total maize loss model to see whether contribution of rodents to total losses was significant or not. From the survey, some farmers did not incur any losses and therefore their losses values were constrained to zero. Moreover, the dependent variable was censored at both right and left sides as the losses values are within the (0-1) interval. Due to censoring, an ordinary least squares regression can result in biased parameter estimates. To overcome that situation, Tobit estimator which is the standard procedure to correct for zero censoring (Wooldridge, 2012) was performed. However, according to Wooldridge (2012), if error terms are not normally distributed and there is homoskedastic problem, Tobit estimates are themselves biased. The presence of non-normal distribution and heteroskedasticy of errors were observed when the diagnostic of Tobit regression model was performed through Lagrange Multiplier (LM) tests of non-normality and heteroskedascity as described in Cameron and Trivedi (2010) (Normality test: $NR^2 = 46.593$, $p < 0.0001$ (total losses model) and $NR^2 = 75.977$, $p < 0.0001$ (rodents losses model)) and homoskedasticity test: $NR^2 = 293.376$, $p < 0.0001$ (total losses model) and $NR^2 = 169.342$, $p < 0.0001$ (rodents losses model)). Therefore the censored least absolute deviation (CLAD) regression was used as alternative to the Tobit regression to identify factors that most influence the magnitude of losses (Powell, 1984). The major advantages of this semi-parametric approach are its robustness to unknown conditional heteroskedasticy, and the provision of consistent and asymptotically normal estimates for a wide range of error distributions.

For the actual losses estimation experiment and microbiological analysis, weight losses, rodents and insects damaged grain percentage and moulds incidence data were arcsine square root (x/100)-transformed while the insects count and total aflatoxin data were log (x + 1)-transformed to normalize them, and then subjected to repeated measures ANOVA (weight losses, rodents and insects damaged grain percentage) or t-test (total mould count, moulds incidence and total aflatoxin) using SPSS version 20. For the repeated measures ANOVA, degrees of freedom were corrected using Greenhouse-Geisser estimates if the assumption of sphericity was violated (Mauchly's test for sphericity) and the means on the consecutive sampling dates were separated by Bonferroni post-hoc tests.

CHAPTER FOUR

RESULTS

4.1. Maize Storage Practices and Farmers' Assessment of Rodent Postharvest Losses

4.1.1. Socio-Demographic Characteristics of Respondents

Socio-demographic characteristics of respondents according to agro-ecological zone are summarized in Table 4.1. The majority of respondents in the LLT, DMA, HLT and MMA zones were male whereas female respondents were the majority in the DT and MT zones. Overall, out of the 630 respondents there was a balanced gender distribution of 51% female against 49% male respondents. Generally, 61.3% of all respondents were within the age of 25 -55 years. More than two thirds had completed the primary level of formal education (69.9%), although the percentage was lower (45.7%) in the LLT zone. In addition, close to three quarters of the respondents (73%) had more than 11 years of experience in maize farming.

The harvested maize was mainly used for household consumption (75.6 ± 1.2%) and income (23.4 ± 1.1%). A small proportion of the maize (1.5 ± 0.3%) was used for donations, payments in kind or planting (Table 4.2). Consumption was the predominant end use of the harvested maize in all the AEZs, except the HLT zone where quantities used for home consumption and sales were not significantly different ($F_{2, 312} = 703.65$, $p < 0.001$ (LLT); $F_{2, 312} = 323.80$, $p < 0.001$(DMA); $F_{2, 312} = 352.82$, $p < 0.001$(DT); $F_{2, 312} = 99.99$, $p < 0.001$ (HLT); $F_{2, 312} = 441.89$, $p < 0.001$ (MT); $F_{2, 312} = 675.64$, $p < 0.001$ (MMA); $F_{2, 1887} = 1709.45$, $p < 0.001$ (Overall sample)).

Table 4.1: Socio-demographic characteristics of respondents (n = 630)

Characteristic	Percentage of respondents in each agro-ecological zone						Overall percentage
	LLT [a]	DMA [b]	DT [c]	HLT [d]	MT [e]	MMA [f]	
	n =105	n = 105	n = 105	n = 105	n = 105	n = 105	
Gender							
Male	59.0	56.2	25.7	66.7	30.5	56.2	49.0
Female	41.0	43.8	74.3	33.3	69.5	43.8	51.0
Age (years)							
< 18	0.0	0.0	0.0	1.0	0.0	1.9	0.5
18-24	4.8	1.9	1.0	6.7	5.7	14.3	5.7
25-40	39.0	30.5	24.8	35.2	43.8	27.6	33.5
41-55	24.8	22.9	34.3	34.3	27.6	22.9	27.8
> 55	31.4	44.8	40.0	22.9	22.9	33.3	32.5
Education level							
No formal education	30.5	10.5	11.4	7.6	12.4	1.0	12.2
Not completed primary school	23.8	26.7	6.7	15.2	14.3	21.0	17.9
Completed primary school	23.8	35.2	54.3	31.4	46.7	35.2	37.8
Completed secondary school	21.9	27.6	27.6	45.7	26.7	42.9	32.1
Maize farming experience (years)							
1-5	10.5	3.8	3.8	30.5	13.3	21.0	13.8
6-10	24.8	13.3	9.5	10.5	10.5	10.5	13.2
11-15	8.6	8.6	9.5	16.2	22.9	25.7	15.2
≥ 15	56.2	74.3	77.1	42.9	53.3	42.9	57.8

[a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

Table 4.2: End uses of maize harvested by farmers

Agro-ecological zones	Percentage of harvest maize		
	Consumption	Sale	Other uses (donations, payment in kinds and planting seeds)
LLT [a]	88.9 ± 2.2a	7.53 ± 2.0b	3.6 ± 1.1b
DMA [b]	74.7 ± 2.7a	24.8 ± 2.7b	0.2 ± 0.2c
DT [c]	77.3 ± 2.7a	22.8 ± 2.7b	0.0 ± 0.0c
HLT [d]	47.6 ± 3.2a	48.7 ± 3.1a	4.7 ± 0.9b
MT [e]	79.5 ± 2.4a	21.1 ± 2.4b	0.0 ± 0.0c
MMA [f]	85.5 ± 1.9a	15.6 ± 2.0b	0.2 ± 0.2c
Overall sample	75.6 ± 1.2a	23.4 ± 1.1b	1.4 ± 0.2c

*Mean (± SE) values within a row followed by the same letter are not significantly different at the 5% probability level

[a] Low land tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

4.1.2. Maize Storage Forms

Maize storage forms varied from one AEZ to another (Table 4.3). Some farmers stored their maize on cobs during the whole storage period, while others stored as shelled loose grains. Other farmers stored in both forms whereby the maize was stored on cobs for the first few months before shelling. In the LLT zone, cob storage was the predominant form of maize storage (72.4%), whereas in the DMA, HLT, MT and MMA zones, storage in the form of grain was predominant (69.5%, 82.9%, 55.24% and 92.4%, respectively). However in the DT zone, maize storage as shelled grain or both cobs and shelled grain was the commonest practice among farmers. Farmers stored maize cobs either with the husk or without the husk (dehusked) while some stored both dehusked and undehusked forms at the same time. Generally, storage of maize as dehusked cobs was the commonest practice ($\chi2$ (2) = 236.02, $p<$ 0.001). In the LLT zone, storage of maize as husked or dehusked cobs was common practice, whereas in the other AEZs farmers predominantly stored cobs in the dehusked form. Overall, however, storage of maize as grain was the commonest practice across the AEZs ($\chi2$ (2) = 217.40, $p < 0.001$).

Table 4.3: Proportions of farmers using different forms of maize storage across in the various agro-ecological zones (n = 630)

Maize storage	Percentage of respondents in each agro-ecological zone						Overall percentage
	LLT [a] n = 105	DMA [b] n = 105	DT [c] n = 105	HLT [d] n = 105	MT [e] n = 105	MMA [f] n = 105	
Storage forms							
Cobs	72.4a	2.9c	1.0b	14.3b	3.8b	4.8b	16.5c
Grain	24.8b	69.5a	40.0a	82.9a	55.2a	92.4a	60.8a
Both cobs and grain	2.9c	27.6b	59.1a	2.9c	41.0a	2.9b	22.7b
$\chi2$ (2)	79.6	71.54	55.254	117.94	44.4	164.8	217.4
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Forms of cob storage[1]							
Husked cobs	45.6a	6.3b	1.6b	0.0b	2.1b	0.0b	16.2b
De-husked cobs	40.5a	93.8a	96.8a	100.0a	97.9a	100.0a	79.0a
Mixture of husked and de-husked cobs	13.9b	0.0b	1.6b	0.0b	0.0b	0.0b	4.9c
$\chi2$ (2)	13.696	52.75	114.29	36	88.128	16	236.02
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within each agro-ecological zone as well as the overall sample, same letters in a column indicate no significant differences between categories at $p < 0.05$.

[a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone; [1] Considers the sum of farmers who stored maize as cobs, and farmers who stored maize as cobs at one stage and thereafter as grain.

4.1.3. Maize Storage Structures

Fig. 4.1 and Table 4.4 show the structures used for maize storage in the various AEZs. Maize cobs were stored in traditional granaries (large cylindrical baskets made of bent sticks placed on raised platform constructed in the homestead, and covered with grass thatch roof or wooden platform with a wall made of mud constructed above the fire place in the kitchen), traditional cribs (raised cylindrical structures made of bent sticks and covered on top with grass thatch), improved cribs with grass thatch (raised rectangular structures with walls made of spaced sisal stems, wooden rafters or timber, and with grass thatch roof), improved cribs with iron sheet roof (raised rectangular structures with wall made of spaced sisal stems, wooden rafters, timber or wire mesh between poles, and with iron sheet roof), or in bags. Other farmers placed the cobs directly on the floor, on a mat or on pallets, or on a hanging rope inside a designated storage room in the living house. Among these storage methods, traditional granaries were predominantly used for cob storage in the LLT and MMA zones, whereas improved cribs with iron sheet roofing were common in the other AEZs for cob storage. Overall, the most predominant storage structures for maize cobs among the farmers were the improved cribs with iron sheet roofing (39.3%) and the traditional granaries (33.2%).

Across the six AEZs, farmers who stored maize as shelled grain primarily used ordinary bags for storage (99.2%), but some stored directly on the floor (2.1%), or on mat/ pallet on the floor (16.3%) in a designated storage room in the living house. Some farmers stored the shelled maize directly on the floor of crib or granary (1.7%) whereas a few farmers stored in hermetic containers such as metal silos (1.0%) and hermetic plastic bags (0.4%) (Fig. 4.1 and Table 4.4). Fig. 4.2 shows the storage places for the bagged maize grain. With exception of HLT zone where bagged maize was predominantly stored in cribs or granaries, bagged maize was mostly stored in a special store room in the living houses ($\chi2$ (5) = 29.6, $p < 0.001$ (LLT); $\chi2$ (5) = 126.78, $p < 0.001$ (DMA); $\chi2$ (5) = 240.88, $p < 0.001$ (DT); $\chi2$ (5) = 148.93, $p <$ 0.001(HLT); $\chi2$ (5) = 86.43, $p < 0.001$(MT); $\chi2$ (5) =243.27, $p < 0.001$ (MMA); $\chi2$

(5) =601.48, $p < 0.001$ (Overall sample)). Overall, 73.2% of farmers stored bagged maize in their living houses whereas only 25.1% stored in cribs and granaries.

Figure 4.1: Maize storage structures across agro-ecological zones. a and b:traditional granaries; c: traditional crib; d: improved crib with grass thatch roof; e: improved crib with iron sheet roof; f: maize cobs stored on the floor in room; g: bagged maize grain stored in special room; h: bagged maize grain stored in crib; i: maize grain packed in plastic hermetic bags and stored in crib.

