EFFECT OF HYGIENE STATUS IN MAIZE STORAGE FACILITIES ON PESTS, MOLDS AND AFLATOXIN CONTAMINATION IN NAKURU COUNTY, KENYA

KOBIA JESEE MAKINYA

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(B.Sc Microbiology and Biotechnology, University of Nairobi)

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DECLARATION

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

Kobia Jesee Makinya Signature........... Date 30/06/2022

Reg. No: I56/81683/2015

This thesis has been submitted for examination with our approval as University of Nairobi supervisors:

Dr. Maina Wagacha, PhD Signature........... Date 07/07/2022

School of Biological Sciences, University of Nairobi

Dr. Judith Odhiambo, PhD Signature........... Date 05/07/2022

School of Biological Sciences, University of Nairobi

Dr. Christopher Mutungi, PhD Signature........... Date 04.07.2022

International Institute of Tropical Agriculture (IITA)

DEDICATION

To my late mum Julia Karuria.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACP: African, Caribbean and Pacific countries

ANOVA: Analysis of Variance

APHLIS: African Post Harvest Losses Information System

aw: Water Activity

CDA: Czapek Dox Agar

FAO: Food and Agricultural Organization of the United Nations

HACCP: Hazard Analysis Critical Control Points

HDPE: High Density Polyethylene

IITA: International Institute of Tropical Agriculture

IPGRI: International Plant Genetic Resources Institute

IPM: Integrated Pest Management

KALRO: Kenya Agriculture and Livestock Research Organization

KEPHIS: Kenya Plant Health Inspectorate

LGB: Larger Grain Borer

MoA: Ministry of Agriculture, Livestock, Fisheries and cooperatives

NCPB: National Cereals and Produce Board

NGO: Non-Governmental Organization

PDA: Potato Dextrose Agar

PICS: Purdue Improved Crop Storage bags

Ppb: parts per billion

SDA: Sabouraud Dextrose Agar

UK: United Kingdom

UN: United Nations

UNEP: United Nations Environmental Programme

USA: United States of America

USDA: United States Department of Agriculture

WHO: World Health Organization

ABSTRACT

Infestation of harvested agricultural produce with pests, pathogens or contamination with mycotoxins during storage negates efforts to eradicate food and nutrition insecurity. Preventive measures, primarily suitable storage structures and cautious adherence to hygiene constitute key actions for effective control of pests and pathogens. However, contribution of recommended postharvest handling and hygiene practices as avenues for timely mitigation have never been examined. The aim of this study was to assess the effect of hygiene in maize storage facilities on pest infestation, mold and aflatoxin contamination. A cross-sectional survey was conducted in 2017 to assess postharvest handling practices, levels of hygiene and their effect on the magnitude of losses in maize farmers' storehouses. A total of 342 rural farmers spread across the high potential moist transitional agro-ecological zone in Nakuru County were interviewed and data recorded in a semi-structured questionnaire and a checklist. In addition, the hygiene status of 40 storehouses where shelled maize grain was stored in bags was assessed and the grains sampled. The stores were ranked into 'poor', 'average' or 'good' hygiene categories depending on the level of adherence to recommended storage hygiene practices. Maize grains that had been harvested and stored in farmer's stores were sampled at intervals of two months beginning April to October 2017. The samples were analyzed for moisture content, quality compliance, insect population, grain damage, weight loss, mold incidence and aflatoxin levels. The main storage bags were polypropylene used by 98.2% of the farmers. Bagged maize was stored either in granaries or designated rooms within dwelling houses. Overall, 90% of the farmers cleaned their storehouses before the most recent harvest was loaded, while only 50% cleaned the storehouses after the harvest had been loaded. Farmers reported 8.3 ± 0.5% weight losses resulting from insects, rodents, molds and theft. Laboratory analysis of maize sampled from farmers' storehouses revealed a significant (P = 0.002) increase (from 12.2 to 14.2%) in moisture content of maize stored under poor hygiene conditions beginning from the second month of storage. Interaction between hygiene status, population of *Sitophilus zeamais* and storage time was highly significant (P <0.001). Good hygiene practices slowed the rate of grain damage and corresponding weight loss. The total population of molds across all the stores increased significantly after four (P < 0.001) and six (P < 0.001) months of storage. Additionally, stores adhering to good hygiene practices recorded significantly lower incidence of *Aspergillus* spp. at the fourth (P = 0.002) and sixth (P < 0.001) months of storage, respectively. This was followed by corresponding significantly ($P = 0.041$) lower levels of total aflatoxin (range 7 – 64 ppb) after four months of storage. Total aflatoxin levels increased approximately four fold for maize stored under hygienic conditions, six fold for storehouses characterized by average hygiene practices, and seven fold for grain stored under conditions of poor hygiene throughout the storage period. At the commencement of the trial, 15% and 22% of samples from hygienic and unhygienic stores respectively had total aflatoxin levels beyond the 10 ppb threshold set by the Kenya Bureau of Standards (KEBS). This proportion increased to 100% and 71% in unhygienic and hygienic stores respectively four months after commencement of the trial. From the Fractional Response Model, high hygiene scores correlated significantly with lower grain losses. Storing maize grains in the bedroom or living room correlated with lower losses by 2.8 and 4.6 percentage points, respectively; compared to storage in granaries, while storage in the kitchen correlated with higher losses by a margin of 19 percentage points. Storage of maize together with other grains or farm equipment was associated with higher losses by 2.8 percentage points. Storage of maize in hermetic containers did not result in significantly lower losses. In addition, repairing or disinfecting the store before introducing a new harvest did not significantly reduce grain losses. Training in grain storage did not have a significant effect either, while maize farming experience and younger age were associated with lower losses by 2.8 and 5.9 percentage points, respectively. Stores where majority of the postharvest handling decisions were made by women had lower losses by 2.8 percent points. This study demonstrates that storing grain under hygienic conditions can help smallholder farmers retard proliferation of molds, aflatoxin contamination and storage pests and consequently prolong safe storage duration of maize grains.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Maize is an important food and income crop for millions of rural farmers in East and Southern Africa. In Kenya, it accounts for about 40% of the daily caloric intake (Ranum *et al*., 2014) and the annual per capita consumption is estimated at 98 kilograms (Muiru *et al*., 2015). However, poor postharvest management results in 20-30% grain loss which is equivalent to US$ 180 – 270 million in forfeited incomes or the grain required to feed 6 - 9 million people each year (C. Mutungi, 2018, personal communication).

Economically significant quantitative postharvest losses occur in the field, during transportation, processing and storage (Abass *et al*., 2014). Before storage, harvested maize undergoes postharvest handling activities such as drying, shelling, winnowing, and bagging. During these stages, significant grain losses are incurred. Harvesting and drying losses in the range of 6 - 10% have been reported in some African countries (Calverley, 1996). However, more losses occur during storage than any other stage in the postharvest chain (Kumar and Kalita, 2017). In on-farm storage in Kenya, maize grain losses have been estimated at 14% (Edoh Ognakossan *et al.*, 2016). Insects, rodents, and molds have been reported to be the major causes of food loss during storage at both farm (Edoh Ognakossan *et al.*, 2016) and off-farm levels (Mwangi *et al*., 2017). Reduction in these losses would enhance global food security, which is a growing concern (Mundial, 2008; Trostle, 2008).

The fact that food losses continue to be high in smallholder storage despite existence of effective control measures calls for better understanding of the strengths and weakness of the approaches that farmers apply to manage stored produce. An alternative frontier proposed for mitigation of storage losses is an integrated pest management strategy that makes the storage conditions unfavourable for habitation and proliferation of molds, insects and rodents (Kader, 2005). Exclusion of molds, insects and rodents can be achieved by among other means, application of best practices such as storage hygiene. Storage hygiene targets two broad areas: cleanliness of grain destined for storage, and cleanliness of storage facility and the surrounding environment (Gwinner *et al.,* 1996; Toews and Subramanyam, 2002).

Cleaning grain refers to the process of separating broken grains, straw, chaff, stones, sand and weed seeds from whole kernels (Kumar and Kalita, 2017). Unclean grain impedes airflow during aeration or drying. Thus effective drying may not be achieved in poorly cleaned grain. Inadequately dried grain promotes proliferation of molds which results in both qualitative and quantitative losses in stored maize. Qualitative losses arise from production of mycotoxins most notably aflatoxin (Tefera, 2012). Mycotoxins in general and aflatoxin in particular have been identified as a food safety problem responsible for human and animal illnesses and deaths in Kenya (Wagacha and Muthomi, 2008; Kang'ethe, 2011; Mboya *et al.*, 2011). Indeed, higher mold infection and mycotoxin levels have been associated with unclean, poorly dried, and damaged maize (Setamou *et al.*, 1997). Inadequately dried grain also promotes proliferation of pests by hampering penetration of fumigants or adhesion of contact pesticide dust (Toews and Subramanyam, 2002). Interaction between mold proliferation and insect feeding is synergistic: apart from the weight losses resulting from insect feeding, their excreta and cadavers contaminate maize. These contaminants along with elevated grain temperature and moisture content resulting from insect's metabolic activity create warm spots that promote fungal activity resulting into further grain deterioration (Tefera *et al.*, 2011a).

Perfect storage hygiene is a basic prerequisite for successful storage and for the effectiveness of all on-going measures in stores aimed at minimizing or controlling losses (Gwinner *et al.*, 1996). However, knowledge linking grain care to storage hygiene in smallholder farm stores is scanty (Toews and Subramanyam, 2002). To this end, storage hygiene is overlooked yet it is an important component of safe and cost-effective grain protection. In the context of modern pest and pathogen control where the trend is a progressive turn towards the use of chemical-free methods, sanitation and other postharvest practices that reduce pest incidence and spoilage should lend greater meaning to technologies such as hermetic bags.

In Australia, Herron *et al*. (1996) reported that combination of good hygiene practices and protectant application prevented development of detectable insect infestation in stored grain. Storage hygiene measures are often simple and effective, and can be performed by farmers with little cost and effort (Gwinner *et al.*, 1996). Few studies have addressed hygiene in smallholder farmers' grain stores in sub Saharan Africa.

The aim of this study was therefore to identify aspects that need greater focus for better grain care. A further aim was to provide information on aspects that need extension support in implementing integrated on-farm storage management options to reduce food losses and improve safety.

1.2 Problem statement

Maize is a food and income crop for millions of rural farmers in East and Southern Africa. In Kenya, the annual per capita consumption is 79 kilograms, accounting for 30.7% of the recommended daily calorie intake (FAOSTAT 2017). Approximately 80% of all the harvested maize is derived from small scale farmers in Kenya. However, high postharvest losses (10-20%) caused by failure to adhere to best storage practices and a climate that favors pest and mold proliferation lead to high postharvest losses (Edoh Ognakossan *et al.*, 2016; Kumar and Kalita, 2017). Identifying best practices that would reduce postharvest losses is a priority for most African countries (Rugumamu *et al*., 1997). The effectiveness of traditionally viable storage practices has over time been compromised by the spread of exotic stored grain pests such as *Prostephanus truncatus* and replacement of traditional resistant maize varieties with high yielding varieties that are more prone to damage (FAO, 2001).

Modern technologies aimed at combating postharvest losses have achieved limited success due to their incompatibility with farmers' practices. For instance, one of the major drawbacks of the hermetic storage is their susceptibility to rodent damage which renders them unhermetic, ineffective and non-reusable (Ndegwa *et al*., 2016).

Direct feeding damage by insects as well as mold infection lowers the weight of the grain, its nutritional value and germination ability. Mold proliferation and insect infestation also cause mycological contamination, odour, and heat damage problems which lower the quality of the grain and predispose the grain to deterioration. Mycotoxicological contamination renders maize unfit for processing into food for humans or feed for animals.

1.3 Justification of the study

In Kenya, maize is the staple food crop and its availability guarantees food security for millions of people. Majority of farmers in Kenya produce and store their maize on-farm hence the need for storage structures. Farmers stock the highest amount of maize, followed by traders, National Cereals and Produce Board (NCPB) and then millers (Mwangi *et al*., 2017).

Despite extensive research and innovations aimed at reduction of postharvest losses, the amount of maize lost postharvest by farmers has remained significantly high (20 - 30%). In fact, one of the major challenges in combating postharvest losses is farmers' unwillingness to take up modern maize storage technologies. Cycles of huge maize postharvest losses result in food insecurity, loss of income and waste of scarce resources. Additionally, compatibility between new storage technologies and farmers' storage practices is almost an overlooked aspect of postharvest research. For instance, store hygiene practices alone have been shown to reduce insect infestation and mold proliferation significantly even before deployment of more robust loss mitigation strategies (Herron *et al*., 1996). To safeguard stored maize from damage by pests or contamination by molds, there is a need to assess the current storage practices, and hygiene practices of small scale farmers and establish whether they have an impact on the build-up of storage pests and molds.

1.4 Objectives

1.4.1 Main objective

The broad objective of this study was to determine the effect of hygiene status in maize storage facilities on build-up of insect pests, molds and aflatoxin contamination in Nakuru County, Kenya.

1.4.2 Specific objectives

The specific objectives of this study were:

i. To assess practices and hygiene status of maize farmers' storage facilities.
ii. To determine the diversity and abundance of storage insect pests, molds and aflatoxin levels in stored maize grain.
iii. To establish the relationship between storage hygiene status and build-up of storage molds, insect pests and aflatoxin contamination levels.

1.5 Hypotheses

i. Maize farmers' storage practices and hygiene status do not differ.

ii. There is no significant difference in the diversity or abundance of storage insect pests, molds and aflatoxin levels in stored maize.

iii. There is no relationship between storage hygiene and build-up of storage insect pests, molds and aflatoxin contamination levels.