Table 4.4: Storage structures used by farmer to store maize across the agro-ecological zones

Maize storage structure	Percentage of respondents in each agro-ecological zone						Overall percentage
	LLT [a]	DMA [b]	DT [c]	HLT [d]	MT [e]	MMA [f]	
Maize cobs (n=247)[1]							
Traditional granaries	94.9a	3.1b	0.0c	0.0b	4.3b	50.0a	33.2a
Traditional cribs	0.0b	3.1b	9.5abc	0.0b	0.0b	12.5a	3.2c
Improved cribs with grass thatch	1.3b	21.9ab	25.4a	0.0b	0.0b	0.0a	9.7bc
Improved cribs with iron sheet roof	1.3b	56.3a	34.9a	77.8a	85.1a	25.0a	39.3a
Bag	0.0b	46.9a	3.2bc	0.0b	0.0b	0.0a	6.9bc
Directly on the floor in room	0.0b	12.5ab	0.0c	5.6b	8.5b	12.5a	4.1bc
Mat/pallet put on the floor in room	2.5b	15.6ab	20.6ab	16.7b	8.5b	12.5a	11.3b
Hanging on rope	0.0b	0.0b	14.3abc	0.0b	0.0b	0.0a	3.6c
χ^2 (7)	491.23	49.549	53.176	73.556	211.76	11.444	249.42
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.1204	<0.001
Shelled maize grain(n = 526)[2]							
Bag	100.0a	100.0a	100.0a	96.7a	100.0a	99.0a	99.2a
Directly on floor in room	6.9bc	5.9b	0.0c	2.2b	0.0b	1.0c	2.1c
On mat/pallet put on the floor in room	44.8ab	6.9b	22.1b	2.2b	5.0b	36.0b	16.4b

Directly on the floor in improved cribs	0.0c	6.9b	0.0c	0.0b	1.0b	0.0c	1.5c
Directly on floor in traditional granary	0.0c	1.0b	0.0c	0.0b	0.0b	0.0c	0.2c
Metal silo	0.0c	3.9b	0.0c	0.0b	0.0b	1.0c	1.0c
Hermetic plastic bags	0.0c	0.0b	0.0c	0.0b	0.0b	2.0c	0.4c
Plastic container	0.0c	0.0b	0.0c	1.1b	0.0b	0.0c	0.2c
Platform	0.0c	1.0b	0.0c	0.0b	0.0b	0.0c	0.2c
Tomato crate	3.5c	0.0b	0.0c	0.0b	0.0b	0.0c	0.2c
$\chi2$ (9)	180.56	696.69	766.31	731.7	848.79	659.78	3752.3
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$.

[a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

[1]Sample sizes for individual AEZs are LLT: n = 79; DMA: n = 32; DT: n= 63; HLT: n = 18; MT: n = 47; MMA: n= 8.

[2] Sample sizes for individual AEZs are LLT: n = 29; DMA: n = 102; DT: n= 104; HLT: n = 90; MT: n = 101; NMA: n = 100.

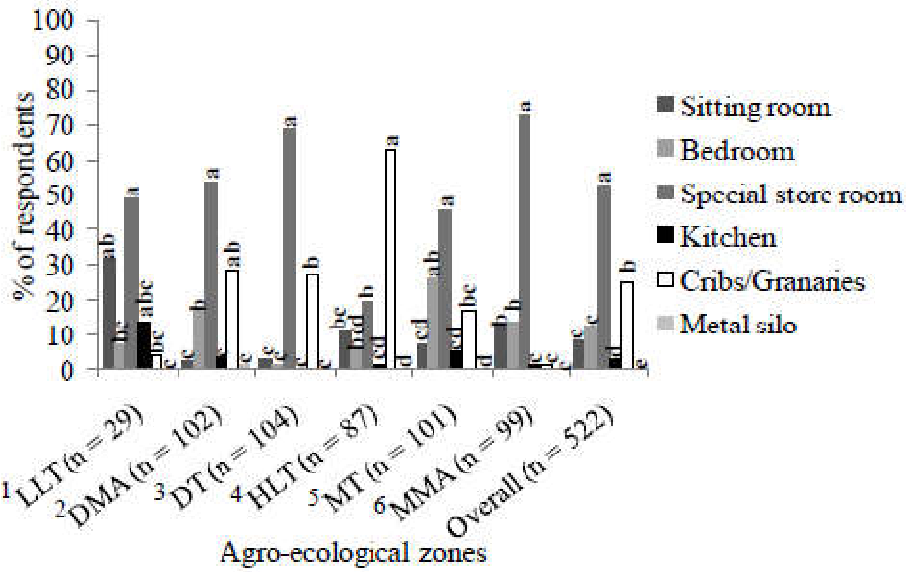

Figure 4.2: Places used by farmers for storage of bagged maize grain. n: sample size

[1]Low land tropical zone, [2]Dry mid-altitude zone, [3]Dry transitional zone, [4]Highland tropical zone, [5]Moist transitional zone, [6]Moist mid-altitude zone. Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$.

The typical maize storage durations varied from one AEZ to another (Fig. 4.3). For maize cobs, 1 - 4 months storage was predominant in DMA, DT and MT zones ($\chi2$ (2) = 64, $p < 0.001$ (DMA); $\chi2$ (2) = 126, $p < 0.001$ (DT); $\chi2$ (2) = 76.89, $p < 0.001$ (MT); $\chi2$ (2) = 5.33, $p = 0.069$ (HLT); $\chi2$ (2) = 1.75, $p = 0.416$ (MMA);)whereas longer storage periods of 5 - 8 months were predominant in LLT zones ($\chi2$ (2) =14.47, $p < 0.001$) (Fig. 4.3a). In HLT and MMA zones, there were no significant differences between the different storage period intervals for cobs storage ($\chi2$ (2) = 5.33, $p = 0.069$ (HLT) and $\chi2$ (2) = 1.75, $p = 0.416$ (MMA)). For shelled maize, storage durations spanning 1 - 4 months were predominant in DMA and DT ($\chi2$ (3) = 56.196, $p < 0.001$ (DMA); $\chi2$ (3) = 67.23, $p < 0.001$ (DT)). In the other AEZs, there was no significant difference between storage periods lasting 1-4 months and 5-8 months ($\chi 2$ (3) =14.44, $p < 0.001$ (LLT); $\chi 2$ (3) = 43.6, $p < 0.001$ (HLT); $\chi 2$ (3) = 62.37, $p < 0.001$ (MT); $\chi 2$ (3) = 51.6, $p < 0.001$ (MMA)) (Fig. 4.3b). Overall, the commonest storage period for cobs spanned 1 - 4 months ($\chi 2$ (2) = 130.72, $p < 0.001$ (Overall sample)) whereas for shelled grains storage period between 1-4 months and 5-8 months were the most common ($\chi 2$ (3) = 263.58, $p < 0.001$ (Overall sample)).

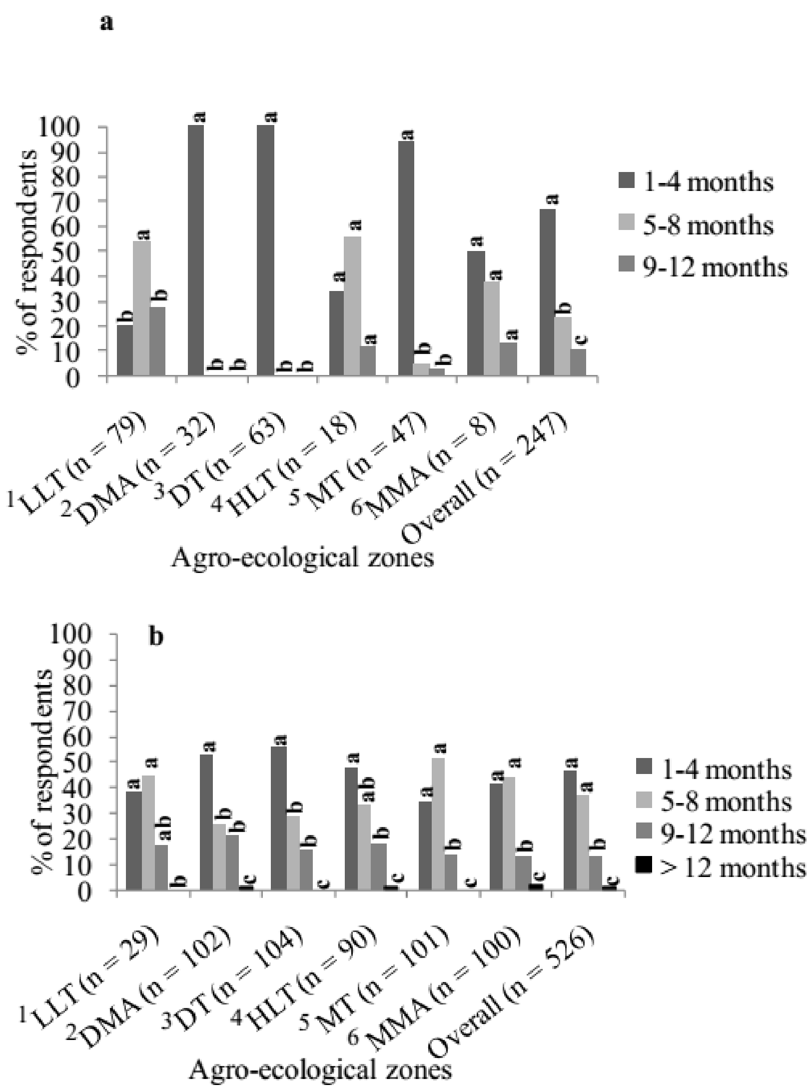

Figure 4.3: Storage duration of maize stored as cobs

(a) and maize stored as grain (b) in the various agro-ecological zones. n: sample size; [1]Low land tropical zone, [2]Dry mid-altitude zone, [3]Dry transitional zone, [4]Highland tropical zone, [5]Moist transitional zone, [6]Moist mid-altitude zone. Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$.

4.1.4. Storage Problems

Fig. 4.4 gives the frequencies of storage problems as experienced by farmers (Fig. 4.4a) and the ranking of the problems across the agro-ecological zones (Fig. 4.4b). In the LLT zone, all the farmers surveyed experienced storage problems, while in the HLT, MMA, DMA, DT and MT zones, 83-98% of farmers reported storage problems. In general, the problem of storage pests (insects, rodents and moulds) was reported by 92% of farmers surveyed. In all the AEZs and for the overall sample, the report of insect and rodents infestations in stores by the farmers was not statistically different. The problem of moulds was reported by 13% of farmers across the country and was the least problem reported by farmers in all AEZs compared to insects and rodents problem ($\chi2$ (2) =97.65, $p < 0.001$ (LLT); $\chi2$ (2) = 62.53, $p < 0.001$ (DMA); $\chi2$ (2) = 40.33, $p < 0.001$ (DT); $\chi2$ (2) = 68.65, $p < 0.001$ (HLT); $\chi2$ (2) = 49.37, $p < 0.001$ (MT); $\chi2$ (2) = 55.23, $p < 0.001$ (MMA); $\chi2$ (2) = 363.19, $p <0.001$ (Overall sample)). Storage pest problems were ranked by farmers according to their perception on the level of damage caused by the respective pests in their stores. In LLT, the majority of farmers ranked rodents as the main storage problem, followed by insects and lastly moulds ($\chi2$ (2) = 89.65, $p< 0.001$). In the other AEZs, insects were ranked as the main storage problem followed by rodents and then moulds ($\chi2$ (2) = 149.83, $p < 0.001$ (DMA); $\chi2$ (2) = 118.13, $p < 0.001$ (DT); $\chi2$ (2) = 121.94, $p < 0.001$ (HLT); $\chi2$ (2) = 54, $p < 0.001$ (MT); $\chi2$ (2) = 114.25, $p < 0.001$ (MMA)). Overall, insects were the most important storage problem followed by rodents ($\chi2$ (2) = 452.98, $p < 0.001$).

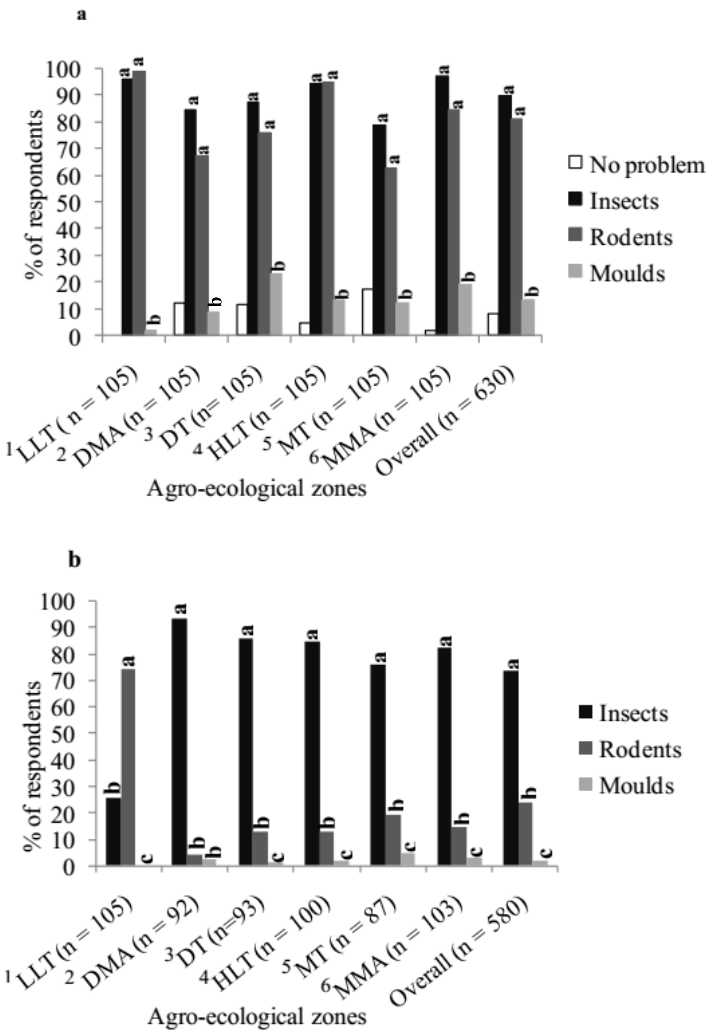

Figure 4.4: Problems encountered by farmers in the storage of maize (a), and the proportion of farmers ranking a particular problem as the main or "number one" storage problem in the agro-ecological zones (b). n: sample size; [1]Low land tropical zone, [2]Dry mid-altitude zone, [3]Dry transitional zone, [4]Highland tropical zone, [5]Moist transitional zone, [6]Moist mid-altitude zone. Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$.

4.1.5. Control of Storage Pests

Tables 4.5 and 4.6 summarize the methods used by farmers to protect maize stored on cobs and as shelled loose grain against storage pests, respectively. The proportion of farmers who did not apply any measures to control insects or rodents varied from one AEZ to another. With regard to insects in maize stored as cobs (Table 4.5), about half of the farmers in the MT zone did not apply any measures while in the HLT zone, all the farmers applied control methods, specifically insecticides and indigenous treatments. For rodents 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. In shelled maize grain storage (Table 4.6), over 92% of the farmers in DMA, DT, HLT, MT and MMA zones applied some form of protection to counter insects whereas about a third of the farmers in LLT did not apply any methods to control insects. Overall, only 7% of the farmers surveyed across the AEZs failed to apply any methods to counter insects when the maize was stored as shelled grain. For rodent control in shelled maize grain storage, over 88% of farmers in LLT, MT and MMA applied some form of control while 30% of the farmers in DMA 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.

Use of pesticides (synthetic insecticides and rodenticides) was the main method used to control insects ($\chi2$ (5) = 254.39, $p < 0.001$ (cob storage); $\chi2$ (8) = 2545.31, $p < 0.001$ (grain storage)) and rodents ($\chi2$ (5) = 326.350, $p < 0.001$ (cob storage); $\chi2$ (6) = 1133, $p < 0.001$ (grain storage)) across the country. Synthetic insecticides used included Actellic Super dust (pirimiphos-methyl 1.6% w/w + permethrin 0.3% w/w), Actellic Gold dust powder (thiamethoxam 0.36% w/w + pirimiphos methyl 1.6%w/w), Skana Super grain dust (malathion 2.0% w/w + permethrin 0.3% w/w), Spintor 0.125% dust (spinosad 0.125% w/w), Sumicombi 1.8% dust (1.5% w/w fenitrothion + 0.3% w/w fenvalerate) and Super Malper dust (malathion 1.6% w/w + permethrin 0.4% w/w). Apart from synthetic insecticides, other methods used were application of cow dung, wood ashes, plant leaves, exposing to sun, admixing with hot pepper, smoking, grain treatment with boiled water, and storage in hermetic plastics bags and metal silos . The hermetic plastic bags encountered were the PICS (Purdue Improved Crop Storage) triple-layer bags (Murdock *et al.*, 2012). The rodenticides used included Red Cat powder (Zinc Phosphide 54% w/w), Mortein Doom Rat Kill (Brodifacoum 0.005% w/w), Indocide (indomethacin) and Baraki Pellets (Difethialone 0.125% w/w). Farmers in all the agro-ecological 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 their stores were cleaned and old stocks removed before loading the new harvest.

Table 4.5: Methods used by farmers to protect maize cobs against storage pests (n = 247)

Control method	Percentage of respondents in each agro-ecological zone						Overall percentage
	LLT [a] (n = 79)	DMA [b] (n = 32)	DT [c] (n = 63)	HLT [d] (n = 18)	MT [e] (n = 47)	MMA [f] (n = 8)	
Insects control							
No control method	27.9	34.4	34.9	0.0	51.1	25.0	32.8
Insecticides	38.0a	62.5a	65.1a	88.9a	21.3a	50.0a	49.0a
Wood/Cow dung ashes	7.6bc	9.4b	0.0b	27.8ab	0.0b	25.0a	6.5bc
Plant leaves	24.1ab	3.1b	0.0b	0.0b	0.0b	0.0a	8.1b
Exposure to sun	1.3c	3.1b	1.6b	0.0b	34.0a	37.5a	8.9b
Hot pepper powder	5.1c	3.1b	0.0b	0.0b	0.0b	0.0a	2.0c
Put fire under granary (smoking)	36.7a	3.1b	0.0b	0.0b	0.0b	0.0a	12.2b
$\chi2$ (5)	56.281	64.778	198.29	59.286	56.154	10.333	254.39
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.066	<0.001
Rodents control							
No control method	5.1	28.1	6.4	50.0	76.6	25.0	25.9
Rodenticides	79.8a	53.1a	74.6a	44.4a	4.3ab	50.0a	57.1a
Cat	49.4a	50.0a	14.3b	22.2ab	17.0a	62.5a	32.8b
Rat trap	44.3a	15.6ab	6.4bc	5.6b	4.3ab	0.0b	19.0c
Plastering the wall and floor of the granary	10.1b	0.0b	0.0c	0.0b	0.0b	0.0b	3.2d
Hunting	6.3b	0.0b	0.0c	0.0b	0.0b	0.0b	2.0d
Bait	0.0b	0.0b	0.0c	5.6b	0.0b	0.0b	0.4d
$\chi2$ (5)	122.16	52	170.6	21.143	24	18.333	326.35
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$. [a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

Table 4.6: Methods used by farmers to protect shelled maize grain against storage pests (n = 526)

Control method	Percentage of respondents in each agro-ecological zone						Overall percentage
	LLT [a] (n = 29)	DMA [b] (n = 102)	DT [c] (n = 104)	HLT [d] (n = 90)	MT [e] (n = 101)	MMA [f] (n = 100)	
Insects control							
No control method	31.0	7.8	6.7	4.4	3.0	5.0	6.8
Insecticides	69.0a	88.4a	92.3a	91.1a	97.0a	54.0a	83.7a
Wood/ Cow dung ashes	6.9b	4.9b	1.0b	6.7b	1.0c	52.0a	12.7b
Plant leaves	13.8b	1.0b	1.0b	0.0b	1.0c	1.0b	1.5c
Exposure to sun	0.0b	2.0b	1.0b	3.3b	9.9b	37.0a	10.1b
Hot pepper powder	0.0b	2.0b	0.0b	0.0b	0.0c	0.0b	0.4c
Put fire under granary/ smoking	3.5b	0.0b	0.0b	0.0b	0.0c	0.0b	0.2c
Use of boiled water	0.0b	0.0b	0.0b	0.0b	1.0c	0.0b	0.29c
Use of metal silo	0.0b	3.9b	0.0b	0.0b	0.0c	1.0b	1.0c
Use of hermetic plastic bags	0.0b	0.0b	0.0b	0.0b	0.0c	2.0b	0.4c
$\chi 2$ (8)	113.33	601.29	739.09	578.4	676.05	281.27	2545.3
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Rodents control							
No control method	6.9	29.4	11.5	30.0	7.9	4.0	15.4
Rodenticides	68.9a	53.9a	68.3a	54.4a	60.4a	62.0a	60.8a
Cat	44.8a	54.9a	19.2b	32.2ab	54.5a	68.0a	45.8b
Rat trap	24.1ab	6.9b	4.8c	17.8bc	18.8b	5.0b	11.2c
Hunting	3.5b	0.0b	0.0c	5.6cd	0.0c	0.0b	1.1d
Bait	0.0b	0.0b	0.0c	13.3bc	0.0c	0.0b	2.3d
Book gum/ stick pad	3.5b	0.0b	0.0c	13.3bc	0.0c	2.0b	0.6d
Use of metal silo	0.0b	3.9b	0.0c	0.0d	0.0c	1.0b	1.0d
$\chi 2$ (6)	61.33	240.11	302.56	93.88	233.51	293.06	1133
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$. [a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

4.1.6. Farmers Training on Grain Storage and Protection Technologies

The proportion of farmers without training on stored maize protection was significantly higher than the proportion of farmers with training, in all AEZ ($\chi2$ (1) = 85.95, $p < 0.001$ (LLT); $\chi2$ (1) = 48.01, $p < 0.001$ (DMA); $\chi2$ (1) = 5.03, $p = 0.025$ (DT); $\chi2$ (1) = 72.09, $p < 0.001$ (HLT); $\chi2$ (1) = 48.01, $p < 0.001$ (MT); MMA: $\chi2$ (1) = 62.49, $p < 0.001$ (MMA); Overall sample ($\chi2$ (1) = 290.77, $p < 0.001$)) (Fig. 4.5). On average, only 16% of farmers across the AEZs had received training.