CHAPTER TWO: LITERATURE REVIEW

2.1 The maize plant: origin, classification and distribution

Maize (*Zea mays* L.) belongs to the grass family graminae (Poaceae); it is an annual plant with an extensive fibrous root system. It is a diploid species with a chromosome number of $2n = 2x = 20$ (Rashad *et al.,* 2013). Maize is one of the oldest human cultivated crops, which originated from meso-America region at least 7000 years ago where it was grown as a wild grass called *teosinte* in the Mexican highlands (FAO, 2006). However, research in genetics suggests that maize was born as a result of formation of a hybrid between two wild grasses - a perennial subspecies of teosinte (*Zea diploperennis*) and a species of *Tripsacum*. By systematically collecting and cultivating plants suited for human consumption, native Americans transformed maize over thousands of years into a plant with larger cobs and more rows of kernels, making it a better source of food (FAO and IPGRI, 2002). Since 2013, maize has become the most crucial staple crop with its global production exceeding 1×10^9 tones (10^{12} kg) (FAOSTAT, 2017). United States, China and Brazil are the leading producers accounting for 31%, 24% and 8% of the total world production, respectively.

2.2 Common maize storage structures used by farmers in Kenya

2.2.1 Traditional granaries

Traditional granaries or cribs are mostly large cylindrical or rectangular structures constructed using locally available plant materials; bent sticks, sisal stems, wooden rafters or timber. The structures are often placed on raised platforms and covered with grass thatched or iron sheet roof (Edoh Ognakossan *et al.,* 2016). Under prevailing climatic conditions, most plant material rot quickly and most cribs have to be replaced every two to three years – although bamboo structures may last up to 15 years with careful maintenance (FAO, 1994). Granaries are mostly suitable for storage in humid countries where grain cannot be adequately dried prior to storage and thus needs to be kept well ventilated throughout the storage period (FAO, 1994).

2.2.2 Sack storage

Storage bags may be made of different materials but most of the bags have a capacity of between 25 and 100kg. Woven polypropylene bags are plastic bags primarily made of polypropylene. They are widely used for grain storage owing to their light weight, higher strength, resistance to tearing and the ability to allow passage of air to the stored grain. Air passage leads to moisture fluctuation. The moisture content in grain stored in polypropylene bags can either decrease (Ng'ang'a *et al*., 2016) or increase (Njoroge *et al.,* 2014) depending on the prevailing weather conditions or level of pest infestation or microbial infection.

Jute and sisal bags are made of natural plant fibers and both are somewhat similar. The bags are the most widely used worldwide. Their advantage over woven polypropylene bags is that they are environmentally friendly and can be reused several times owing to inherent toughness that reduces the risk of tearing. Handling jute bags is simple because of their coarse texture enabling fairly high stacks to be erected (FAO, 1994).

After filling with grain, the bags can be sealed either by hand stitching or by using a stitching machine (APHLIS, 2016). Cereals stored in sacks should be regularly inspected to keep them safe from attacks by pests (De Groote *et al*., 2013). One of the shortcomings of sack storage is that they require pesticide treatment - or at least boiling in water - in order to reduce chances of insect infestation (FAO, 1994). Sacks are also prone to rodent damage which subsequently exposes the stored grain to rodent infestation. However, the sacks confer the farmer the advantage of storage convenience in that the grain stored in bags can easily be moved from one storage location to another.

2.2.3 Hermetic storage bags

Hermetic bags present an emerging, simple, low-cost triple or double layer bagging technology. The bags are made up of an outer polypropylene bag with one or two inner high density polyethylene (HDPE) linings (De Groote *et al*., 2013). The technology is based on the principle of generating an oxygen-depleted, carbon dioxide enriched interstitial atmosphere caused by the respiration of living organisms in the ecological system of the sealed bag (Obeng-Ofori, 2011). Respiration from storage insect pests causes a decrease in oxygen levels and a corresponding increase in levels of carbon dioxide leading to suffocation and dehydration of weevils (Navarro *et al*., 1994). When oxygen levels become sufficiently low, pests in the bag stop feeding, become inactive, and eventually die of asphyxiation (Moreno-Martinez *et al*., 2000) or desiccation (Murdock *et al.*, 2012).

Hermetic grain storage bags are effective in protection of not only maize but also a wide variety of other crops such as cowpeas, peanuts, sorghum, wheat, as well as common beans against insect pests and fungal pathogens (Murdock *et al*., 2012; Anankware *et al*., 2013; Baoua *et al*., 2014; Mutungi *et al*., 2014; Njoroge *et al*., 2014; Vales *et al*., 2014; Maina *et al*., 2017). Additionally, the hermetic condition induces fungistatic effect when oxygen concentration drops to 1% or below (Richard-molard, 1988).

2.2.4 Metal silos

A metal silo is a cylindrical grain storage structure made from galvanized iron sheet in such a way that it can be hermetically sealed. Widely used in Central America for grain storage, the metal silo has been introduced in several African countries including Kenya, Malawi and Swaziland by FAO and several Non-Governmental Organizations (FAO, 2008). The metal silo just like the hermetic bags, operates on the hermetic technology concept, where suffocation inside the container kills insect pests. Some advantages of the metal silo over hermetic bags are its durability and its ability to protect grains from insect pests as well as rodents (Tefera *et al.*, 2011a).

2.2.5 Other storage containers and structures

Some small scale farmers store their grain in baskets, pots, buckets or underground pits (Manandhar *et al.*, 2018; Befikadu, 2019). Underground storage pits are fired and layered with woven bamboo or straw. Majority of these structures are constructed around the homestead and they provide protection mostly against sun and rain. Space is the major challenge with these systems as they can only accommodate a limited volume of grain (Manandhar *et al.,* 2018).

2.3 Hygiene in grain storage

2.3.1 Concept of hygiene in grain storage

Storage hygiene is a multifaceted concept covering two broad areas; one, non-grain constituents that are found in the grain at the time of harvesting and/or handling; and two, storage and sanitation of the grain storage facility and its surrounding environment (Toews and Subramanyam, 2002).

Material contaminants that render grain unclean include; weed seeds, stems, straw, chaff, sand other grains, cracked kernels, dirt, and dust. Cleaning the grain of excess particles and other foreign debris is a vital component of storage hygiene since they not only reduce the effectiveness of grain protectants but also the aeration efficiency of the stored grain (Toews and Subramanyam, 2002).

Most stored grain insect infestations develop from small numbers of pests' preexisting in or around the storage structures. Making an environment inhabitable for pests and unfriendly for their breeding is therefore, the basis of grain hygiene (FAO, 2001). Good storage hygiene practices would therefore involve proper management of stored grain with sanitation of bins, equipment, and the surrounding grounds before the grain bound for storage is harvested. Grain residues or older grain stocks held over from previous seasons provide ideal breeding sites; they thus may serve as excellent sources of insect infestations for freshly introduced grain (Taruvinga *et al.*, 2014).

Toews and Subramanyam (2002), observed that in unclean bins, application of residual insecticide did not control insects effectively since small particles such as chaff, dust and broken pieces absorbed the applied insecticide thus very little was available for insect contact. In addition, presence of food helped insects survive insecticide exposure. The effectiveness of residual insecticide was enhanced on dust free and clean surfaces. Therefore, sanitation of empty sacks and bins followed by application of residual pesticide is vital for controlling insect pests (Highley *et al.*, 1994).

Waste and spilled grain acts as reservoir of insects and fungal spores. Removal of these remnants from the storehouse and equipment before new grain is loaded is an essential aspect of effective grain hygiene (Grains Research and Development, 2016). Some insects not normally found in whole grain can survive in unclean grain by feeding on cracked grain, chaff, dust or other dockage particles. Cleaning the excess dockage from the grain therefore would discourage multiplication of these pests (Kiaya, 2014). Most of these insects do not damage whole grains, however, their biological processes such as respiration produce moisture and heat, which do not only reduce the quality of stored grains but also render the grain more prone to mold infection (Tefera *et al*., 2011a).

Williams and McDonald (1983), observed that invasion of grains by molds results in rot, discoloration, seedling blights, mycotoxin contamination and subsequent loss of viability. Sone (2001) revealed that broken kernels enhance development of storage molds since fungi easily infiltrate broken kernels than intact ones. Similar findings were reported by Dharmaputra *et al.* (1995) who observed that mechanical damage like cracking or scouring provided entry points for fungal spores.

2.3.2 Importance of hygiene in grain storage

Sanitation is the first line of defense in protection of stored grain from damaging insect pests. Storing clean and dry grain discourages proliferation of molds and multiplication of insects. Setamou *et al*. (1997) reported that low mycotoxin levels were associated with less damaged maize (less than 2% broken kernels) compared to those in maize with higher damage. Since aflatoxins are normally present in highest concentrations in broken and cracked kernels, cleaning the grain with a rotary screen or gravity table can reduce the aflatoxin concentration of the grain. Cleaning also offers the advantage of preventing accumulation of fines and trash in the center of the container in which the grains have been stored; this in turn improves air movement through the grain in storage (Vincelli *et al.*, 1988).

2.4 Fungi affecting stored maize grain

2.4.1 Major fungal species associated with maize in storage

Molds commonly implicated in contamination of maize are grouped into field and storage fungi. Toxigenic *Alternaria* and *Fusarium* spp are often classified as field fungi since they infect the grain in the field when the water activity is high whereas *Aspergillus* and *Penicillium* spp are considered as storage fungi because they infect and grow on maize grain during storage when the moisture levels are lower (Mannaa and Kim, 2017). However, species of *Aspergillus, Fusarium* and *Penicillium* can occur both in the field and storage (Jedidi *et al*., 2018).

Figure 1: Common fungal pathogens associated with maize

(a) Unthreshed maize cobs infected with *Aspergillus flavus* and (b) *Fusarium* and *Aspergillus* spp on threshed maize kernels

(Rashad *et al.*, 2013)

2.4.2 Factors affecting proliferation of molds in stored maize

The key factors that affect growth of fungi in stored grain include moisture, temperature, aeration and PH (Befikadu, 2019). The factors are interactive during progression of deterioration but moisture and temperature are probably the key factors (Mannaa and Kim, 2017). Moisture content affects the temperature of the grain directly; higher moisture levels lead to increase in temperatures. High temperatures and water activity encourage proliferation of mold (Table 1). Increase in temperatures can also be brought about by respiration of grain (Brewbaker, 2003). Spoilage molds exhibit growth over a wide range of temperatures, some can grow below freezing whereas others will grow at temperatures above 50˚C. Generally, for any substrate, the rate of mold growth declines with decreasing temperature and availability of water (Magan and Lacey, 1988).

The proportion of cracked kernels in a batch of grain affects proliferation of mold. Kernel breakage caused by handling or insect boring predisposes the grain to mold invasion by exposing the endosperm. Estimations have led to projections that for instance, increasing the quantity of broken grains by 5%, reduces the storage life of the grain by roughly one order of magnitude (FAO, 1994).

2.4.3 Control of molds in stored grain

Proliferation of molds in stored grain remains a challenge despite years of research **(**Munkvold, 2003)**.** The key factors that determine whether grain in storage would be invaded sufficiently by fungi are among others; the moisture content, temperature, relative humidity, amount of broken grains and foreign materials present, extent of preexisting fungal invasion, presence of insects and mites and lastly, length of time the grain is held in the storage facility (Lacey and Morgan, 1991). All of these factors are interactive; however, the major determinants are moisture content, relative humidity, temperature and storage duration in that order (Lacey and Morgan, 1991).

Table 1**:** Optimal growth conditions for common maize storage molds

Fungal species	Temperature (ºC)	Water activity (aw)
Fusarium proliferatum	15	0.97
Fusarium verticillioides	30	0.97
Aspergillus flavus	33	>0.98

Source: Marin *et al.* (1996)

The most efficient and reliable method of controlling molds in stored grain involves reducing the moisture content to accepted levels before storage. This can be accomplished by sun drying, air drying, drying over the fire or drying using mechanical dryers and subsequently controlling the relative humidity and temperature during storage. After harvest, drying the grain to a water activity lower than 0.7 can help retard mold growth (Beuchat *et al.*, 2013).

2.5 Mycotoxins associated with maize grains

2.5.1 Types of mycotoxins contaminating maize

Mycotoxins are toxic secondary metabolites synthesized in crops by some fungi either in the field, during storage or food processing (Bennet and Klich, 2003; Wagacha and Muthomi, 2008). FAO estimates that about one quarter of the world's cultivated crops are contaminated by mycotoxins (USDA, 2003). Mycotoxins exhibit high chemical stability and processes such as food processing or cooking cannot destroy them. Monitoring mycotoxins in food is thus an important health, and trade concern (FAO, 2001).

Common mycotoxins with reference to toxicity, incidence and economic importance include; aflatoxins produced by *Aspergillus flavus* and *Aspergillus parasiticus*; deoxynivalenol produced by *Fusarium graminearum, Fusarium culmorum* and *Fusarium avenaceum;* fumonisins produced by *Fusarium verticillioides* and *F. proliferatum*; ochratoxins produced by *Aspergillus ochraceus*; and zearalenones produced by *Fusarium graminearum* (Brown *et al.,* 2005; Klich *et al.,* 2007; Frisvad *et al.,* 2011*;* Moser *et al.*, 2016).

Mycotoxins exhibit varied molecular structures. For instance, more than twenty different molecules of aflatoxins have been reported. However, the most prominent types are; B_1, B_2, G_1 and G_2. These types are usually reported in dry foods such as cereals but other types such as M_1 and M_2 have been reported in milk or meat (Pummi and Peter, 2017).

2.5.2 Public health concerns of mycotoxins

Diseases caused by ingestion of mycotoxins by humans or animals are known as mycotoxicoses. Most mycotoxicoses are caused by molds from the following genera; *Fusarium, Aspergillus* and *Penicillium* species (Egbuta *et al.,* 2017). Consumption of mycotoxins contaminated grain may lead to induction of tumors, acute liver damage, attack on the central nervous system and hormonal effects (Oguz *et al*., 2003; Egbuta *et al.,* 2017). Exposure to high levels may cause death while long term chronic exposure can result in cancer, nervous disorders and mutagenicity (KEPHIS, 2006).

In developing countries such as Kenya, hundreds of deaths resulting from consumption of mycotoxin contaminated grain have been reported (Azziz-Baumgartner *et al*., 2005). In Africa, where susceptible crops such as maize and groundnuts are staple foods, aflatoxicosis is a major health concern (Shephard, 2003). The most acute aflatoxicosis in the world was experienced in Machakos County in Kenya in 2004 where 125 deaths and 317 cases of hepatic failure were reported (Azziz-Baumgartner *et al*., 2005). Prior to this aflatoxicosis incident, a previous outbreak is reported to have occurred in the same region between 1981 and 1982. Several patients, 12 of whom died, were admitted to three hospitals presenting with hepatitis. Studies showed that two families, from which 8 of the 12 deaths had occurred, had been feeding on maize containing as much as 12, 000 parts per billion (p.p.b) of aflatoxin B_1. Liver tissue at necroscopy contained up to 89 p.p.b of mycotoxin (Ngindu *et al*., 1982). Mycotoxin contamination is therefore a source of mortality and morbidity (Adeyeye, 2016).

2.5.3 Methods of mycotoxin detection and quantification

Chemical diversity, varying concentration, differences in chemical and physiological properties, and the wide range of agricultural products in which mycotoxins are produced pose a challenge in development of a single method of detection (Krska *et al*., 2008). Most methods therefore target single or closely related mycotoxins. Analytical techniques such as thin layer chromatography (TLC), high performance liquid chromatography (HPLC) and Enzyme-linked immunosorbent assay (ELISA) have been used to quantify various mycotoxins in recent studies. These methods involve a sample preparation step followed by chromatographic separation (Probst *et al*., 2014). However, ELISA is preferred over HPLC owing to its simplicity, rapidness and low cost.

For some mycotoxins such as aflatoxin, fast, accurate and less labour-intensive methods based on ELISA have been applied in the recent past (Probst *et al*., 2014). Highly sophisticated, multi-mycotoxin detection methods based on liquid chromatography coupled with multiple stages of mass spectrometry have been developed to allow multiple, accurate and simultaneous detection of different mycotoxins without the need for sample preparation and clean-up protocols (Krska *et al*., 2008). Various rapid and straight forward immunoassay-based tests such as the rapid disposable membrane based assay tests (flow through tests, dip stick tests and test strips) have been developed for on-site use (Krska and Molinelli, 2009).

2.6 Insect pests of stored maize

2.6.1 Common insect pests responsible for postharvest losses in stored maize

Insect pests are the major cause of losses of grain in storage. Up to 9% losses in stored maize due to insect infestation has been reported in Kenya recently (Edoh Ognakossan *et al.*, 2016). Insect pests implicated in severe economic damage of stored maize are the maize weevil *Sitophilus zeamais* Motsch (Coleoptera: Curculionidae) and the larger grain borer (LGB) *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) (Suleiman *et al.*, 2015). Other storage insect pests of importance include the Angoumois grain moth *Sitotroga cerealella* Oliv. (Lepidoptera: Gelechiidae), the lesser grain weevil *Sitophilus oryzae* Linne (Coleoptera: Curculionidae), Red flour beetle, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) and dried bean beetle

Callosobrunchus maculatus F. (Coleoptera: Bruchidae) (Markham *et al*., 1994; Gitonga *et al*., 2015).

Figure 2: Larger grain borer (*Prostephanus truncatus*) emerging from unthreshed maize kernels (Savidan, 2002)

2.6.2 Factors affecting multiplication of insects in stored maize

Multiplication and propagation of insects in grain depends on a wide range of factors including moisture content, temperature of the grain and level of damage. Other factors possessing a profound effect on the population of insects in grain include; the amount of foreign material present in the grain and the atmosphere surrounding the grain (Montross *et al*., 1999; Ng'ang'a *et al*., 2016). According to Hayma (2003), the favorable conditions for most grain storage insects lie between temperatures of 25 to 35°C and 70 to 80% relative humidity.

Suleiman *et al.* (2015) reported that maize variety, temperature and storage time had significant effects on insect infestation and maize quality parameters. Maize variety factors such as kernel hardness, antibiosis, husk protection, pericarp surface texture among others acting alone or in combination may be responsible for increased insect resistance in stored grain (Goftishu and Belete, 2014).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

Assessment of storage hygiene practices and sampling of stored maize grain were conducted among maize farmers in Nakuru County, Kenya. The County is located within the Great Rift Valley and borders seven other Counties namely Laikipia to the North, Kajiado and Kiambu to the South, Nyandarua to the East, Kericho and Bomet to the West, Narok to the South west (Figure 3).

A field survey was carried out among smallholder maize farmers in Njoro ($0^0$19’44.4”N; $35^0$56’40” E) and Rongai ($0^0$10’23.99” N; $35^0$51’49.75” E) sub-Counties, Nakuru County (Figure 3) in the highland tropical (HLT) zone of Kenya in March 2017. The sites were selected because of their high maize production potential (De Groote, 2002), cosmopolitan population, with numerous small holder farms, vast agricultural enterprises and a wide variety of food grains cultivated (Ogeto *et al*., 2013). Njoro sub-County receives annual average rainfall of about 600 - 1800 mm, temperatures range between 11 and 24.5°C with an elevation of 1650 - 2450 meters above sea level (m a.s.l). In Rongai sub-County, annual rainfall ranges between 600 and 1000mm, temperatures range between 17 and 29°C with an altitude of 1650-1850 m a.s.l (Ogeto *et al*., 2013).

The study sites experience mono-modal rainfall pattern and maize farming is the predominant agricultural activity. The crop is planted during the onset of the long rain season in April and harvested on or before the start of short rain season in October/November. Other crops cultivated in the study sites include; wheat, beans, sorghum, cowpeas, Irish potatoes and vegetables.

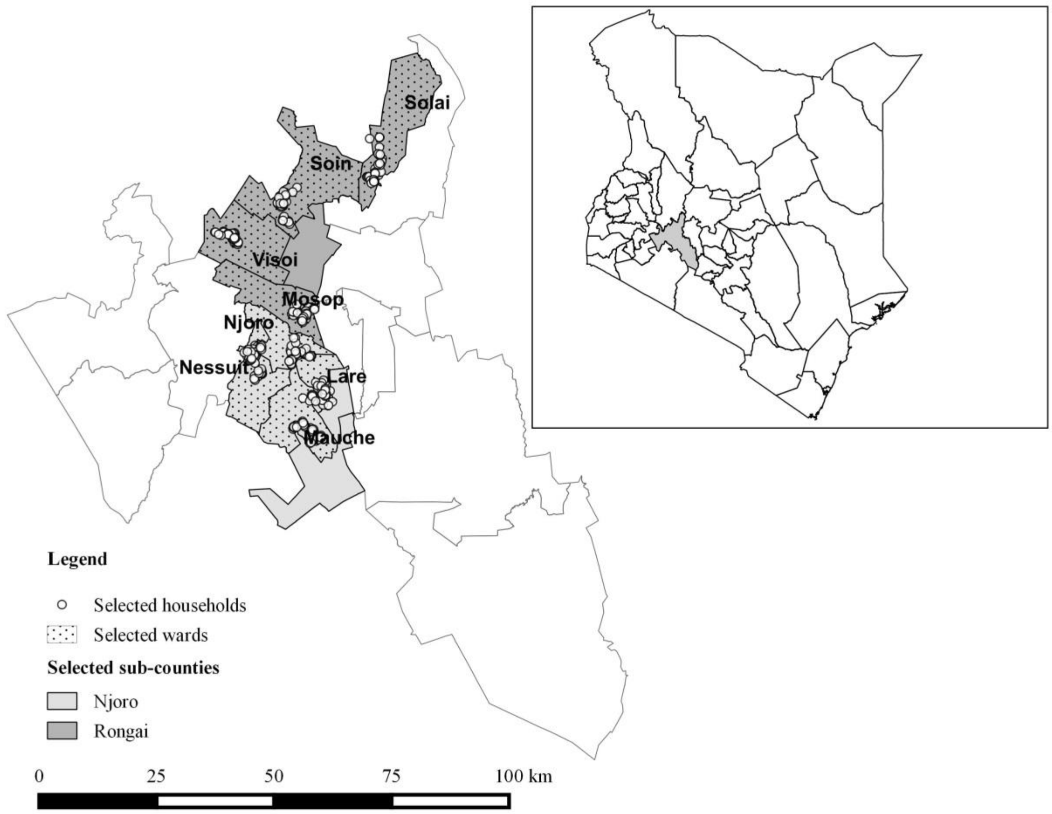

Figure 3: Map of Nakuru County showing the sub-Counties, wards and households surveyed during the study

3.2 Determination of sample size and data collection

The sample size was determined using Cochran's proportionate to size methodology (Mugenda and Mugenda, 2003). The ratio of farm families to households stood at 0.69 (Foeken and Owuor, 2001) and at 95% confidence level, a minimum sample size of 329 farmers was adequate for the survey. To identify respondents for the survey, four out of six wards in Njoro sub-County and four out of five wards in Rongai sub-County were randomly selected. In Njoro sub-County, 47 farmers in each of the four wards (Mauche, Lare Njoro and Nessuit) who had harvested maize in 2016 were selected randomly and interviewed whereas in Rongai sub-County, 38 farmers in each of the four wards (Soin, Visoi, Solai and Mosop) who had harvested maize in 2016 were selected randomly and interviewed. A total of 342 maize farmers spread out in the two sub-Counties were thus interviewed.

In each of the households visited, the person involved in postharvest handling and storage of maize was identified and interviewed. Trained enumerators conducted face to face interviews in the Kenyan national language (Kiswahili). Enumerators were pooled from a group with an understanding of the national language and at least one of the native languages common in the survey area (Kikuyu, Kalenjin). Whenever farmers with limited proficiency of the national language were encountered, one of the enumerators conversant with the farmers' native language carried out the interview.

Data on socio-demographic characteristics of farmers, storage structures, postharvest handling practices, hygiene practices during storage, storage problems encountered, strategies used to cope with the storage problems and the proportion of grain lost during the immediate preceding season were collected from each of the respondents using a semi structured questionnaire (Appendix I). A structured checklist (Appendix II) was used by the enumerators to collect additional data on the hygiene status of maize storage structures. To enable estimation of storage losses, the concept of postharvest losses as well as the various loss causing agents were first explained to the respondents. A list of major grain loss causing agents was included in the questionnaire. From this list, respondents were then asked to estimate quantity of grain lost to each of the pests relative to the total harvest from the immediate preceding storage season.

3.3 Selection of farmers for on-farm experimentation, estimation of hygiene score and sampling of maize from selected storehouses

Maize grain was sampled from smallholder farmers in four wards of Nakuru County; Mauche and Lare wards in Njoro Sub County, Soin and Mosop wards in Rongai Sub County. The trial was timed to coincide with the period when maize had been harvested and postharvest handling practices undertaken. Forty farmers (ten from each ward) who stored more than 400kg (five 90kg bags) of shelled improved maize variety (H6213) maize grain in bags were recruited for the trials.

The selected stores were sampled for baseline (two months into storage) and subsequently at intervals of two months for a period of seven months. To obtain samples for examination of diversity and abundance of molds and insects, grains were collected from bagged maize using a sampling spear. To ensure the collected samples were representative, all bags were sampled for farmers storing less than ten bags and only ten bags were randomly sampled for farmers who stored more than ten bags. Approximately 1kg composite sample of shelled maize grain was collected in sterile zip lock bags. The sample was divided into four portions of about 250g sub-samples by quartering on a laboratory bench. Each of the four sub-samples was randomly selected and used for determination of either; quality compliance, insect counts, the resultant weight loss, storage molds and aflatoxin concentration. An ELB-USB-2 data logger (Lascar electronics Inc., Pennsylvania, USA), programmed to record data every 30 min was placed in each of the storehouses to record the relative humidity and temperature during the entire storage period.