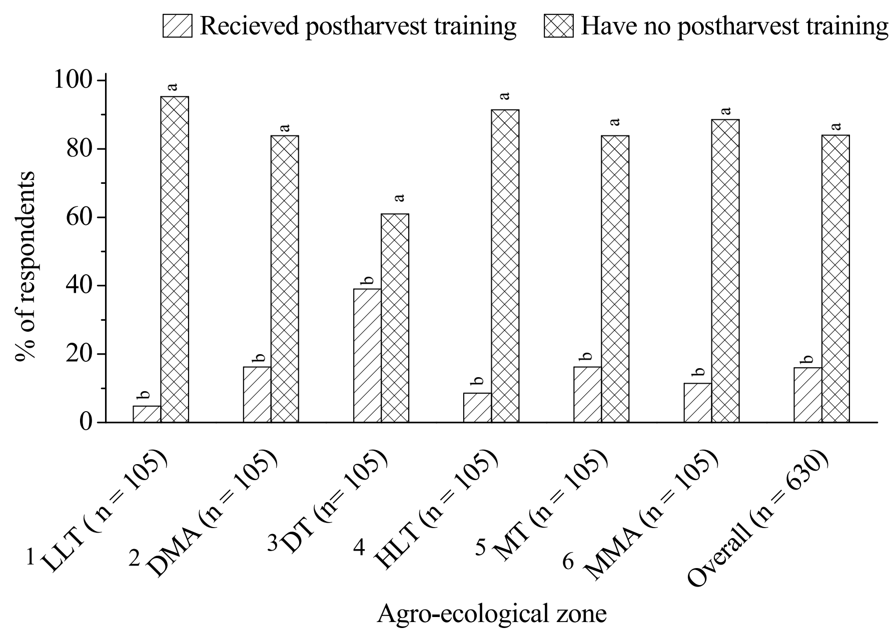

Figure 4.5: Proportion of farmers who had or had not received training on stored grain and protection technologies in the various agro-ecological zones. n: sample size

[1]Low land tropical zone, [2]Dry mid-altitude zone, [3]Dry transitional zone, [4]Highland tropical zone, [5]Moist transitional zone, [6]Moist mid-altitude zone. Within each agro-ecological zone as well as the overall sample, same letters indicate no significant differences between categories at $p < 0.05$.

4.1.7. Losses During Maize Storage

The results of perceived maize losses during storage are presented in Table 4.7. For maize stored on cobs, rodents and insects caused losses that varying between 1.3 - 9.7% and 3.3 - 8.3%, respectively, whereas losses attributed to mould were less than 1% across the AEZs. The total perceived losses varied between 6 - 17%, and on average were 11.2 ±0.7%. There was significant difference between the AEZs for the losses due to rodents ($F_{5, 241} = 38.38$, $p < 0.001$), insects ($F_{5, 241} = 4.72$, $p < 0.001$), moulds ($F_{5, 241} = 3.77$, $p = 0.003$) and total losses ($F_{5, 241} = 7.79$, $p < 0.001$). Rodent infestation caused significantly higher losses in the LLT zone as compared to the other AEZs whereas insect infestation caused highest and lowest losses in the MMA and DT zones, respectively. Within the AEZs, significant differences were observed between the losses caused by rodents, insects and moulds ($F_{2, 234} = 296.38$, $p < 0.001$ (LLT); $F_{2, 93} = 30.45$, $p < 0.001$ (DMA); $F_{2, 186} = 29.67$, $p < 0.001$ (DT); $F_{2, 51} = 19.66$, $p < 0.001$ (HLT); $F_{2, 138} = 15.73$, $p < 0.001$ (MT); $F_{2, 21} = 5.71$, $p = 0.01$ (MMA)). Moreover, the magnitude of losses due to moulds was the lowest in all the AEZs. Losses emanating from rodents were significantly higher than those caused by insects in the LLT zone alone.

For the maize stored as shelled grain, losses due to rodents and insects varied between 2.7 - 8.7% and 7.4 - 12.9%, respectively, whereas losses caused by moulds were lower than 1%. Total losses varied between 10 - 20% (average 15.5 ± 0.6%) and the effect of AEZ was highly significant ($F_{5, 520} = 16.82$, $p < 0.001$ (rodent); $F_{5, 520} = 3.14$, $p = 0.008$ (insects); $F_{5, 520} = 3.29$, $p = 0.006$ (moulds); $F_{5, 520} = 6.44$, $p < 0.001$ (total losses)). Similar to maize stored on cobs, perceived losses due to rodent were highest in the LLT zone whereas losses due to insect infestation were highest in the MMA zone. Comparisons within the AEZs showed that there are significant differences between the losses caused by rodents, insects and moulds in all the AEZs ($F_{2, 84} = 69.71$, $p < 0.001$ (LLT); $F_{2, 303} = 119.60$, $p < 0.001$ (DMA); $F_{2, 186} = 29.67$, $p < 0.001$ (DT); $F_{2, 267} = 191.72$, $p < 0.001$ (HLT); $F_{2, 300} = 60.22$, $p < 0.001$ (MT); $F_{2, 297} = 91.49$, $p < 0.001$ (MMA)). Moulds caused the lowest losses, in all the AEZs. No significant differences were observed between levels of losses caused by rodents and insects in LLT and DT whereas in the other zones, the magnitudes of losses caused by insects were significantly higher than those caused by rodents.

On average, irrespective of the AEZ and maize storage forms, farmers perceived losses due to rodents, insects and moulds to be 4.7, 8.6, and 0.5%, respectively, and were significantly different for the three loss agents ($F_{2, 2316} = 637.94$, $p < 0.001$). A comparison, however, showed that when maize was stored on cobs, only losses due to moulds differed significantly from the ones caused by insects and rodents ($F_{2, 738} = 181.64$, $p < 0.001$) whereas for maize stored as shelled grain the losses caused by insects were significantly higher than those caused by rodents ($F_{2, 1575} = 489.11$, $p < 0.001$) as observed for the overall average losses. Generally, losses were higher in maize stored as shelled grain and total losses exceeded 5% in all AEZs irrespective of the form of storage. Total losses exceeded 15% in LLT and MMA zones for maize stored on cobs, and in LLT, HLT, MT and MMA zone for maize stored as shelled grain. Lowest losses percentages were found in the DT and DMA zones for both forms of maize storage.

Table 4.7: Storage losses incurred by farmers on maize during storage across the agro-ecological zones

Maize storage form	Perceived weight losses (%)			
	Rodents	Insects	Moulds	Total[1]
Maize cobs (n = 247)				
LLT [a]	9.7 ±0.7a* A**	6.0 ±0.5abc B	0.0 ±0.0b C	15.5 ±1.0a
DMA [b]	1.3 ±0.2c B	5.6 ±0.8bc A	0.8 ±0.6ab C	7.7 ±1.1b
DT [c]	2.2 ±0.2bc A	3.3 ±0.4c A	0.6 ±0.2a B	6.0 ±0.5b
HLT [d]	5.0 ±1.2b A	8.3 ±1.8ab A	0.1 ±0.1ab B	13.3 ±2.8ab
MT [e]	2.6 ±0.6c B	5.5 ±1.3bc A	0.4 ±0.2ab C	11.3 ±2.6b
MMA [f]	3.3 ±1.3bc AB	13.4 ±5.1a A	0.1±0.1b B	16.9 ±5.7ab
Average losses	4.8 ±0.4A	5.5 ±0.4A	0.4 ±0.1B	11.2 ±0.7
Shelled grain (n = 526)				
LLT [a]	8.7 ±1.0a A	7.4 ±1.2b A	0.0 ±0.0c B	16.1 ±1.8ab
DMA [b]	3.2 ±0.4c B	9.9 ±1.0ab A	0.2 ±0.2c C	13.2 ±1.2bc
DT [c]	2.7 ±0.3c A	7.6 ±0.9b A	0.3 ±0.1abc B	10.6 ±0.9c
HLT [d]	6.6 ±0.5a B	10.0 ±0.7ab A	0.5 ±0.2ab C	17.2 ±1.1a
MT [e]	3.8±0.6c B	11.2 ±1.3ab A	0.9 ±0.3ab C	16.6 ±1.6abc
MMA [f]	6.0 ±0.7b B	12.9 ±1.1a A	0.9 ±0.3a C	20.1 ±1.4a
Average losses	4.6 ±0.2B	10.1 ±0.5A	0.5 ±0.1C	15.5 ±0.6
Overall average losses[2]	4.7 ±0.2B	8.6 ±0.3A	0.5 ±0.1C	14.1 ±0.4

*Mean (± SE) values within a column in each storage form category followed by the same lower case letter are not significantly different at the 5% probability level;** Mean (± SE) values within a row in each storage form category followed by the same upper case letter are not significantly different at the 5% probability level.

[1]Total losses refer to the sum of the losses due to insects, rodents and moulds in each agro-ecological zone.

[2] Overall average losses refer to the average losses calculated irrespective of maize storage forms and agro-ecological zones

[a] Low land tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

4.1.8. Factors Affecting Maize Postharvest Losses due to Rodents

From the CLAD regression model (Table 4.8), factors that significantly influenced the magnitude of losses due to rodents were experience in maize farming, use of improved cribs with roof in iron sheet or thatch, use of rodenticides, use of traps and type of AEZs. In all AEZs, lower levels of losses by rodents were positively associated with the experience in maize farming ≥ 16 years ($p = 0.093$) and use of trap as rodent control measure ($p = 0.001$). The model results also showed that higher levels of losses were associated with the use of improved cribs with iron sheet roof ($p = 0.079$) or thatch ($p = 0.040$), the use of rodenticides ($p = 0.009$) and the LLT zone while lower losses were associated with all the other AEZs. With regard to the total losses, lower levels were associated with the use of insecticides ($p = 0.088$), cat ($p < 0.0001$) and traps ($p = 0.001$) for rodent control, and the agro conditions of the DT zone ($p = 0.063$). The presence of rodents in stores ($p < 0.0001$), the storage of maize during both the long and short rain seasons ($p = 0.092$), and the agro conditions of MT ($p = 0.089$) and MMA zones ($p = 0.005$) were associated with higher levels of total losses.

Table 4.8: Regression of the influence of socio-economic, storage and agro-ecological factors on level of perceived losses due to rodents and the total losses during on-farm maize storage

Variable	Rodents losses		Total losses	
	Coefficient (SE)	*P*-value	Coefficient (SE)	*P*-value
Constant	8.94 (2.22)	<0.0001***	0.99 (5.45)	0.855
Socio-economic characteristics				
Gender (dummy = 0 if male; dummy = 1 if female)	0.48 (0.45)	0.289	-0.75 (0.80)	0.352
Age (dummy = 0 if age < 41 years; dummy = 1 if age ≥ 41 years)	0.38 (0.51)	0.454	0.86 (0.95)	0.368
Education level (dummy = 0 if no formal education was received or did not complete primary education; dummy = 1 if completed primary or secondary school)	-0.63 (0.53)	0.238	-1.75 (1.23)	0.154
Experience in maize farming (dummy = 0 if experience in maize farming is < 16 years; dummy = 1 if experience in maize farming ≥ 16 years)	-0.88 (0.52)	0.093*	-1.28 (1.00)	0.200
Storage practices and management				
Storage as shelled grain (dummy = 0 if stored maize as cobs; dummy = 1 if stored maize as shelled grain)	0.67 (1.36)	0.620	4.45 (4.18)	0.287
Practice of both cobs and shelled grain storage (dummy = 0 if stored maize as cobs; dummy = 1 if practice of both cobs and shelled grain storage was done)	-0.30 (1.41)	0.827	0.98 (3.84)	0.798
Use of improved cribs with iron sheet roof (dummy = 0 if no; dummy = 1 if yes)	1.63 (0.92)	0.079*	0.16 (1.78)	0.926
Use of improved cribs with grass thatch roof (dummy = 0 if no; dummy = 1 if yes)	1.63 (0.79)	0.040**	2.91 (1.87)	0.121
Use of traditional granaries (dummy = 0 if no; dummy = 1 if yes)	1.34 (2.03)	0.508	5.33 (4.23)	0.208
Storage duration (dummy = 0 if maize was stored for > 9 months; dummy = 1 if maize was stored for < 9 months)	-0.38 (0.60)	0.530	0.45 (1.19)	0.704