Additionally, using a standard checklist, the store was inspected to ascertain the general condition of the storage environment, the exterior and interior structural status, and cleanliness (Gwinner *et al*., 1996). The overall hygiene score was the outcome of the evaluation of a fixed set of attributes grouped into six criteria ($x_1 – x_6$) as follows:

x_1: Physical condition of the grain — (1) damaged cobs not stored together with the produce; (2) maize free of foreign matter (pieces of cobs, sheaths, dust, filth); (3) produce has no signs of rewetting (e.g. water marks on bags); (4) produce has normal smell, color and appearance (rotten/diseased/moldy grain); (5) no live insects on produce);

x_2: Status of store surrounding — (1) surroundings free of discarded grains, old bags, and cobs; (2) surroundings free from domestic waste, refuse pits or trash dumping sites; (3) surroundings clear of weeds, tall grasses, and bushes; (4) surroundings free of evidence rodents (droppings, burrows, gnawed grains); (5) surroundings free of stagnant water);

x_3: Soundness of the exterior of the store — (1) roof of store intact; (2) store sufficiently raised; (3) walls free of holes or cracks; (4) ventilation openings have screens to prevent entry of insects, rodents, and birds; (5) store fitted with rat guards/ rodent traps;

x_4: Soundness of the interior of the store — (1) walls, door, and roof undamaged; (2) holes and cracks on wall absent or filled to seal hiding places for pests; (3) ventilation openings function properly; (4) doors and windows of store /granary close well; (5) floor smooth without cracks or widely-spaced junctions;

x_5: Adherence to good storage practices in the store — (1) bagged produce placed on pallets or raised platform; (2) stacked bags do not have perforations/ physical damage; (3) Bags stacked away from the wall; (4) bags stacked in a way that allows adequate ventilation; (5) bags stacked away from non-food commodities (empty insecticide containers, empty fertilizer sacks, empty rodent baits); (6) bags stacked away /separated from other food commodities; (7) domestic animals (poultry, calves, sheep, goat) do not reside in the store; (8) old stocks kept separately from the new harvest; (9) unused bags and pallets stored away/ separately;

x_6: Cleanliness of the store — (1) walls and roof free of accumulated dust, dirt, cobwebs; (2) floor free of spilled grain, dirt, trash; (3) walls, floor, and ceiling free of crawling or flying insects; (4) surfaces of bags free of crawling insects; (5) store is free of evidence of rodent presence (hairs, droppings, pungent smell); (6) store is free of evidence of birds (feathers, droppings); (7) grain handling equipment (buckets, samplers, tarpaulins, brooms, sieves) clean; (8) difficult-to-reach areas clean (corners, underneath pallets, behind the doors, floor cracks/ junctions; (9) store free of musty smell or dampness on walls/ceilings.

For each criterion, the score was [1] if more than half of the attributes were satisfied, and [0] if not. Thus, each store received a maximum score of six and a minimum of zero at each sampling occasion. The scores were averaged for the number of sampling occasions (2 – 4 depending on when the stocks became depleted) to give the overall hygiene score of the store. This hygiene ranking score for the observed hygiene practices was thus a continuum ranging from 0 to 6. The hygiene scores were then classified into a 3-point likert rating as follows; 0 = Poor hygiene (for scores between 0 and 2), 1 = Average hygiene (scores of 2 and 3), and 2 = Good hygiene (for scores of 5 and 6). Data was ordered into these three hygiene levels for purposes of analysis and interpretation. In this trial, sampling was done from the batch of grain stored for farmers own use, therefore no grain was set aside for experimental sampling. Depletion of stocks by some of the farmers occurred before conclusion of the trial. In these storehouses, data was collected up to the point where depletion of stock occurred. Nine and twenty farmers had exhausted their stocks at fourth and sixth month sampling intervals and from these farmers, samples were not available for the particular sampling regimes.

3.4 Determination of maize grain moisture content

The moisture content was determined in triplicates with approximately thirty grams of maize sample using a digital electronic moisture meter (Pfeuffer HE 50, Germany) reading to 0.1%. Approximately ten grams of the maize sample were placed in the bottom section of the measurement cell. The top section of the measurement cell was then brought into place with the help of ratchet screw. The measurement cell was placed on the meter unit and maize was selected from the product programs using the rotary switch. Once the measurement button was pressed, a temperature corrected value was displayed automatically. An average of triplicate values obtained for each test sample was recorded as the moisture content for that particular sample.

3.5. Assessment of quality compliance

From one of the sub-samples obtained, 200g of grain was weighed and used for assessment of quality compliance according to East African standard, maize grain specifications (EAS2:2013). Grain was sieved through a 4.5 mm round-hole sieve. All the foreign organic matter (sand, soil, glass, fiber) that passed through the sieve was collected. Large foreign organic matter retained on top of the sieve was handpicked.

The foreign organic matter collected from the bottom of the sieve and those handpicked from the top of the sieve were weighed and expressed as a percentage of the total sample. Inorganic matter was then determined by sorting out foreign materials of non-biological origin from the working sample and expressing the results as a percentage of the total sample.

To determine the percentage of broken grain, broken grain and small kernels that passed through the 4.5 mm sieve were collected, weighed and expressed as a percentage of the total sample. Pest damaged grain were then determined by hand picking insect damaged kernels from the portion retained at the top of the sieve, weighing and expressing the weight as a percentage of the total sample. Rotten and diseased grain were handpicked from the batch retained on top of the sieve, weighed and expressed as a percentage of the total sample. Discolored grains were also handpicked from sample retained by the sieve and expressed as a percentage of the total sample.

In the same manner, shriveled grains were handpicked from the sample weighed and expressed as a percentage of the total sample. The parameter total defective grain was determined by calculating 70% of the total weight of all the individual defects (pest damaged, rotten, diseased, discolored and shriveled) previously handpicked.

3.6 Mold analysis

3.6.1 Total mold count

Total mold count was determined using the dilution plating method on Sabouraud Dextrose Agar (SDA) (Dextrose 40g, peptone 10g, agar 15g in in 1000 mL distilled water; pH 5.6 ± 0.2 at 25°C) amended with 20mg/L chloramphenicol. Ten grams of maize kernels were weighed from the sample and milled using a laboratory mill (Knife Mill Cup KM-400 MRC Lab, MRC International, Westminster, UK). The ground sample was then added to 90ml distilled peptone water in conical flasks and shaken thoroughly for two minutes. 1ml of suspension was drawn and added into 9ml sterile peptone water. The resulting solution was then serially diluted to a 10^{-4} dilution.

Replica 0.1mL aliquots of 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} were spread plated on SDA amended with chloramphenicol and incubated at room temperature (23 ± 2°C) for 5 days. The number of colonies in the Petri dishes were enumerated and recorded as colony forming units per gram (CFU/g) and calculated using the formula:

$$CFu/g = \frac{(Number\ of\ colonies * Dilution\ factor)}{Volume\ of\ culture\ plate} \qquad \text{(i)}$$

3.6.2 Determination of mold incidence

Mold incidence was determined using direct plating (Pitt and Hocking, 2009) on Czapex Dox Agar (Sucrose 30g, Sodium nitrate 2g, Dipotassium phosphate 1g, Magnesium sulphate 0.5g, Potassium chloride 0.5g, Ferrous sulphate 0.01g, agar 15g in 1000mL distilled water; pH 7.3 ± 0.3 at 25°C). One hundred kernels were randomly scooped from the sample, surface sterilized for 3 min in NaOCl (1.3%), rinsed for 30 seconds in 70% ethanol to remove excess NaOCl and subsequently rinsed with three bouts of sterile distilled water under aseptic conditions. The kernels were then dried off the excess water using sterile paper towel in a laminar flow cabinet, plated on CDA amended with 1g/l chloramphenicol (five kernels per plate) and incubated at room temperature (23 ± 2°C) for five days. The number of kernels showing fungal growth on each of the Petri dishes was enumerated. Different fungal species from kernels with multiple infections were enumerated separately. Fungal colonies were isolated and sub cultured on CDA for five days and identified using cultural and morphological characteristics as described by Pitt and Hocking (2009). The percentages of kernels infected by each fungal species were calculated as follows:

$$\% \; Incidence = \frac{Number \; of \; infected \; grains}{Total \; number \; of \; grains} * 100 \qquad \text{(ii)}$$

3.7 Determination of aflatoxin levels

Total aflatoxin was quantified by Enzyme-Linked Immunosorbent Assay (ELISA) using Neogen Veratox® (Neogen, Lansing, MI) total aflatoxin kits. 100g of each of the test samples were weighed and milled. Duplicate 5g of the ground sample was vortexed vigorously for three minutes in 25 mL of 70% methanol solution and then filtered through a Whatman No.1. The filtrate was collected and used as the sample for analysis. Reagents in the test kits were first allowed to warm at room temperature (23 ± 2°C) after which the content of each bottle was mixed by swirling prior to use. 100µL of the enzyme conjugate was added to the mixing wells. Using a pipette, 100µL of each of the four aflatoxin standards (0ppb, 5ppb, 15ppb and 50ppb) were added onto the first four mixing wells, sample extracts were then added beginning from the fifth well. The liquid in the wells (conjugate + standard or sample) was mixed three times using a 4-channel pippettor after which 100µL of the mixture was then obtained and transferred to the antibody coated wells. The mixture was incubated at room temperature for two minutes, contents of the wells were shaken out and the wells rinsed five times with distilled water. The wells were then turned upside-down and any remaining water was tapped out on a paper towel. Using the 4-channel pippettor, each of the wells was filled with 100 µL of the substrate solution and incubated at room temperature for 3 minutes after which 100 µL of the stop solution was added.

Absorbance was measured using UT-6100 auto microplate reader (MRC International, UK) at 650 nm. Aflatoxin concentration (OD650) of the liquid in each well was compared with (OD650) readings of the standards to generate a calibration curve using the known standards. The results were then multiplied by the dilution factor to obtain the contamination level of each sample in parts per billion (ppb). Veratox® has a lower detection limit of 1.4 ppb and a quantification range of 5 – 50 ppb.

3.8 Determination of insect population

Maize sub samples (250g) were stored in a refrigerator at 4°C for three hours to immobilize crawling insects and later sieved. Tunneled kernels were broken mechanically using a pair of forceps to remove any insects lodged inside the grain. After all visible insects had been counted; each sample was soaked in water for 48 hours to reveal hidden infestations. For each sample, the number of insects were obtained before and after soaking. These were summed up for each species to generate the total population for that particular sample.

3.9 Determination of weight loss and damage resulting from insect feeding

Percentage grain damage and the resultant weight loss were determined using count and weigh method (Boxall, 1986). From one of the sub-samples, 125g was weighed and sieved through a 2 mm round-hole sieve. Pieces of broken kernels were sorted and discarded. The remaining dust free whole kernels were sorted into insect damaged and undamaged grains.

Percentage of damaged grain was calculated as follows;

$$\%\ Damage = \frac{(Nd)}{(Nd\ + Nu)}\ * 100 \qquad \text{(iii)}$$

Percentage weight loss was calculated using the formulae below

$$\%\ Weight\ loss = \frac{[(Wu \times Nd)\ - (Wd \times Nu)]}{Wu(Nu + Nd)}\ * 100 \qquad \text{(iv)}$$

where:

Nu = Number of undamaged grains

Nd = number of insect damaged grains

Wu = Weight of undamaged grains

Wd = weight of insect damaged grains

3.10 Data analyses

Data on socio-demographics, pre-storage practices (drying, sorting and threshing), storage structures, hygiene practices (cleaning grain, cleaning and disinfesting the storehouse), storage challenges and coping strategies used by farmers were expressed as percentages and summarized as contingency Tables or Graphs. Differences among categories for different postharvest practices were determined using the Chi-square test and pairwise comparisons performed using the ‘chisq.multcomp’ function with bonferroni *p*-values adjusted in the RVAideMemoire package (Herve, 2018) of the R 3.4.3 software (R Core Team, 2017).

Data on magnitude of perceived storage losses (reported by respondents in kilograms) was converted into percentages of the quantity of maize stored. The percentage losses were then tested for normality using the Shapiro-Wilk normality test: ($df = 341$, statistic = 0.701, $p < 0.001$ (total losses); ($df = 341$, statistic = 0.568, $p < 0.001$ (insect losses); ($df = 341$, statistic = 0.278, $p < 0.001$ (mold losses); ($df = 341$, statistic = 0.580, $p < 0.001$ (rodent losses); ($df = 341$, statistic = 0.201, $p < 0.001$ (losses due to theft). The data were not normally distributed and therefore, an arcsine square root (x/100) transformation was performed after which the transformed data was re-tested for normality: ($df = 341$, statistic = 0.985, $p < 0.001$ (total losses); ($df = 341$, statistic = 0.907, $p < 0.001$ (insect losses); ($df = 341$, statistic = 0.521, $p < 0.001$ (mold losses); ($df = 341$, statistic = 0.924, $p < 0.001$ (rodent losses); ($df = 341$, statistic = 0.280, $p < 0.001$ (losses due to theft). The data was not normally distributed even after the transformation, therefore Kruskal-Wallis test and Wilcoxon rank-sum test which do not require the test data to be normally distributed were used to test for statistical differences in R 3.4.3 software.

Prior to analysis, data on moisture content, insect counts, weight losses, mold incidence and aflatoxin concentration was tested for normality using the Shapiro-Wilk normality test. Normally distributed data was subjected to one way analysis of variance (ANOVA) and significantly differing means separated using Tukey’s honestly significant difference (HSD) test at 95% confidence interval. Data found not to be normally distributed was subjected to Kruskal-Wallis test after which significantly differing means were pair wisely separated using Kruskal-Nemenyi test in the ‘PMCMR’ package in R 3.4.3 software. To assess the effect of hygiene on progression of variables over time, two way analysis of variance (ANOVA) was used for normally distributed data whereas negative binomial regression was run for datasets that were not normally distributed.

A regression analysis of the data from 40 farmers whose stores were sampled over 7 months elucidated the relationships between loss levels (dependent variable) and storage practices, hygiene, and the socio-economic characteristics of the farmers. Explanatory variables were grouped into two categories: (i) the farmers' socio-economic characteristics (gender, age, education level, experience), and (ii) the storage and hygiene practices (storage structures, place of storage, storage of maize with other products, store disinfestation, storage duration, training on grain storage protection, and hygiene score of the farmer's store). As the losses data were expressed as fractions (kg/kg) bounded between [0 –1], an ordinary least squares regression would result in biased parameter estimates. Other models, such as Tobit, are also biased due to the non-normal distribution and heteroskedasticity of their error terms. The Fractional Response Model (FRM) proposed by Papke and Wooldridge (1996) was thus used to overcome this limitation. The model synthesizes and extends the generalized linear models and quasi-likelihood methods to a class of functional forms with satisfying properties that overcome most of the known limitations of the other conventional econometric models for bounded dependent variables (Ogoudedji *et al*., 2019; Chegere, 2018). Other advantages of the model are the direct estimation of the conditional expectation of the dependent variable, allowing the bounded values [0 and 1] as well as intermediate values to appear. The model also gives consistent parameter estimates regardless of the distribution of the dependent variable and computes standard errors by default (Gallani *et al*., 2015; Baum, 2008). STATA 14 (StataCorp L.P., TX, USA) was employed to perform the regression analysis using the logit Quasi-Maximum Likelihood estimation method. The marginal effects were computed from the fitted model to make interpretation of the model's results easier.