Storage of short rain season harvest only in a year (dummy = 0 if no; dummy = 1 if yes)	-0.09 (0.89)	0.912	1.35 (0.61)	0.617
Storage of harvests of both short and long rain seasons in a year (dummy = 0 if no; dummy = 1 if yes)	0.26 (0.75)	0.720	3.29 (1.95)	0.092*
Use of insecticides (dummy = 0 if no; dummy = 1 if yes)	-0.20 (0.66)	0.761	-2.12 (1.24)	0.088*
Use of rodenticides (dummy = 0 if no; dummy = 1 if yes)	2.26 (0.86)	0.009***	-1.11 (1.41)	0.432
Cat (dummy = 0 if no; dummy = 1 if yes)	-0.40 (0.58)	0.491	-5.76 (1.22)	<0.0001***
Trap (dummy = 0 if no; dummy = 1 if yes)	-5.38 (1.67)	0.001***	-4.27 (1.36)	0.001***
Received training in grain storage protection (dummy = 0 if no; dummy = 1 if yes)	0.88 (0.75)	0.239	1.22 (1.21)	0.313
Presence of rodents in storage (dummy = 0 if no; dummy = 1 if yes)			14.05 (2.75)	<0.0001***
Agro-ecological zones (LLT[a] = base category)				
DMA[b]	-8.73 (1.36)	< 0.0001***	1.64 (2.37)	0.488
DT[c]	-9.33 (1.43)	< 0.0001***	-3.91 (2.27)	0.086*
HLT[d]	-4.28 (1.61)	0.008***	0.98 (2.78)	0.724
MT[e]	-9.17 (3.68)	< 0.0001***	5.03 (2.95)	0.089*
MMA[f]	-5.56 (1.57)	0.004***	7.12 (2.56)	0.005***
Pseudo R^2	0.198		0.189	
Final sample size	544		588	

Significance of P-value: *$P < 0.1$; **$P < 0.05$; ***$P < 0.01$.

[a] Lowland tropical zone, [b] Dry mid-altitude zone, [c] Dry transitional zone, [d] Highland tropical zone, [e] Moist transitional zone, [f] Moist mid-altitude zone.

4.2. Actual Weight Losses and Percentage Damage Grains Caused by Rodents in Storage

Results of grain weight losses and damage due to rodents during the experiment are presented in Table 4.9. Fig. 4.6 shows rodents damage on the stored maize during the experiment. For maize stored on cobs, during the 3 months period of storage, there was an average weight loss and average rodents-damaged grains percentage of 11.37% (range 5.2-18.3%) and 44.17% (range 37.0-47.5%), respectively. Weight loss increased steadily and significantly with the storage duration (Repeated-measures ANOVA, $F_{2.41,\ 14.47} = 122.661$, $P < 0.001$). Rodents' damage however, during the trial varied significantly, only when compared to 0 month (Repeated-measures ANOVA, $F_{1.72,\ 10.34} = 14.034$, $P = 0.001$).

In shelled maize grain storage, during the 3 months of storage, there was an average weight loss and average rodents-damaged grains percentage of 4.6% (range 2.2-6.9%) and 24.6% (range 21.4-27.1%), respectively. Weight loss increased as storage duration increased but differed significantly between sampling dates only after 1 month of storage (Repeated-measures ANOVA, $F_{1.75,\ 15.75} = 15.407$, $P < 0.001$). For rodents-damaged grains percentage, a significant difference was observed only between the damage level at 2 months and 0 month of storage (Repeated-measures ANOVA, $F_{2.25,\ 20.29} = 7.054$, $P = 0.004$).

Generally, insect damage of maize on cobs and shelled maize grain storage during the trial was negligible (<1%) and only *S. zeamais* (< 1 insect) was observed between the two primary storage insects pest targeted.

Figure 4.6: Rodent's damages to the maize stored (a) spilled over shelled maize grains from sack due to rodents' attacks and (b) damaged cobs by rodents.

Table 4.9: Actual weight loss due to rodent and percentage damaged grains in cobs and shelled maize storage in the experiment at Mwarakaya ward (Kilifi-south) over end of June to end of September 2015.

Sampling intervals (months)	Cumulative weight losses (%)	Damage due to rodents (%)	Damage due to insects (%)	Presence of the two majors stored maize insects pest	
				S. zeamais	*P. truncatus*
Cobs storage					
0	0.0 ± 0.0d	0.0 ± 0.0b	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a
1	5.2 ± 0.8c	37.0 ± 8.5a	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a
2	12.8 ± 3.5b	49.5 ± 6.7a	0.0 ± 0.0a	0.0 ± 0.0a	0.0 ± 0.0a
3	18.3 ± 1.6a	47.5 ± 14.5a	0.2 ± 0.1a	0.9 ± 0.4a	0.0 ± 0.0a
Shelled maize grain stored in bags					
0	0.0 ± 0.0a	0.00 ± 0.0b	0.4 ± 0.1a	0.0 ± 0.0a	0.0 ± 0.0a
1	2.2 ± 1.1a	21.4 ± 9.9ab	0.6 ± 0.3a	0.0 ± 0.0a	0.0 ± 0.0a
2	4.7 ± 1.5b	25.4 ± 8.3a	0.3 ± 0.1a	0.0 ± 0.0a	0.0 ± 0.0a
3	6.9 ± 2.1b	27.1 ± 9.4ab	0.5 ± 0.2a	0.0 ± 0.0a	0.0 ± 0.0a

Means (± SE) within a column followed by the same letter do not differ significantly from each other at $p < 0.005$.

4.3. Rodents Species Associated with the Losses and their Population Estimation

Over the 4 months period of trapping, 65 rodents' individuals were captured from a total of 1200 trap nights (Table 4.10). All the rodents individuals captured throughout the trapping period were *R. rattus* (Fig. 4.7). The trap success during the study ranged from 0.62 to 10% and overall showed a gradual increase in the last two months of the trapping.

Table 4.10: Rodents species associated with the losses and their population estimation

Months	Number of captures			Trap nights	Percentage trap success (%)
	Rattus Rattus	*Mastomys natalensis*	*Mus musculus*		
Aug-15	8	0	0	240	3.33
Sept-15	2	0	0	320	0.62
Oct-15	23	0	0	320	7.19
Nov-15	32	0	0	320	10.00
Total	65	0	0	1200	5.41

Figure 4.7: Rattus rattus captured (a) Dead *R. rattus* caught in snap trap, (b) Live *R. rattus* in locally-made trap and (c) Cadaver of *R. rattus* used for identification.

4.4. Influence of Rodents Damages on the Grains Contamination by Storage Moulds and Aflatoxins

Table 4.11 summarizes the results of the microbiological and total aflatoxin contamination in the rodents-damaged grains sample and non-damaged grains sample. Fig. 4.8 shows the incidence of moulds on the grains and fungal genera identified. The total moulds count was significantly higher with the rodent damaged grain samples than with the non-damaged grain samples ($t(4) = 7.914$, $p = 0.001$). In regard to mould incidence on the maize kernels, *Aspergillus* and *Fusarium* were the main fungal genera observed in the two samples. However, a significant difference was observed between the two samples only for *Fusarium* incidence ($t(4) = 3.85$, $p = 0.011$). Irrespective of the fungal genera the percentage of kernels infected with moulds was significantly higher in the rodent damaged grain samples ($36.5 \pm 6.3\%$ of grain non-infected) compared to the non-damaged grain samples ($74.6 \pm 3.2\%$ non-infected). For the total aflatoxin analysis, no significant difference was observed between the rodents-damaged grain sample and the non-damaged grain sample ($t(18) = 1.88$, $p = 0.077$).

Table 4.11: Total mould counts, incidence of *Aspergillus* spp, *Fusarium* spp and total aflatoxin level in the rodent damaged grains sample and non-damaged grain sample.

Sample	Total mould count (log_{10} cfu g^{-1})	Fungal genera present (%)				Total aflatoxin (ppb)
		Aspergillus	*Fusarium*	Others	None	
Rodents damaged grains	5.3 ± 0.2a	34.9 ± 8.8a	33.3 ± 8.2a	3.2 ± 3.2a	36.5 ± 6.3b	5.5 ± 1.7a
Non-damaged grains	3.7 ± 0.1b	20.6 ± 5.7a	1.6 ± 1.6b	3.2 ± 3.2a	74.6 ± 3.2a	2.2 ± 1.1a

Means (± SE) within a column followed by the same letter do not differ significantly from each other (t-test, 5%).

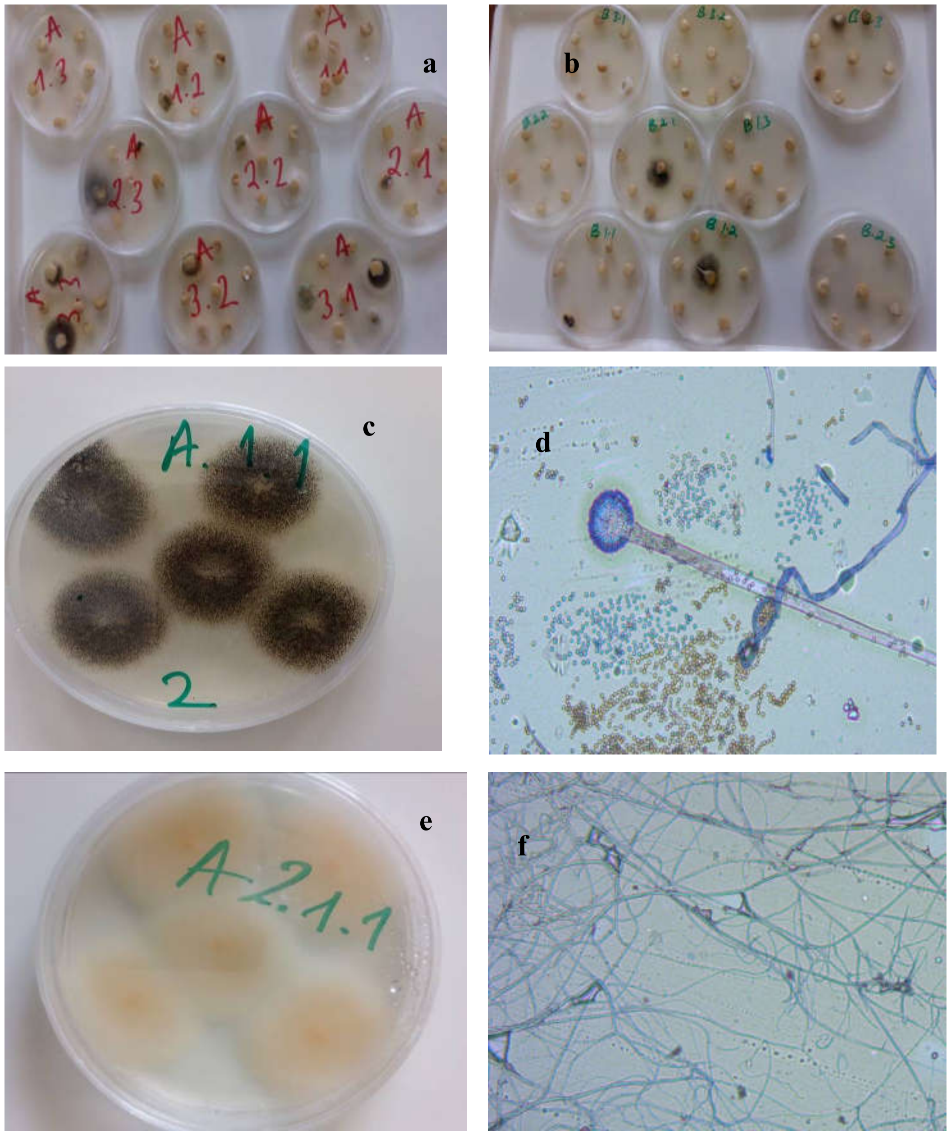

Figure 4.8: Microbiological analysis on rodents damaged grains and non-damaged grains

(a) Mould incidence on rodents damaged grains, (b) mould incidence on non-damaged grains, (c) Sub-culture of *Aspergillus* spp colonies on Czapek Dox Agar media, (d) Microscope slide showing *Aspergillus* spp., (e) Sub-culture of *Fusarium* spp colonies on Czapek Dox Agar media and (f) Microscope slide showing *Fusarium* spp.

CHAPTER FIVE

DISCUSSION

5.1. On-Farm Maize Storage System

On-farm storage losses are recognized as a serious problem that affects the food security of many rural households, and a myriad of factors among them socio - economic, cultural, agro-climatic, influence the level of losses (World Bank, 2011). An assessment of the magnitudes of these losses, and the postharvest systems linked to them, is a first step in their mitigation. A number of studies in Africa reported that agro-ecological zones influence the storage practices of farmers even within the same country (Hell *et al.*, 2000; Udoh *et al.*, 2000; Ngamo *et al.*, 2007; Nukenine, 2010). In this study, this observation was made, for instance, in the low popularity of crib storage in the LLT zone as compared to the other AEZs.

Traditional granaries, specifically wooden platform with wall made of mud constructed above the fire place in the kitchen rooms were the dominant storage structures in the LLT zone. Cribs, which can be constructed entirely from locally available plant materials (Nukenine, 2010), have the advantages of allowing free air circulation for adequate drying of maize during storage particularly in humid zones (Hell *et al.*, 2000; Udoh *et al.*, 2000). The LLT zone is hot and humid (Hassan *et al.*, 1998). It is probable that the temperature ranges in the LLT zone help to reduce the moisture content of the harvested maize in the field thereby eliminating the need to have cribs. However, the choice of storage structures is an interaction of a host of environmental, economic, and socio-cultural factors. For instance, some studies in West Africa showed low adoption of the cribs among farmers who considered them costly, labour intensive and not offering sufficient privacy (FAO 1992). Gitonga *et al.* (2015), in their study covering the six maize AEZs of Kenya, reported that the most important factors that farmers considered when choosing a storage facility were effectiveness against storage pests followed by security of the stored grain and durability of the storage facility. However in the present study, the observed trends in use of specific storage structures were also related to availability and exposure to storage technologies, and level of yields. The LLT zone lies along the coast where high relative humidity persists, and environmental temperatures are high (20 - 29°C) compared to the other AEZs (10 - 28°C). In addition, the LLT zone, together with MA and DT zones is also a low yields zone (< 1.5 tons/ha) while the HLT and MT zones are high yielding (> 2.5 tons/ha) and MMA zone moderately yielding (1.44 tons/ ha) (Hassan, 1998). These, together with other factors related to socio-cultural aspects might explain why the traditional platforms raised over the fire place were predominant in the LLT zone and not in other zones.

In all the AEZs, use of bags (polypropylene or sisal) for storage of shelled maize and use of granaries and cribs for storage of maize in cobs were the most common storage practices. A very low use rate of hermetic storage plastic bags technologies was observed in the study, and was only reported by some farmers in the MMA zone. Probable reasons to this low popularity could be farmers' exposure to such technologies and also their availability. Adoptions studies, for example, of triple-layer plastic bags in West and Central Africa (Moussa *et al.,* 2014) consistently showed that a key constraint to farmers' use of this technology is the local availability. It should be also noted that introduction and dissemination of the hermetic grain storage bags in East Africa was still at early stages at the time of the study, and therefore marketing and promotion campaigns or the supply chains for the technology were not yet well established (Hodges and Stathers, 2015). Nevertheless, results also showed that on-farm maize storage is mainly in the form of shelled maize but the shelled maize, packed in bags, is frequently stored in designated rooms in living houses, and less frequently in granaries and cribs.

The predominance of maize storage in the form of shelled maize observed in the present study was also reported by Golob *et al*. (1999) in their study in Kenya. They also observed in their study that maize storage in the form of cobs was the most common storage practice in the LLT zone which is similar to the findings of the present study. According to Golob *et al.* (1999), the predominance of the shelled maize form storage was related to the advent of the Larger grain borer (*P. truncatus*) in East Africa as the coping strategy adopted by the extensions services in East Africa focused mainly on the simple recommendation of shelling maize, treating it with Actellic Super Dust (ASD) and storing it in an appropriate container. Storage periods last predominantly 1 - 4 months for maize in cobs, 1-4 and 5-8 months for shelled maize, and insects and rodents are the main causes of storage losses, whose controls mainly rely on synthetic insecticides, rodenticides and biological control of rodents using cats. Similar observations were reported by Nduku *et al*. (2013), in a comparative analysis of maize storage structures in Kenya, although 8 - 9 months was reported to be the average storage period. In a separate study, Bett and Nguyo (2007), however, reported an average maize storage period of 4 months in the Eastern and Central parts of Kenya, which is consistent with the current study's findings. The short periods of storage are probably related to the marketing and consumption behavior of many small-scale farmers, who harvest a few bags of maize for subsistence but, additionally, rely on the sale of maize for household income.

5.2. Magnitudes of Farmers' Perceived Weight Losses

Results of the present study show that rodents are the second most important maize storage pest problems in Kenya, after insects. The larger grain borer and the maize weevil are the main storage insect pests in farm storage in Kenya (Bett & Nguyo 2007; De Groote, 2013; Nganga *et al.*, 2016). This observation is supported by the results of the current study in which regression model showed that presence of rodents in storage contributed significantly to total postharvest losses incurred by farmers. Farmer estimates of losses due to rodents varied between 1.3 - 9.7% depending on the agro-ecological zone, and on average contributed 43% of the total losses (11.2 ± 0.7%) when maize is stored as cobs and 30% of the total losses (15.5 ± 0.6%) when the maize is stored as loose grain. In Mozambique, Belmain *et al.* (2003) conducted a field trial on stored maize on cobs and measured cumulative weight losses of 54.7 ± 5.1% (attributed to rodents and insects) during 8 months of storage in the absence of rodent control methods. However, in the presence of mechanical traps, the losses decreased to 18.9 ± 4.2%. The huge difference from losses reported in this study could be attributed to the fact that in making their estimates, farmers likely considered their withdrawal of the stored maize for consumption, sale or other uses, unlike in the study of Belmain *et al.* (2003) where withdrawals were neither allowed nor corrected for. Additionally, the losses reported in the present study are attributed to a 1-4 months storage period. According to Henkes (1992), on-farm storage losses depend on storage duration, but more importantly, on the rate at which withdrawal for consumption or other uses is done. However, the losses reported in this study are perceived losses which could be different from measured losses as the possibility of underestimation or overestimation of the actual losses by farmers exists. In spite of this potential limitation, surveys are a preferred losses estimation approach by as large sample of the population can be studied. Furthermore, Hodges *et al.* (2014) suggested that survey approach should complement the actual measurement of losses as it is essential to put the loss data obtained into the contexts of both of farming and household.

The LLT zone was identified as the main hotspot region for losses due to rodents during maize storage. In this zone, the majority of farmers (74.3%) ranked rodents as the number one storage problem, and the levels of losses caused by rodents were higher than those caused by insects. A higher proportion of farmers using rat traps as compared to the other AEZs, was also observed. The significance of the rodents in the LLT zone is probably related to factors that affect the distribution of commensal rodents. The *R. rattus* is more often abundant in coastal areas (Gillespie and Myers, 2004), and is largely confined to warmer climates (Timm *et al.*, 2011). However, the effects of altitude on the distribution of rodent species are more important because factors such as wet or dry conditions which relate to annual cycles of rainfall affect the diversity, reproduction and survival rates. Higher diversities and populations are found in the wet low altitude regions (Stanley *et al.*, 1998; Kasangaki *et al.*, 2003; Venturi *et al.*, 2004; Makundi *et al.*, 2007), and under the warm conditions that prevail in the LLT zone.

5.3. Factors Affecting Maize Losses

From regression analysis done in this study, maize storage forms were not significant as far as rodent storage losses are concerned. The same observation was also made for total losses implying different form of storage exposed maize to pest attack in the same way. However, maize storage structures such as improved cribs with iron sheet or thatch roof contributed significantly to the increase of losses due to rodents. This is explained by the fact that these storage structures, as constructed, were not rodent proof and are likely to provide harborage points for rodents. During the surveys, it was observed that apart from the metal silo used by a few farmers, all the other storage structures were not rodent-proof. Moreover, none of the farmers interviewed had rat guards installed on their storage structures. Fixing rat guards on the poles of granaries is recognized as an effective method for preventing rodents from gaining access to grain storage structures provided they are fixed at a height of at least 1 m above ground, and there are no trees and other leverage objects close to the granary (Mejia, 2003). The structural nature of the majority of the granaries and cribs probably made it difficult to fix rat guards on the foot poles, which could be related to possible lack of knowledge on this method of rodent control.

When the total losses of maize were considered, none of the storage structures were significant in the regression model suggesting that the level of protection of the stored maize was dependent on other factors. From the regression models, it was expected that losses would be lower with shorter storage duration. However, storage period even though having a negative sign was not a significant determinant of the level of losses. This was probably because, the number of farmers storing for ≥ 9 months was small, and did not influence significantly the model when the storage duration variable was transformed in to dummy variable (take value of 1 when the storage duration is < 9 months; and 0 when the storage duration is ≥ 9 months). Storage season, when taken individually (harvest of the short rain season or long rain season) was also not significant in influencing the losses caused by rodents or total losses suggesting that there is no specific seasonality for the pest infestation during maize storage in on-farm stores. According to Bonnefoy *et al.* (2008) rodent multiplication can occur throughout the year, implying a fairly constant presence of rodents around the unprotected produce, although seasonal population peaks may occur depending on availability of food among other factors (Ballenger, 1999). However, storage season influenced the total losses incurred by farmers when storage of the harvests of both short and long rain seasons was done. This is probably related to build up of infestation levels from one season to the next without a break in pest cycle.

Among the methods used to control rodents, rodenticides and traps were significant in the regression model for the losses caused by rodent. It was of interest, however, that the model result implied rodenticides use was associated with higher losses as opposed to lower losses. The reasons for this result are unclear as the active ingredients (zinc phosphide, brodifacoum and difethialone (second generation anti-coagulant)) of the rodenticides reported by the farmers are known to provide good control of rodents even where some rodents evolve resistance (Lodal 2001; Staples *et al.*, 2003; Eason *et al.*, 2012; Buckle, 2013). However, factors such as inappropriate use in terms of dosage or frequency of application by farmers can also elicit neophobic (avoidance) behaviour in some rodent species (MacDonald *et al.*, 1999; Quy, 2001). Moreover adulterated or expired products may significantly compromise the effectiveness. According to Buckle (1999), acute rodenticides such as zinc phosphide are favoured by smallholder farmers because of their low cost but are also prone to adulteration during manufacture and distribution, which results in low quality baits. Buckle (1999) also reported that even when they are properly made, acute rodenticides baits have the disadvantage of eliciting 'bait shyness' because rodents are able to relate to the symptoms of poisoning when sub-lethal doses are administered.