CHAPTER FOUR: RESULTS

4.1 Storage hygiene, postharvest handling practices and their contribution to storage losses in on-farm stored maize

4.1.1 Socio-demographics of respondents and farm characteristics

The sampled farming population consisted of a significantly higher proportion (56.7%; (χ^2 (1) = 6.19, p = 0.013) of female respondents (Table 2). This was also the case in Rongai sub-County (58.4%; (χ^2 (1) = 4.38, p = 0.036). However, the gender distribution in Njoro sub-County was statistically even (χ^2 (1) = 2.128, p = 0.145). Two thirds (68.2%) of the respondents were aged between 25-55 years (Table 2). Overall, 35.4% of the respondents were aged below 40 years. Three quarters (76.7%) of maize farmers in both sub-Counties had completed at least eight years of formal education. Generally, only 5.8% of respondents in both sub-Counties had not acquired any formal education. In both sub-Counties, 70.2% of the respondents had more than 11 years of experience in maize farming.

In both sub-Counties, the proportion of farmers storing maize for short duration (1-4 months) was significantly lower (χ^2 (2) = 33.54, $p < 0.001$ (Njoro sub-County); (χ^2 (2) = 44.12, $p < 0.001$ (Rongai sub-County) compared to longer storage durations (5-8 months and 9-12 months) (Figure 4).

Table 2: Socio-demographic characteristics of respondents in Njoro and Rongai sub-counties, Nakuru County

		Percentage of respondents		
		Njoro sub-County (n = 188)	Rongai sub-County (n = 154)	Overall (n = 342)
Gender	Female	55.3^{a}A	58.4^{a}A	56.7^{a}
	Male	44.7^{a}A	41.6^{b}A	43.3^{b}
	$\chi 2$ (1)	2.13	4.39	6.19
	p-value	0.14	0.036	0.013
Age (Years)				
	< 18	0.0^{c}A	0.0^{b}A	0.0^{c}
	18-24	4.8^{b}A	0.6^{b}B	2.9^{b}
	25-40	36.7^{a}A	27.3^{a}B	32.5^{a}
	41-55	35.1^{a}A	36.4^{a}A	35.7^{a}
	> 55	23.4^{a}A	35.7^{a}A	28.9^{a}
	$\chi 2$ (4)	108.12	103.34	200.49
	p-value	<0.001	<0.001	<0.001
Experience in maize farming (years)				
	1-5	18.1^{b}A	9.1^{b}B	14.0^{b}
	6-10	18.1^{b}A	13.0^{b}A	15.8^{b}
	11-15	13.8^{b}A	11.7^{b}A	12.9^{b}
	16-20	16.0^{b}A	8.4^{b}B	12.6^{b}
	>20	34.0^{a}B	57.8^{a}A	44.7^{a}
	$\chi 2$ (4)	24.34	138.53	131.89
	p-value	0.002	<0.001	<0.001
Level of formal education				
	No formal education	8.0^{c}A	3.2^{c}B	5.8^{c}
	< 8 years	21.8^{b}A	12.3^{b}B	17.5^{b}
	Completed 8 years	38.3^{a}A	40.3^{a}A	39.2^{a}
	Completed 12 years	24.5^{a}A	26.0^{ab}A	25.1^{b}
	> 12 years	7.4^{c}B	18.2^{b}A	12.3^{c}
	$\chi 2$ (4)	62.05	60.74	112.91
	p-value	<0.001	<0.001	<0.001

Within each sub-County as well as the overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare the two sub-Counties; same letters indicate no significant difference ($P > 0.05$).

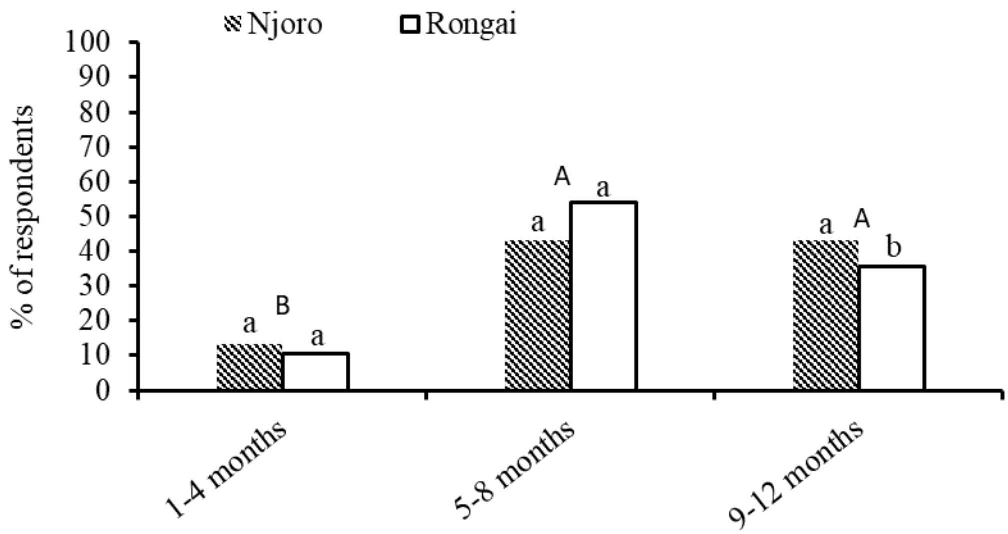

Figure 4: Proportion (%) of respondents who stored maize for different durations (Months) in Njoro and Rongai sub-Counties.

Same uppercase letters indicate no significant difference (*P* > 0.05) among categories in the overall sample. Lowercase letters compare the two sub-Counties; same letters indicate no significant difference (*P* > 0.05).

4.1.2 Storage structures and bag types used by maize farmers

Maize was stored in granaries or rooms within the dwelling house. Granaries were not uniformly constructed but were mostly raised rectangular structures constructed using wooden rafters or timber with iron sheet roofing (improved cribs, 98%) or grass thatched (traditional granaries, 2%). On the other hand, rooms within the dwelling house were almost exclusively (94.2%) iron sheet roofed. The floors were earthen (48.2%) cemented (36.5%), or made of timber spread out on raised platforms (15.3%). Walls were made of bricks (27%), timber (21.9%) or mud (51.1%). Farmers' stored maize in the living room, bedroom or kitchen but in some instances, a special store room purposely used for grain storage was constructed within the dwelling house.

In Rongai sub-County, a significantly higher proportion (42.9 %; (χ2 (3) = 18.71, p = < 0.001) of respondents who stored maize in dwelling houses had constructed a special room that served as a store. In Njoro sub-County a significantly lower (13.5%; (χ^2 (3) = 12.70, p = 0.003) proportion of farmers kept bagged produce in the kitchen (Table 3).

Bag usage was significantly higher than other storage structures in both sub-Counties; (χ^2 (3) = 517.06, $p < 0.001$(Njoro) and (χ^2 (3) = 462, $p < 0.001$(Rongai). All farmers (100%) in Rongai sub-County stored maize in bags. In Njoro sub-County, 96.8% stored maize grain in bags while the remaining proportion stored maize directly on the floor in the rooms within the dwelling house (1.6%), granaries (1.1%) or in metal silos (0.5%). In the overall sample, farmers mainly used woven polypropylene bags (87.5%). Compared to other bag types (hermetic, jute/sisal, polypropylene + jute/sisal). The use of woven polypropylene bags was significantly higher in both sub-Counties (χ^2 (3) = 425.74, $p < 0.001$ (Njoro); (χ^2 (3) = 282.62, $p < 0.001$ (Rongai). However, comparing the popularity of specific types of bags between the two sub-Counties, use of woven polypropylene bags was significantly more popular (χ^2 (1) = 4.91, $p < 0.027$) in Njoro sub-County whereas hermetic bags were significantly more widely used (χ^2 (1) = 5.14, $p < 0.023$) in Rongai sub-County. Storage of bagged maize in granaries than in rooms within the dwelling house was significantly widely practiced in both sub-Counties (χ^2 (1) = 8.51, $p = 0.004$ (Njoro) and (χ^2 (1) = 5.09, $p = 0.024$ (Rongai).

Table 3: Storage structures, types of bags used and locations where bagged maize was stored in Njoro and Rongai sub Counties

	Percentage of respondents		
	Njoro sub-County (n = 188)	Rongai sub-County (n = 154)	Overall (n = 342)
Storage structure			
Bags	96.8^{a}A	100^{a}A	98.2^{a}
Metal silo	0.5^{b}A	0.0^{b}A	0.3^{b}
Directly on the floor in the house	1.6^{b}A	0.0^{b}A	0.9^{b}
Directly on the floor in the granary	1.1^{b}A	0.0^{b}A	0.6^{b}
$\chi 2$ (3)	517.06	462	978.58
p-value	<0.001	<0.001	<0.001
Type of bag used			
Woven polypropylene	91.2^{a}A	83.1^{a}B	87.5^{a}
Jute or sisal	2.2^{b}A	0.6^{c}A	1.5^{c}
Woven polypropylene + jute/sisal	2.2^{b}A	3.2^{c}A	2.7^{c}
Hermetic	4.4^{b}B	13.0^{b}A	8.3^{b}
$\chi 2$ (3)	425.74	282.62	703.6
p-value	<0.001	<0.001	<0.001
Storage location for bagged maize			
Granary	61.0^{a}A	59.1^{a}A	60.1^{a}
Living room	6.6^{bc}A	9.7^{b}A	8^{bc}
Bedroom	14.8^{b}A	11.7^{b}A	13.4^{b}
Kitchen	4.4^{c}A	1.9^{c}A	3.3^{c}
Special store room	13.2^{b}A	17.5^{b}A	15.2^{b}
$\chi 2$ (4)	198.05	156.65	352.69
p-value	<0.001	<0.001	<0.001

Within each sub-County as well as the overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare the two sub-Counties; same letters indicate no significant difference ($P > 0.05$).

4.1.3 Postharvest handling practices

Among the surveyed farmers, 90.4% sorted out damaged cobs after harvesting. A significantly higher proportion of respondents sorted mold damaged cobs (81.2%) compared to those who sorted insect damaged grains (47.6%). The proportion of respondents who sorted insect damaged grain was in turn significantly higher (χ^2 (3) = 155.97, p = <0.001) than those who sorted other types of damage including rodent damage (28.8%) and damage caused by birds (19.4%). Three quarters of farmers (76%) dried their maize before storage. Among the platforms used to dry maize, tarpaulin usage was significantly higher than other platforms for farmers who stored their grain in granaries as well as those who stored their grain in rooms within the dwelling house. Other platforms used to dry maize were bare ground (16.5%), concrete floors (4.2%) and roof tops (0.8%) (Table 4).

Overall, use of shelling machines was significantly the most preferred (82.2%; χ^2 (3) = 601.27, p = < 0.001) method of shelling maize (Table 4). The shelled grain was then cleaned off foreign matter. A significantly higher proportion of farmers (86.9%; (χ^2 (3) = 190.89, p = < 0.001) reported encountering chaff compared to other components of foreign material cleaned from the grain (dust 32.6%, sand 9.9%, broken cobs 7.4%, and weed seeds 6.7%). There were no major differences in the manner in which farmers conducted postharvest handling practices in the two localities.

Table 4: Grain postharvest handling practices by farmers in Njoro and Rongai sub Counties

	% of respondents by storage place		% of respondents by locality		Overall (n = 342)
	Granary (n = 205)	Room in house (n = 137)	Njoro (n = 188)	Rongai (n = 154)	
Sort damaged cobs	89.3B	92A	88.8A	92.4A	90.4
Insect damage	47.0^{b}B	48.4^{b}A	43.5^{b}A	52.5^{b}A	47.6^{b}
Mold damage	80.3^{a}B	82.5^{a}A	81.5^{a}A	80.9^{a}A	81.2^{a}
Rodent damage	31.1^{bc}A	25.4^{c}B	25.6^{c}A	32.6^{b}A	28.8^{c}
Bird damage	18.0^{c}A	21.4^{c}A	22.6^{c}A	15.6^{c}B	19.4^{c}
χ^2 (3)	89.92	66.89	85.51	73.25	155.97
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Dry maize before storage	70.2A	84.7A	75.5A	76.6A	76
Dry on bare earth	16.0^{b}A	17.2^{b}A	13.0^{b}A	17.8^{b}A	16.5^{b}
Dry on tarpaulins	77.8^{a}A	79.3^{a}A	81.9^{a}A	77.1^{a}A	78.5^{a}
Dry on concrete floor	4.9^{c}A	3.4^{c}A	3.6^{c}A	5.1^{c}A	4.2^{c}
Dry on roof top	1.4^{c}A	0.0^{c}A	1.4^{c}A	0.0^{c}A	0.8^{c}
χ^2 (3)	220.61	190.21	242.35	178.88	410.62
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Thresh grains	100A	100A	100A	100A	100
Hand threshing	2.9^{c}A	1.5^{c}A	4.3^{bc}A	0.0^{c}A	2.3^{c}
Beat exposed cobs with a stick	3.4^{c}A	6.6^{bc}A	2.7^{c}A	6.6^{bc}B	4.7^{c}
Beats cobs in a sack with a stick	10.7^{b}A	10.9^{b}A	10.1^{b}A	11.7^{b}A	10.8^{b}
Use threshing machines	82.9^{a}A	81.0^{a}B	83.0^{a}A	81.2^{a}A	82.2^{a}
χ^2 (3)	370	231.79	339.36	263.4	601.27
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Removes foreign matter	79.5B	86.9A	77.7A	88.3A	82.5
Weed seeds	6.7^{c}A	6.7^{c}A	6.8^{c}A	6.6^{c}A	6.7^{c}
Chaff	84.7^{a}B	89.9^{a}A	82.2^{a}A	91.9^{a}A	86.9^{a}
Sand	9.2^{c}A	10.9^{c}A	12.3^{c}A	7.4^{c}A	9.9^{c}
Dust	33.7^{b}A	31.1^{b}A	33.6^{b}A	31.6^{b}A	32.6^{b}
Broken cobs	9.2^{c}A	5.0^{c}B	6.2^{c}A	8.8^{c}A	7.4^{c}
χ^2 (4)	249.76	211.66	214.05	248.21	460.12
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Remove foreign matter by:					
Sieving	47.2^{a}A	32.8^{b}B	32.9^{b}A	50.0^{a}A	41.1^{b}
Winnowing	64.4^{a}A	74.8^{a}A	63.0^{a}A	75.0^{a}A	68.8^{a}
Hand picking	11.6^{b}A	14.5^{c}A	16.3^{c}A	9.0^{b}B	12.8^{c}
Sheller fan	11.9^{b}A	9.4^{c}A	9.7^{c}A	12.2^{b}A	10.9^{c}
χ^2 (3)	101.38	96.62	81.33	113.68	190.89
p – value	<0.001	<0.001	<0.001	<0.001	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the categories (storage place or locality) are not significantly different ($P > 0.05$).

4.1.4 Storage hygiene practices

Hygiene practices applied on the different types of bags used for grain storage are presented in Table 5. Overall, exclusive use of recycled bags from previous seasons was not widely practiced (12.2%). However, more than a quarter (28.0%) of the farmers used both new and re-cycled bags. Treatment of the bags before re-use was practiced by 51.9% of the farmers who stored maize in granaries (n = 202) while amongst those who stored in rooms within the house (n = 134), 32.5% did not treat bags prior to filing with the newly harvested grain. In Njoro sub County, a significantly higher (χ^2 (1) = 4.95, p = 0.026) proportion (59.7%) of farmers did not treat recycled bags. Recycled bags were disinfested by treating with chemicals (53.2%), exposing in the sun (17.7%), and dipping in hot (19.4%) or cold water (9.7%). Of these treatment methods, treating with chemicals was significantly popular (χ^2 (3) = 22.51, p < 0.001) among farmers who stored their grain in granaries. However, use of various methods of disinfesting bags did not differ significantly (χ^2 (3) = 6.24, p = 0.101) among farmers storing maize in rooms within the dwelling house.

Among the different chemicals used for treatment of recycled bags, Actellic® super dust (Pirimiphos-methyl 1.6% w/w + Permethrin 0.3% w/w) was predominantly (65.2%) used among farmers who stored grain in granaries whereas, Skana® super (Malathion 2% w/w +permethrin 0.3% w/w) was the pesticide of choice (50 %) among farmers who stored maize in rooms. Overall, among the pesticides used for treatment of bags across the different storage systems, Actellic® super dust was used by a significantly higher proportion of farmers (51.5%; χ^2 (3) = 15.84, p = 0.001) compared to Skana® super and K-Obiol® DP2 dust (5% w/w deltamethrin) (Table 5).

In some of the storehouses, maize was stored together with other grain types, stovers, processed animal feeds, used bags, plastic containers or agrochemicals (Figure 4). The proportion of farmers storing stovers, animal feeds, used bags, plastic containers or agrochemicals together with maize was significantly higher in granaries (χ^2 (1) = 31.12, p < 0.001 (stovers); χ^2 (1) = 29.81, p < 0.001 (animal feeds); χ^2 (1) = 10.61, p = 0.001 (used bags); χ^2 (1) = 19.29, p < 0.001 (plastic containers) and χ^2 (1) = 15.07, p < 0.001 (agrochemicals) while the proportion storing other grain types was significantly higher in rooms within the dwelling house (χ^2 (1) = 4.45, p < 0.035). Other types of grain stored together with maize included beans, wheat, peas, sorghum and/or millet. Storage of beans together with maize was significantly popular (77.3%; χ^2 (6) = 571.01, p < 0.001) compared to other grain types (Figure 5). The proportion of farmers storing wheat was significantly higher in granaries than in rooms within the dwelling house (χ^2 (1) = 5, p = 0.025).

Nine tenths of farmers (89.8%) cleaned their stores before introducing newly harvested grain (Table 6). Sweeping was the preferred method of cleaning the stores and was practiced by significantly higher proportion of farmers who used granaries for maize storage (χ^2 (2) = 127.92, p = < 0.001) as well as those who stored in rooms within the dwelling house (χ^2 (2) = 71.73, p = < 0.001). Half (49.7%) of farmers cleaned their storehouses once the harvested grain had been introduced. However, frequency of cleaning varied greatly depending on the storage regime. Generally, farmers who stored grain in rooms within the dwelling house cleaned their stores more frequently compared to those who stored in granaries (Figure 6). The proportion of farmers cleaning their stores on a daily and weekly basis was significantly higher in rooms within the dwelling house (χ^2 (1) = 14.22, p < 0.001 (daily) and χ^2 (1) = 7.41, p = 0.006 (weekly) whereas the proportion of farmers who cleaned their stores once a month or twice a year was significantly higher among farmers who stored their grain in granaries (χ^2 (1) = 4.00, p < 0.045 (monthly) and χ^2 (1) = 9.80, p = 0.002 (after six months). Less than half of farmers (44.4%) disinfested their stores before introducing new grain. Actellic® super dust was widely used for disinfestation of granaries (70.8%) compared to rooms in the dwelling house (48.2%). However, 13.2% of the surveyed farmers reported disinfesting their storehouses but could not recall the particular brand of disinfestant used.

Table 5: Bag usage and treatment approaches for recycled maize storage bags by farmers in Njoro and Rongai sub Counties, Nakuru County

	% of respondents by storage place		% of respondents by locality		
	Granary (n = 202)	Room in house (n = 134)	Njoro (n = 182)	Rongai (n = 154)	Overall (n = 336)
Bag usage					
Uses new bags	60.9^{a}A	58.2^{a}B	57.7^{a}A	62.3^{a}A	59.8^{a}
Recycles bags	10.9^{c}A	14.2^{c}A	13.2^{c}A	11.0^{c}A	12.2^{c}
Both new and recycled	28.2^{b}A	27.6^{b}B	29.1^{b}A	26.6^{b}A	28.0^{b}
$\chi 2$ (2)	78.13	40.94	55.53	63.91	118.62
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment of recycled bags					
Treats recycled bags	51.9^{a}A	37.5^{a}B	40.3^{a}A	53.4^{a}A	45.9^{a}
Do not treat	48.1^{a}A	62.5^{a}A	59.7^{a}A	46.6^{a}B	54.1^{a}
$\chi 2$ (1)	0.11	3.5	2.92	0.28	0.9
p-value	0.936	0.061	0.087	0.599	0.344
Methods used to treat bags					
Chemicals	56.1^{a}A	47.6^{a}B	58.1^{a}A	48.4^{a}A	53.2^{a}
Hot water	17.1^{b}A	23.8^{a}A	25.8^{a}A	12.9^{a}A	19.4^{b}
Cold water	7.3^{b}A	14.3^{a}A	6.5^{b}A	12.9^{a}A	9.7^{b}
Exposing in the sun	19.5^{b}A	14.3^{a}A	9.7^{b}A	25.8^{a}A	17.7^{b}
$\chi 2$ (3)	22.51	6.24	20.74	10.42	27.68
p-value	<0.001	0.101	<0.001	0.01	<0.001
Chemicals used to treat recycled bags					
Cannot recall	21.7A	30A	33.3A	13.3A	24.2
Actellic® super dust	65.2^{a}A	20.0^{a}B	50.0^{a}A	53.3^{a}A	51.5^{a}
Skana® super dust	8.7^{b}A	50.0^{a}A	11.1^{ab}A	33.3^{ab}A	21.2^{ab}
K-obiol® DP 2 dust	4.3^{b}A	0.0^{a}A	5.6^{b}A	0.0^{b}A	3.0^{b}
$\chi 2$ (2)	20.33	5.43	9.5	7.538	15.68
p – value	<0.001	0.066	<0.097	0.023	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the categories (storage place or locality) are not significantly different ($P > 0.05$).

Table 6: Store cleaning practices applied by maize farmers in Njoro and Rongai sub Counties, Nakuru County

	% of respondents by place of storage		% of respondents by locality		
	Granary (n = 205)	Room in house (n = 137)	Njoro (n = 188)	Rongai (n = 154)	Overall (n = 342)
Cleans store before introducing harvest	88.8B	91.2A	86.7A	100A	89.8
Mode of cleaning:					
Swept only	72.5^{a}A	68.8^{a}B	70.7^{a}A	71.3^{a}A	71.0^{a}
Mopped only	9.3^{b}A	12.0^{b}A	13.4^{b}A	7.0^{c}B	10.4^{c}
Swept and mopped	18.1^{b}A	19.2^{b}A	15.9^{b}A	21.7^{b}A	18.6^{b}
$\chi 2$ (2)	127.92	71.73	103.37	97.524	199.16
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Cleans store after introducing harvest	42.4A	60.6A	47.9A	51.9A	49.7
Mode of cleaning:					
Swept only	65.5^{a}A	63.9^{a}A	68.9^{a}A	60.0^{a}A	64.7^{a}
Mopped only	2.3^{cd}A	4.8^{b}A	3.3^{b}A	3.8^{c}A	3.5^{c}
Dusted	13.8^{bc}A	6.0^{b}A	11.1^{b}A	8.8^{bc}A	10.0^{b}
Swept and mopped	1.1^{d}B	15.7^{b}A	7.8^{b}A	8.8^{bc}A	8.2^{b}
Swept and dusted	17.2^{b}A	9.6^{b}A	8.9^{b}A	18.8^{b}A	13.5^{b}
$\chi 2$ (4)	121.22	102.72	135.89	84.75	216.76
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Disinfests the store	46.8A	40.9B	34.0A	57.1B	44.4
Disinfectant used:					
Cannot recall	9.4A	19.6A	20.0A	8.0A	13.2
Actellic® super dust	70.8^{a}A	48.2^{a}B	50.8^{a}B	71.3^{a}A	62.5^{a}
Skana® super dust	8.3^{b}A	17.9^{ab}A	10.8^{bc}A	12.6^{b}A	11.8^{b}
Sevin® dudu dust	3.1^{b}A	5.4^{bc}A	4.6^{bc}A	3.4^{bc}A	3.9^{bc}
K-obiol® DP2 dust	3.1^{b}A	0.0^{c}A	4.6^{bc}A	0.0^{c}A	2.0^{c}
Rodenticide	3.1^{b}A	3.6^{bc}A	7.7^{bc}A	0.0^{c}B	3.3^{bc}
Cow dung	2.1^{b}A	5.4^{bc}A	1.5^{c}A	4.6^{bc}A	3.3^{bc}
$\chi 2$ (5)	238.45	68.47	84.38	237.98.47	301.34
P-value	<0.001	<0.001	<0.001	<0.001	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences ($P > 0.05$). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the categories (storage place or locality) are not significantly different ($P > 0.05$)