One main limitation associated with use of rodenticides relates to safety when the poisonous baits have to be used around households where food is stored, as some rodent species may inadvertently move poison baits away from granaries to areas where children play or food is prepared or stored (Belmain *et al.*, 2015). There is also the risk of unwanted poisoning as rodenticides or baits are toxic to non-target animals. Considering this, mechanical traps and biological control are to be recommended. The result of the regression model showed that farmers who set traps would incur significantly lower storage losses due to rodents. Similar results were reported in Bangladesh, Myanmar and Mozambique (Belmain *et al.*, 2003; 2015), and in Laos (Brown & Khamphoukeo, 2010). In Laos for instance, 54.5% of the farmers considered trapping as the most effective method of controlling rodents followed by rodenticides (12.5%) and cats (9.5%). Trapping is, however, perceived to be labor intensive, and the effectiveness is influenced by the migratory behavior of rodents (Palis *et al.*, 2007). To overcome these limitations, community coordinated trapping was suggested (Belmain *et al.*, 2015). The use of cats as an approach to reducing losses had the hypothesized effect in the rodent losses model, as well as the total losses model, although the coefficient was only significant in the total losses model probably due to sample size effects on the model. However, it is also possible that introducing cats for rodent control may not be effective because predation only influences the behavior of rodents without necessarily having a significant effect on the population density (MacDonald *et al.*, 1999). Furthermore, other factors such as the presence of domestic waste, poor hygiene, poor housing structures and improper handling of leftover food may provide an environment favorable to habitation and proliferation of rodents (Panti-May *et al.*, 2012) and can compromise rodent control efforts.

Among the socio-demographic characteristics (gender, age, education level and experience in maize farming), experience in maize farming was significant and contributed to lower postharvest losses due to rodents. However, when the total losses were considered, none of the socio-economic variables was significant in the regression model which suggests that the magnitude of the total postharvest losses was not influenced by these factors. Socio-economic characteristics have been reported to influence postharvest losses differently in different regions. Similar to the findings in this study, Martins *et al.* (2014) in their study on the managerial factors affecting postharvest losses in Mato Grosso Brazil observed that education level did not influence the magnitude of losses although it was hypothesized that higher education level should lead to lower losses. In a study of postharvest losses perceptions from nationwide living standards surveys in Malawi, Uganda and Tanzania, Kaminski and Christiaensen (2014), reported perceived lower magnitudes of postharvest losses in households where the household head had a post primary education. Additionally, households headed by females experienced lower losses.

The lack of awareness or poor knowledge of good postharvest 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 (Kitinoja *et al.*, 2011; Abass *et al.*, 2014; Affognon *et al.*, 2015). Findings of the present study, however, showed that training on grain storage and protection technologies did not necessarily result in lower storage losses either arising from rodents or other loss agents as farmers who received training incurred similar magnitudes of postharvest losses as those farmers who did not receive the training. This observation suggests that farmers probably did not apply knowledge transferred 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 trainings and other interventions being too narrow or short-lived to pay off (Kaminski & Christiaensen, 2014).

5.4. Actual Weight Losses Caused by Rodents in Storage

Results of weight losses obtained in the actual rodent losses estimation experiment in the Kilifi-South study show that rodents are a significant problem for the safe storage of maize in the coastal area. For over 3 months of storage, farmers lose in average 12.1% and 4.6% of their maize on cobs and shelled maize grain stored respectively due to rodents infestation. Although, the perceived weight losses due to rodents reported by farmers may not be accurate, the impact of rodents in stores they have reflected in the coastal area is consistent with the actual weight losses estimated. In a related work in Mozambique with maize cobs, Belmain *et al*. (2003) reported 3.1-

12.8% (average 7%) and 2.5-4.1% (average 3.4%) of cumulative weight losses due to rodents within 3 months of storage respectively in non-controlled rodents and controlled rodents' area. Another study in Tanzania reported an average of 0.2% and 0.1% weight losses due to rodents over 7 months of storage respectively with shelled maize grain stored in open cribs and unprotected sack (Mdangi *et al.*, 2013). However the difference between losses data in the present study and those reported by Belmain *et al.* (2003) and Mdangi *et al*. (2013) studies could be related to the non-correction for moisture content change when estimating losses in these two studies and to the rodents' infestation pressure in the stores which can be linked to the differing habitats and ecology among countries.

According to Hodge *et al*. (2014), weight losses should normally be expressed as loss in dry matter to do not include any changes in weight due to changes in grain moisture content. In Belmain *et al*. (2003) and Mdangi *et al*. (2013) studies, weight losses were not corrected for moisture content compared to our study where weight losses were expressed on dry matter basis. The non correction of moisture content when estimating weight losses might interfere with the losses quantification in underestimating or overestimating weight losses as reduced moisture content increases weight losses and increased moisture content reduces weight losses. Additionally weight losses reported by Mdangi *et al*. (2013) were not cumulative and this may also justify the gap between their results and our results. It was also observed in the experiment that, rodents had preference for the stored cobs than the stored shelled maize grain in bags as rodents' losses were higher in cobs storage than in shelled maize grain storage. The reason for this is unclear as famers storing shelled maize grain and those storing maize cobs were located in the same environment. However it should be noted that shelled maize grains storage is not a common practice in the area; farmers predominantly store their maize as cobs size. This situation may have influenced the neophobia behaviour of rodents present in the stores as they are not used to bagged shelled maize grain storage practice in the villages.

5.5. Diversity of Rodents' Species Associated to the Losses in on-Farm Maize Storage

With regards to the rodents trapping, it was expected during the course of the study to find in the captures the three commensal rodents' species (*R. rattus*, *M. musculus* and *M. natalensis*) known to be responsible for most post-harvest crop damage in East Africa (Makundi *et al.*, 1999). However *R. rattus* was the only rodents' species captured inside farmers dwelling over the 4 months of the trapping. *M. natalensis* was especially expected to be captured during the last two months of the trapping period which coincided with the end of the harvest period as it moves from the fields to frequently invade storage structures at the end of the harvest season due to absence of food in fields (Makundi *et al.*, 1999) whereas *M. musculus* was expected to be captured at any moment during the trapping period as it inhabits houses and storage structures like *R. rattus* (Mdangi *et al.*, 2013). The capture of *R. rattus* alone over the 4 months of trapping nevertheless supports the consideration that it is the most abundant rodent species residing inside houses across Africa (Kilonzo, 2006) and consistent with Belmain *et al.* (2003) and Mdangi *et al.* (2013) trapping findings inside dwellings where farmers stored food. In Belmain *et al*. (2003) study, *R. rattus* was the main species (74.3%) caught over one year trapping and was followed by *M. natalensis* (20.1%) and *Saccostomus campestris* (5.6%). In Mdangi *et al*. (2013) study, a total of 125 *R. rattus* against 8 *M. natalensis* were captured over the 7 months of trapping inside dwellings where farmers stored food. Moreover, three possible reasons could explain the absence of *M. natalensis* and *M. musculus* over the 4 months of trapping. One reason would be the presence of inter-specific competition between these species and *R. rattus.*

According to Taylor *et al.* (2012), *M. natalensis* only enters smallholder African houses in large numbers when *R. rattus* is completely absent from the regional environment. It has been also reported in many studies (King *et al.*, 1996; Choquenot & Ruscoe, 2000; Courchamp *et al.*, 2000; Ruscoe, 2001) that rats are strong competitors of mice, affecting negatively the rate of change in mouse abundance and even excluding them when resources are scarce. King *et al*. (1996) for instance found that where populations of mice and ship rats coexist in New Zealand forests, mice are scarcer than rats. The second reason likely to justify the absence of *M. natalensis* is the nesting behaviour difference between it and *R. rattus*. Usually *R. rattus* species appears to be predominantly confined to areas of human settlement whereas *M. natalensis* live in burrows in the fields (Belmain *et al.*, 2003; Mdangi *et al.*, 2013) and therefore since trapping was done inside dwelling, probability to capture *M. natalensis* is low. The third reason which can explain the absence of *M. natalensis* and *M. musculus* could be related to the fact that our data were limited to 4 months trapping while rodent abundance may vary with a longer trapping period. For instance *M. natalensis* population vary among seasons, years and localities and are largely influenced by the amount and duration of rainfall (Leirs *et al.*, 1989, Makundi *et al.*, 2005). The increase of the trap success during the last two months of the trappings could be related to the more availability of food resources in the farmers' stores as this period coincided with the end of the harvest and beginning of the storage of maize in the stores. According to Krebs (1999), food is clearly one of the dominant ecological factors limiting and regulating rodent populations and therefore rodent density would be generally dependent upon food availability in the dwelling.

5.6. Influence of Rodents Damages on the Grains Contamination by Storage Moulds and Aflatoxins

The observation of potentially toxigenic fungi of the genera *Aspergillus* and *Fusarium* on the stored maize grains in the experiment is in agreement with findings from previous investigations (Bii *et al.*, 2012; Wagara *et al.*, 2014) on stored maize grains collected from rural households in Kenya. The higher total moulds count, higher infection rates regardless of the fungal genera and the high *Fusarium* incidence on the rodents-damaged grains than on non-damaged grains indicate that rodents' damage to the grain has an influence on its contamination by moulds. This may be due to the fact that injuries caused by rodents on the grains when feeding offered entry to fungal spores and predisposed the grains to high mould infection.

According to Chen *et al*. (2011), kernel breakage creates an infection court for opportunistic pathogens. It might also be possible that rodents when feeding on the grains transmit fungal spores through their mouths. This hypothesis is supported by the fact that fungi and rodents do not occur independently in natural ecosystems as it is known that their internal organs or shelters are active locations for fungal diversity in which storage fungi are found (Otcenášek & Dvorák, 1962, Hubálek *et al.*, 1980; Herrera *et al.*, 1997; Hawkins, 1999). In this regard, as rodents migrate from their shelters to feed on the maize grain, this could constitute a fungal spore transmission-bridge and therefore, expose the grain to high susceptibility of fungi spores. However, *Aspergillus* infection and total aflatoxins content in the samples were not influenced by rodent damages to the grains although previous study reported that maize with the most broken kernels was found to be most contaminated with aflatoxins (Mutiga *et al.*, 2014). Payne *et al.* (2010) for example reported that the susceptibility of maize to infection by *A. flavus* and aflatoxin contamination increases with kernel damage. These results with *Aspergillus* and the total aflatoxins content may suggest that grain damage alone cannot fully justify the mould infection rate observed in the rodents damaged grains sample. Other factors such as environmental conditions, moisture content, cropping history and tillage among others could play a role as samples used for the mycological analysis are composites samples made with grains from the different farmers involved in the losses assessment trials. It has also been reported that even among grains of the same ear or lot, difference in fungal infection and growth, as well as aflatoxin production can occur (Gloria, 2011). Nonetheless, although many grains were infected by *Aspergillus* genus in the tested samples, total aflatoxin levels were very low in the samples. The total aflatoxin levels recorded in the two samples were well below 20 ppb which is the allowable limit of aflatoxin contamination for human consumption according to both the US Food and Drug Administration (FDA) and the World Food Program (WFP). The allowable limit in Kenya was recently decreased from 20 to 10 ppb (Daniel *et al.*, 2011).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

This study reveals that maize storage practices including storage structures, storage form, duration of storage, and stored maize protection methods varied across maize growing AEZs. Also perception of storage pest problems by farmers differs from one AEZ to another. There are, however, some similarities in the storage practices such as the popularity of bags for shelled grain storage and the application of chemicals (insecticides or rodenticides) as main storage protectants.

The total perceived storage losses incurred range between 6 – 20 % depending on AEZ and form of storage. Of these losses, rodents contribute 30 - 43% country wide, and are perceived as the second most important storage problem for farmers implying that the impact of rodents in grain stores in Kenya should not be under-estimated. The LLT zone was the main hotspot region for rodent postharvest losses. The results also showed that actual quantification of the losses and the perceived weight losses are consistent in reflecting the impact of rodents in farmers' stores. Only *R. rattus* species were associated to the losses.

Rodent damages to the grains influenced their contamination by storage moulds suggesting that removal of rodent-damaged grains from grain before use can improve farmers' food safety.