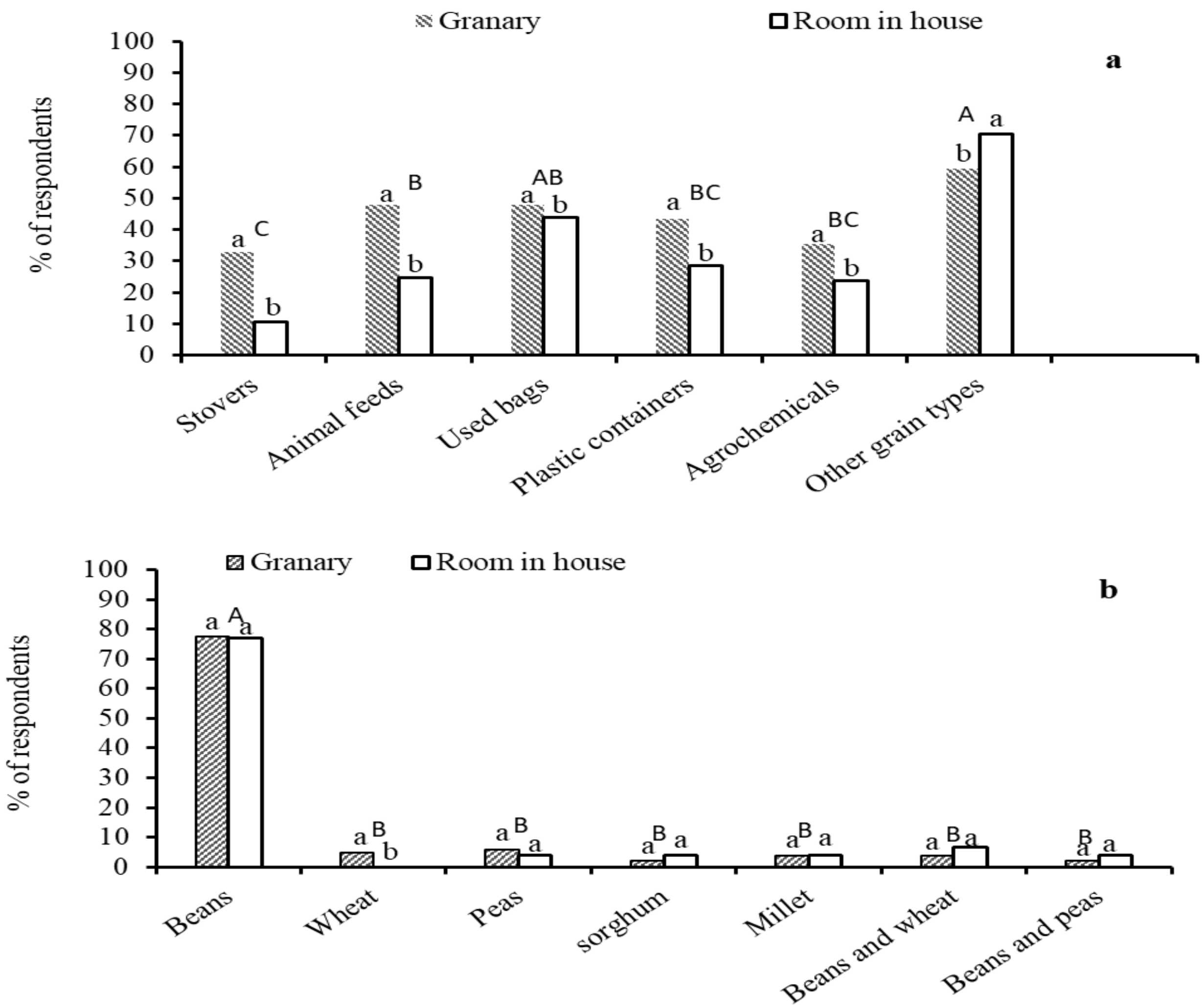

Figure 5: Other products stored together with maize (a) and other grain types stored together with maize (b)

Same uppercase letters indicate no significant difference ($P > 0.05$) among categories in the overall sample. Lowercase letters compare storage in granaries versus dwelling rooms; same letters indicate no significant difference ($P > 0.05$)

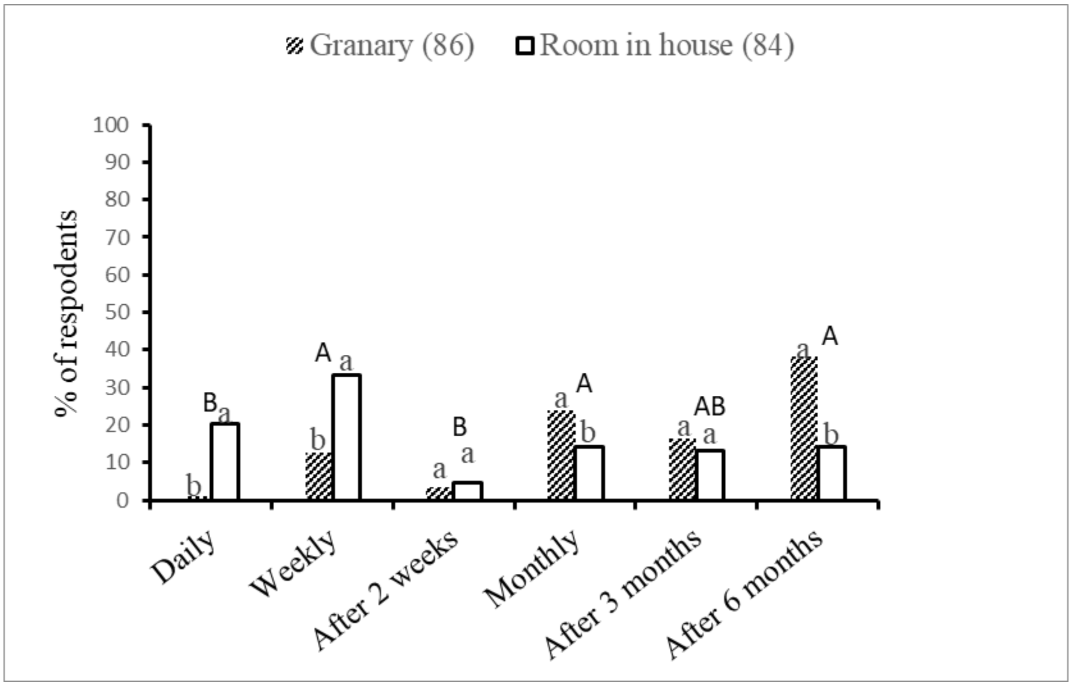

Figure 6: Frequency of cleaning the storehouses after maize is loaded.

Same uppercase letters indicate no significant difference ($P > 0.05$) among categories in the overall sample. Lowercase letters compare storage in granaries versus dwelling rooms; same letters indicate no significant difference ($P > 0.05$).

Figure 7: Common practices and storage materials in maize farmers' storehouses in Njoro and Rongai sub Counties, Nakuru County

Granary with a clean surrounding (a); granary surrounded by animal feeds, discarded bags and tall grass (b); polypropylene bags placed on raised platform in a clean special store room (c); unclean granary floor (d); dusty polypropylene bags and spilled grains (e); bagged maize stacked together with used home appliances (f); maize stored with oily machines, old tarpaulins and used bags (g); bagged maize stored on top of Irish potatoes (h); spilled grain around a granary that is not fitted with rat guards (i).

4.1.5 Storage problems, magnitude of perceived losses and control measures

Majority (94.7%) of the respondents attributed grain losses to insects, rodents, molds and theft. Insects and rodents were the leading cause of grain losses in storage (86.4%). However, the proportion of farmers who experienced problems from insects (80.9%) was not statistically different from those who experienced rodent problems (86.4%) (Figure 8a). Less than a quarter of the farmers reported losses arising from molds (21.6%) or theft (17.9%). Farmers who stored grain in granaries (40%) and within rooms in the dwelling house (47.4%) ranked insects as the 'most important' storage problem (Figure 8b). On average, losses arising from insect infestation were the highest (3.92 ± 0.37) followed by those resulting from rodent attack (3.31 ± 0.29) (Table 7).

To offset losses arising from insects and molds, farmers used a vast array of control methods. Among insect control methods deployed, insecticide application was significantly (χ^2 (4) = 422.71, $p < 0.001$) more widely practiced by 56.4% of the farmers. Application of wood ash, plant leaves, exposure to sun and sieving were applied with lower frequencies (Table 8). Actellic® super dust was the insecticide of choice by a significantly higher (χ^2 (3) = 270.42, $p < 0.001$) proportion (70.5%) of farmers. Other insecticides applied with lower frequencies included; Skanna® super (Malathion 2% w/w +permethrin 0.3% w/w), K-Obiol® DP2 dust (5% w/w deltamethrin) and Sevin® dudu dust (Carbaryl 7.5% w/w) (Table 8).

It was noted that more than one third (37.4%) of all the surveyed farmers did not report molds as a storage problem. Another, 17.3% reported experiencing mold problems but did not apply any form of protection. Among mold control methods applied, exposure to sun was used by a significantly higher (χ^2 (2) = 42.94, $p < 0.001$) percentage of farmers (23.4%) across the two storage systems. Other molds control methods used by smaller proportion of farmers included cleaning surface mycelial growth and sorting out infected kernels.

Table 7: Magnitude of storage losses (% w/w) caused by the various loss agents as perceived by farmers in Njoro and Rongai sub Counties, Nakuru County

	Storage place		Locality		Average
	Granary	Room in house	Njoro	Rongai	
Insects	3.6 ± 0.43^{a}A	4.4 ± 0.67^{a}A	3.77 ± 0.45^{a}A	4.09 ± 0.62^{a}A	3.92 ± 0.37^{a}
Molds	1.09 ± 0.25^{b}A	1.03 ± 0.4^{b}A	1.74 ± 0.38^{b}A	0.24 ± 0.09^{b}A	1.06 ± 0.22^{b}
Rodents	3.45 ± 0.39^{a}A	3.12 ± 0.45^{a}A	3.49 ± 0.43^{a}A	3.10 ± 0.38^{a}A	3.31 ± 0.29^{a}
Theft	0.23 ± 0.10^{c}A	0.33 ± 0.08^{c}A	0.25 ± 0.11^{c}A	0.32 ± 0.11^{b}A	0.27 ± 0.07^{c}
Total	8.12 ± 0.57	8.58 ± 0.99	8.12 ± 0.57	8.58 ± 0.99	8.3 ± 0.52

Mean (± S.E.) values within a column followed by the same lowercase superscript letter are not significantly different ($P > 0.05$); values across the rows followed by the same uppercase letter under the categories of storage place or locality are not significantly different ($P > 0.05$)

Table 8: Control measures practiced by maize farmers against insects and molds in Njoro and Rongai sub Counties, Nakuru County

	% of respondents by storage place		% of respondents by locality		
	Granary (n = 205)	Room in house (n = 137)	Njoro (n = 188)	Rongai (n = 154)	Overall (n = 342)
Insect control					
Insects not a problem	3.4A	6.6A	6.4A	2.6B	4.7
No control measures	13.7A	10.9B	18.1A	5.8B	12.6
Insecticide application	57.1^{a}A	55.5^{a}B	49.5^{a}A	64.9^{a}A	56.4^{a}
Applies wood ash	3.4^{c}A	4.4^{bc}A	4.2^{b}A	3.2^{c}A	3.8^{c}
Use of plant leaves	3.9^{c}A	1.5^{c}A	2.1^{b}A	3.9^{c}A	2.9^{c}
Exposure to sun	12.2^{bc}A	13.1^{b}A	12.8^{b}A	12.3^{c}A	12.6^{b}
Sieves	6.3^{bc}A	8.0^{bc}A	6.9^{b}A	7.1^{c}A	7.0^{b}
$\chi 2$ (4)	321.8	198.5	246.7	232.9	518.6
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Insecticides used					
Cannot recall	10.3A	11.8A	14.0A	8.0A	10.9
Actellic® super dust	71.8^{a}A	68.4^{a}B	69.9^{a}A	71.0^{a}A	70.5^{a}
Sevin® Dudu dust	1.7^{b}A	7.9^{b}A	6.5^{b}A	2.0^{c}A	4.1^{b}
K-Obiol® DP2 dust	6.0^{b}A	1.3^{b}B	4.3^{b}A	4.0^{bc}A	4.1^{b}
Skana® super dust	10.3^{b}A	10.5^{b}A	5.4^{b}B	15.0^{b}A	10.4^{b}
$\chi 2$ (3)	199.1	113.9	135.1	137.8	311.3
p-value	<0.001	<0.001	<0.001	<0.001	<0.001
Mold control					
Molds not a problem	36.6A	38.7A	35.1A	40.3A	37.4
No control measures	15.6A	19.7A	11.7B	24.0A	17.3
Exposure to sun	23.9^{a}A	29.2^{a}A	29.3^{a}A	22.1^{a}B	26.0^{a}
Cleaning mycelia	10.2^{b}A	2.9^{c}B	9.0^{b}A	5.2^{b}A	7.3^{c}
Sorting infested kernels	13.7^{ab}A	9.5^{bc}B	14.9^{b}A	8.4^{b}B	12.0^{bc}
$\chi 2$ (2)	13.0	37.0	22.9	20.8	42.9
p-value	0.002	<0.001	<0.001	<0.001	<0.001

Down the columns: granary (storage place), room in house (storage place), Njoro (locality), Rongai (locality) and overall sample, same superscript lowercase letters within a category indicate no significant differences (*P* > 0.05). Uppercase letters compare practices in granary storage versus room in house storage (across rows) and storage in Njoro versus Rongai; values across the rows followed by the same uppercase letter under the categories (storage place or locality) are not significantly different (*P* > 0.05)