Finally, findings from this study clearly demonstrated that the postharvest impact of rodents is an important food security issue. However, since some of the findings of this research are self-reported by the farmers, they should, help to incentivize farmers, to invest more in developing rodent-proof storage technologies. The findings should enable policy makers to understand the impact rodents may have on national food security, nutrition and health. This way, they can identify where to invest in awareness creation and training for appropriate intervention.

6.2. Recommendations

According to the findings of the study, I recommend that more attention must be paid to hygiene around houses, construction of rat guards around grain store poles and community rodents trapping programmes. Moreover, improved awareness and right application of insecticides and trap practices could mitigate losses in on farm-stored maize.

In addition, there is a need to look at the economics of postharvest loss control by investigating the minimal thresholds for losses below which it is not financially viable to employ different types of control measures.

Furthermore, research should target food safety and health issues related to potential transmission of gastro-enteric diseases and zoonoses to householders in rural areas due to rodent infestations.

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APPENDICES

Appendix i: Questionnaire for Rodent's Losses Assessment Study on Maize During Storage in Kenya

icipe
African Insect Science for Food and Health

We are representing ICIPE and are doing a survey in order to learn more about postharvest losses due to rodents (rats and mice) that affect farming households. The point of this work is to get an accurate understanding of the size of losses so that we can support farmers to improve their postharvest practices and thus reduce these losses.

We request that you answer the questions as accurately and honestly as possible so that our understanding and future activities are then based on addressing the real postharvest situation and problems faced by farmers like yourself.

Questionnaire N°	**Region:**
Interviewers' Name:	**County:**
	Sub-county:
Date:	**Location:**
Agro-ecological zone:	**Sub-location:**
	Village:
GPS co-ordinates:	

I- DEMOGRAPHIC AND SOCIO-ECONOMIC CHARACTERISTICS OF THE RESPONDENTS

1. Name of the farmer: ____

2. Phone no:____

3. Gender of the farmer: (0) Male [ ] / (1) Female [ ]

4. Age range

(0) Below 18 years [ ] /(1) Between 18 – 24 years [ ] /(2) Between 25 – 40 years [ ]

(3) Between 41 -55 years [ ] / (4) Above 55 years [ ]

5. Level of education

(0) No formal education [ ] (1) Not completed primary school [ ]

(2) Completed primary school [ ] (3) Completed secondary school [ ]

6. How long have you been in maize farming?

(0) 1 – 5 years [ ] / (1) 6 – 10 years [ ] / (2) 10 – 15 years [ ] / (3) Above 16 years [ ]

II -STORAGE PRACTICES AND STRUCTURE

a) Harvest season

7. How many maize crop seasons do you have here?

Number of maize crop season	Starting from (precise the month)	Ending (precise the month)	Precise if it is the long rain (LR) season or short rain (SR) season
(0) One [ ]	______________	______________	LR [ ] / SR [ ]
(1) Two [....]			
1st season	_______________	________________	LR [ ] / SR [ ]
2nd season			LR [ ] / SR [

b) Storage practices and structure

8. In which form do you store your maize?

(0) As cobs [ ] / (1) As grain [ ] / (2) Both [ ]

9. If you store **as cobs**, do you store with husks or do you dehusk?

(0) With husks [ ] / (1) Dehusked [ ]

10. What storage structure (container) do you use to store your **maize cobs**?

a. Granary/Cribs [ ]: specifiy the local name of the granary_________________________

(If it is granary/cribs, do the supporting poles/posts have rat guards? (0) Yes [ ] (1) No [ ])

b. Bags [ ]

(Which of these bags: (0) Polypropylene bag [....]/ (1) Jute or Sisal [.....]/ (2) Both (Poly + Sisal/Jute) [ ])

2. Directly on the floor in room [ ]

3. On mat put on the floor in room [ ]

4. Others (please list)____

11. What construction material do you use for your granary?

WALL: (0) Wood [ ]/ (1) Bamboo [ ]/ (2) Clay [ ]/ (3) Wire fence [ ]/ (4) Others (specify)____

ROOF: (0) Thatch [ ]/ (1) Iron sheet [ ]/ (2) Others (specify)______

12. Where is your granary located? (0) Field [ ] / (1) Within the homestead [ ]

13. For how many months or weeks do you store your **maize cobs**? _________________________________(Please specify the unit months or weeks)

14. What (container) storage structure do you use to store your **maize grain**?

0. Bags [ ]

(Which of these bags: (0) Polypropylene bag [ ]/ (1) Jute or Sisal [ ]/ (2) Both (Poly + Sisal/Jute) [ ])

1. Directly on the floor in room [ ]

2. On mat put on the floor in room [ ]

3. Others (please list)____

15. After you put your maize in bags, in which **place** do you store them?

(0) Sitting room [ ] /(1) Bedroom [ ] /(2) Special store room [ ] /(3) Kitchen [ ]

(4) Granary [ ] (Please give the local name___________________________________)

(5) Others (Please list)____

16. For how many months/ weeks do you store your **maize grain** before the stock is exhausted?____(Please specify the unit months or weeks)

17. How many bags can your granary hold?

____

18. If you store in room, what material did you use to build your room?

Materials of the room's wall: 0. Concrete material [ ] / 1. Clay [ ] /

2. Timber [ ] / 3. Others [ ] (Please give the name_____________________________)

Material of the house's roof: 0. Thatch [ ]/ 1. Iron sheet [ ]/ 2. tile [ ]

3. Other [ ] (Please give the name____)

19. Do you store other products or any other thing together with maize?

In cribs: (0) Yes [ ]/ (1) No [ ]

In room: (0) Yes [ ]/ (1) No [ ]

In other containers: (0) Yes [ ]/ (1) No [ ]

If Yes to any case above, what else do you store together with maize?

In cribs (List) …………………………………………………………………………..

....

In room (List) ………………………………………………………..................................

In other containers
(List)……………………………………………………………..........

III- STORAGE PROBLEMS

20. Do you have storage problems/ challenges? (0) Yes [ ]/ (1) No [ ]

If yes, what was the cause of the problem/ challenge? (Problem/ challenge can be many)

(0) Infestation by insects [ ] / (1) Infestation by rodents (Rats and mice) [ ]

(2) Infestation by moulds [ ] / (3) Attack by birds in the store [ ]

(4) Theft [ ]

(5) Others (list)____

21. On the problems/challenges mentioned above, please rank in order of relative importance using the following scale **1, 2, 3, 4, 5** (1 = Very important / 2 = Important / 3 = Moderately important/ 4 = Of little importance/ 5 = Not important)

Storage problem	**Order of importance (1, 2, 3, 4, 5)**

22. Do rodents (rats and mice) make harbor in your store?

Granary (0) Yes [ ] / (1) No [ ]

Storage room (0) Yes [ ] / (1) No [ ]

23. Do rodents (rats and mice) cause you any health problem?

(0) Yes [ ] / (1) No [ ] / (2) May be [ ] / (3) Do not know [ ]

If yes, please specify the health problem

A- PROBLEMS ON <u>MAIZE COBS</u>

(Please ask the question **(A)** first before the question (**B**))

24. **A.** What is the percentage of maize lost due to storage problems **<u>in general</u>** when you store your maize **<u>as maize cobs</u>**?

B. Please estimate the percentage of maize loss due to problems (rodent, insect and mould infestation and other (theft)) mentioned above (in the question 20) during your **<u>maize cobs</u>** storage

Losses due to:	**<u>Maize cobs storage</u>**			
	2013		**2014**	
	Harvest of long rain season	**Harvest of short rain season**	**Harvest of long rain season**	**Harvest of short rain season**
A) Loss in general				
B) Rodents				
Insects				
Mould				
Others (specify)				

25. When do you observe rodents (rat and mice) problem on maize cobs?

(0) A few weeks/ months after the beginning of storage [ ]

(Please specify in indicating the unit months/ weeks) How many weeks/months after storage____

(1) At the end of storage [ ]

B- PROBLEMS ON MAIZE GRAIN

(Please ask the question **(A)** first before the question (**B**))

26. **A.** What is the percentage of maize lost due to storage problems **in general** when you store your maize **as maize grain**?

B. Please estimate the percentage of maize loss due to problems (rodent, insect and mould infestation and other (theft)) mentioned above (in the question 20) during your **maize grain** storage

Item	**Maize grain storage**			
	2013		**2014**	
	Harvest of long rain season	**Harvest of short rain season**	**Harvest of long rain season**	**Harvest of short rain season**
A) Loss in general				
B) Rodents				
Insects				
Mould				
Others (specify)				

27. When do you observe this problem on maize stored in bag?

(1) After a few weeks/ months after the beginning of storage [ ]

(Please specify in indicating the unit months/ weeks) How many weeks/months after storage____

(2) At the end of storage [   ]

IV- STRATEGIES TO COPE WITH STORAGE PROBLEMS

28. Are there any activities/ methods you use for controlling the storage problems?

(0) Yes [   ] /   (1) No [   ]

If Yes, what do you do to solve storage problem on **maize cobs**?

AGAINST INSECTS	**CONTROL METHOD**
1. Use of insecticides? (0) Yes [ ] / (1) No [ ]	**If yes, give the name of the insecticides**
2. Other methods	
AGAINST RODENTS (RATS AND MICE)	**If yes, give the name of the products**
1. Rodenticides/raticides? (0) Yes [ ] / (1) No [ ]	
2. Other methods	

If Yes, what do you do to solve storage problem on **maize grain**?

AGAINST INSECTS	**CONTROL METHOD**
1. Use of insecticide? (0) Yes [ ] / (1) No [ ]	**If yes, give the name of the insecticides**
2. Other methods	
AGAINST RODENTS (RATS AND MICE)	**If yes, give the name of the products**
1. Rodenticides/raticides? (0) Yes [ ] / (1) No [ ]	
2. Other methods	

29. Do you think your methods of rat control are effective? (0) Yes [ ] / (1) No [ ]

30. Do you clean the storehouse (cribs, room or other structures) before a new storage?

(0) Yes [ ] / (1) No [ ]

31. Do you remove old grains? (0) Yes [ ]/ (1) No [ ]

32. What do you do to clean the store (cribs, room or other structure) before storage? (Narrative)____

____

33. Do you have any additional ideas about how rodent problems could be reduced /solved?

(0) Yes [ ] / (1) No [ ]

34. If yes, mention please:____

____

35. Did you receive any training on grain storage protection methods? (0) Yes [ ]/ (1) No [ ]

If yes who provided the training?

(Please list)____

V- Production, consumption and sale of maize

36. How much land has your household allocated to growing maize? _________________acres

37. How many bags of maize were harvested during:

	Harvest of **long rain** season	Harvest of **short rain** season
Last year (2013)?		
This year (2014)?		

38. How many bags of maize do you expect from your harvest of this season?

____

39. What were the end uses of maize harvested?

	Harvest of **long rain** season	Harvest of **short rain** season
Last year (2013)	(0) Only consumption [ ] (1) Only sale [ ] (2) Both (consumption + sale) (3) Others (specify)____________ ____________________________	(0) Only consumption [ ] (1) Only sale [ ] (2) Both (consumption + sale) (3) Others (specify)___________ ____________________________
This year (2014)	(0) Only consumption [ ] (1) Only sale [ ] (2) Both (consumption + sale) (3) Others (specify)____________ ____________________________	(0) Only consumption [ ] (1) Only sale [ ] (2) Both (consumption + sale) (3) Others (specify)___________ ____________________________

40. How many bags of your maize harvested are **usually reserved** for home consumption? __________

41. How many bags of your harvested maize did you **sell durin**g the:

	Number of bags sold during the **long rain** season	Number of bags sold during the **short rain** season
Last year (2013)?		
This year (2014)?		

42. What was the price range of one maize bag in?

	Price range	Average price
2013		
2014		