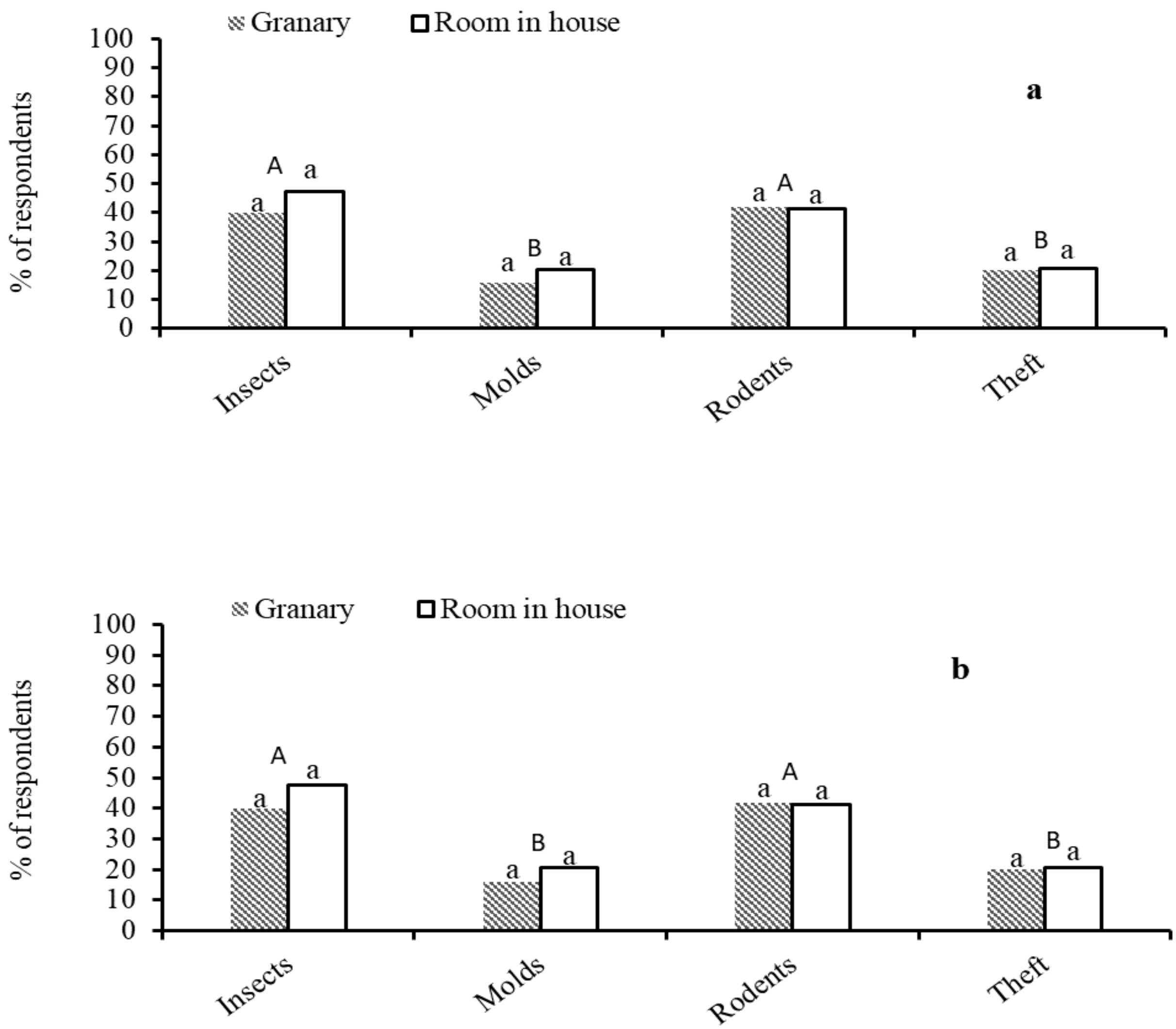

Figure 8: Causes of storage problems (a) and the frequency of farmers who ranked a particular problem as the 'most important' during storage (b).

Same uppercase letters indicate no significant difference ($P > 0.05$) among categories in the overall sample. Lowercase letters compare storage in granaries versus dwelling rooms; same letters indicate no significant difference ($P > 0.05$).

4.2 Storage practices among the experimental storehouses from which grain was sampled

Less than half (42.5%) of all the surveyed farmers had their storehouses surrounded with discarded grains, old bags and cobs (Table 9). In addition, the stores were located in vicinities full of weeds, tall grasses or bushes. Exterior walls of almost three quarters (72.5%) of the storehouses surveyed were associated with presence of holes, cracks or other perforations capable of allowing pest entry. These stores were also characterized by external walls that were dusty, cobweb laden or were associated with different types of debris. Half of the storehouses (50%) from which grain was sampled had internal walls that were either cracked or creviced. Bagged maize was placed directly on the floor in slightly more than half (52.5%) of the storehouses.

General store cleanliness was observed by almost half (47.5%) of the farmers recruited for experimentation. Clean stores were typified by walls and roofs that were free of accumulation of dust, dirt, spillages, cobwebs and other debris. Cleanliness of hidden surfaces, doors, windows and grain handling equipment was also used to discern hygienic stores from those that were deemed unhygienic.

Less than a third (30%) of the farmers isolated damaged cobs after drying. About two thirds of these (66.7%) sorted moldy, discolored or rotten cobs. A small proportion (8.3%) sorted insect damages while a quarter (25%) sorted damages caused by rodents, termites or birds. The damaged cobs were either thrown away, sold, consumed or fed to livestock (cattle, chicken, goats or sheep). Three quarters (77.5%) of the farmers cleaned shelled grain by removal particulate matter. Mechanisms deployed in removal of particulate matter included; winnowing (54.8%), sieving (19.4%) or relying on fans attached to the threshing machines (25.8). More than half (63.3%) of the farmers reported that chaff was the main component of the particulate material separated from the grain. Other types of particulate matter sieved from grain included a mixture of chaff and dust (16.7%), dust (10%) and weed seeds (10%).

Almost all (90%) the farmers cleaned their storage structures before the new harvest was loaded. However, only about half (47.5%) cleaned their storehouses after the harvests had been loaded. Cleaning was performed by sweeping, mopping or dusting. Majority (57.5%) of the farmers sprinkled their storehouses with protectants including; Actellic® super dust (Pirimiphos-methyl 1.6% w/w +Permethrin 0.3% w/w), Skanna super (Malathion 2% w/w +permethrin 0.3% w/w) or rodenticides.

Table 9: Hygiene practices by maize farmers in Njoro and Rongai sub Counties, Nakuru County

Hygiene attribute	Percentage of respondents within different hygiene levels			
	Good (n = 9)	Average (n = 18)	Poor (n = 13)	Overall (n = 40)
Storehouse surrounding, exterior and interior				
Surrounded by grain, old bags and cobs	22.2	55.6	84.6	57.5
Surrounded by weeds, tall grasses and bushes	0	5.6	15.4	7.5
Cracked/perforated walls	55.6	33.3	61.5	55
Dusty walls and floor	55.6	50	61.5	55
Cleanliness and storage practices				
Unclean hidden surfaces	33.3	44.4	61.5	47.5
Dirty handling equipment	55.6	50.0	61.5	55
Other products stored together with maize	33.3	44.4	46.2	42.5
Bags stored directly on the floor	33.3	27.8	61.5	40
Postharvest handling				
Isolated damaged cobs	44.4	11.1	30.8	25
Cleaned grain	100	72.2	69.2	77.5
Cleaned store before harvest was loaded	100	100	69.2	90
Cleaned store after harvest was loaded	66.7	38.9	46.2	47.5
Sprinkled storehouse with protectants	33.3	72.2	53.8	57.5

4.3 Effect of storage conditions on moisture content of stored grains

At the commencement of the trial, moisture content varied between treatments but was lowest in stores with poor hygiene practices. Throughout the trial period, moisture content decreased steadily in hygienic stores from an average of 12.7 ± 0.5 (range: 9.8-14.7%) to 12.4 ± 0.6 (range: 9.9-13.7%). The decrease in moisture content in these stores was however not significant ($\chi 2$ (3) = 0.28, P = 0.964). In contrast, mean moisture increased in stores characterized with either average or poor hygiene practices. In moderately hygienic stores, moisture content increased from an initial average of 12.4 ± 0.3 at the commencement of trial to 13.5 ± 04 after 4 months after which it dropped to 13.3 ± 0.4 during the last 2 months of storage. Moisture increase in moderately hygienic stores was however not significant (F = 2.66; df = 3, 53; P =0.96). In storehouses characterized by poor hygiene practices, moisture levels increased to levels that were significantly higher from the second month of storage onwards (F = 5.78; df = 3, 39; P =0.002) from initial moisture content of 12.2 ± 0.3 (range: 10.3-13.6%) to 14.2 ± 0.7 (range: 12.2-17.1%) (Figure 9)

Interaction between hygiene levels and moisture content at different sampling points were not significantly different (F = 0.34; df = 2, 37; P =0.715 (commencement of trial), ($\chi 2$ (2) = 2.10, P = 0.350(after 2 months), ($\chi 2$ (2) = 1.22, P = 0.542(after 4 months), (F = 0.83; df = 2, 17; P =0.449(after 6 months). Equally, interaction between hygiene, storage duration and moisture content were not significant (F = 1.38; df = 6, 119; P = 0.228) (Figure 10).

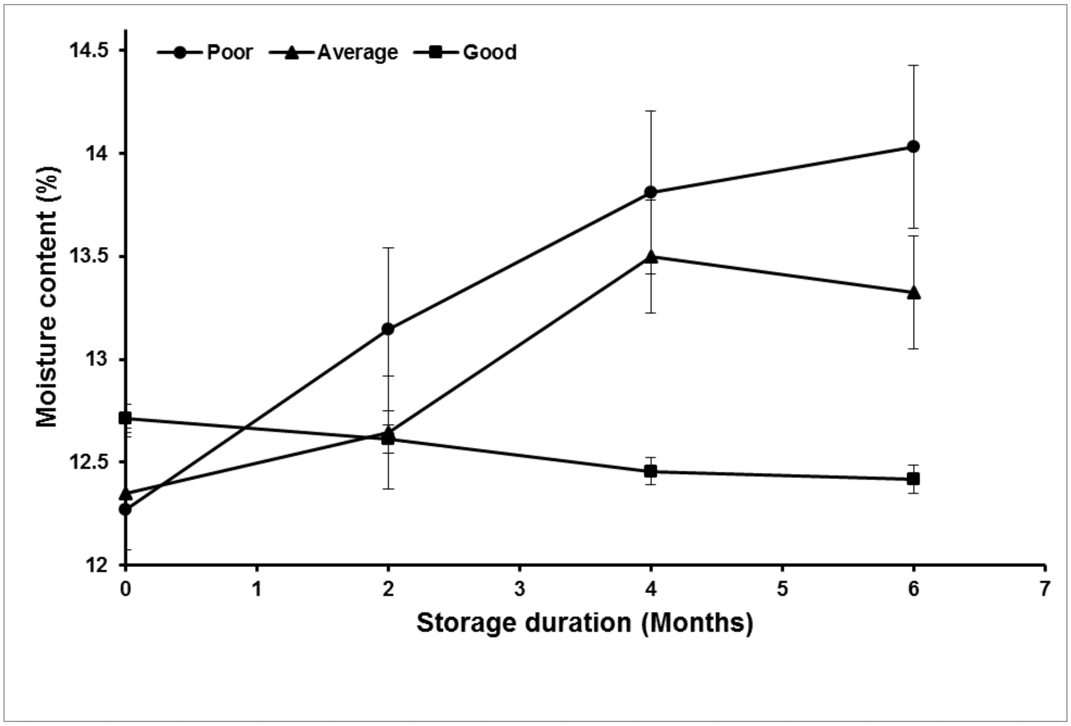

Figure 9: Moisture content (%) of maize stored in structures characterized by poor (●), average (▲) or good (■) hygiene practices

Error bars represent standard error of the mean; Sampling was conducted between April and October 2017 in Njoro and Rongai sub Counties, Nakuru County

4.4 Effect of hygiene on quality compliance parameters

The proportion of foreign material increased steadily throughout the trial and reached significantly higher levels with the samples collected after four months of commencement of trial ($\chi2$ (3) = 36.19, *P* <0.001) (Table 10). Comparison between treatments showed significant differences after four months of storage with samples from stores exhibiting poor hygiene practices recording significantly higher proportion of foreign and inorganic material after the fourth and sixth months of storage ($\chi2$ (3) = 6.99, *P* = 0.030); ($\chi2$ (3) = 7.69, *P* = 0.021) respectively. It was also observed that whereas foreign mater content below the recommended levels was maintained in hygienic stores throughout the trial period, this was not the case with the other store types. Particularly, in unhygienic and averagely hygienic stores, the acceptable foreign matter content threshold (1.5%) was surpassed after the second and the fourth month of storage, respectively.

Overall, significant increases in the proportion of broken kernels were recorded only after the first two months of storage ($\chi2$ (3) = 21.05, $P < 0.001$). Interaction between pest damage and storage duration was significant ($\chi2$ (3) = 30.52, $P < 0.001$).

The proportion of rotten, diseased, discolored and shriveled grain increased significantly with storage duration ($\chi2$ (3) = 16.28, $P < 0.001$). The proportion of total defective grain increased steadily and significantly throughout the trial period ($\chi2$ (3) = 26.66, $P < 0.001$). Mean total defective grain exceeded allowable limits after two months in stores characterized by poor hygiene practices whereas in other treatments, such threshold was reached after four months of storage.

Table 10: Quality compliance parameters of maize samples collected from stores characterized by good, average or poor hygiene levels in Njoro and Rongai sub Counties, Nakuru County

	Duration of storage (Months)			
Treatment	0	2	4	6
Foreign and inorganic material (%)				
Good	0.74 ± 0.38a	0.79 ± 0.19a	1.27 ± 0.32a	1.20 ± 0.30a
Average	0.80 ± 0.22a	0.89 ± 0.21a	1.79 ± 0.31ab*	1.81 ± 0.48ab*
Poor	0.68 ± 0.13a	1.59 ± 0.30a*	2.98 ± 0.57b*	3.65 ± 0.84b*
Broken kernels (%)				
Good	1.24 ± 0.24a	2.14 ± 0.41a	2.97 ± 0.53a	3.40 ± 0.66a
Average	1.62 ± 0.22a	2.24 ± 0.29a	2.16 ± 0.41a	2.63 ± 0.56a
Poor	1.60 ± 0.18a	2.08 ± 0.17a	2.28 ± 0.38a	3.14 ± 0.88a
Pest damaged grain (%)				
Good	1.73 ± 0.43a	3.14 ± 0.67a*	3.18 ± 0.53a*	3.95 ± 0.64a*
Average	2.50 ± 0.63a	5.18 ± 1.23a*	4.91 ± 1.27a*	6.86 ± 2.20a*
Poor	3.19 ± 1.70a*	5.58 ± 2.01a*	8.35 ± 2.84a*	14.61 ± 4.92a*
Rotten, diseased, discolored and shriveled kernels (%)				
Good	4.49 ± 0.93a	6.85 ± 1.92a*	6.49 ± 1.30a*	7.67 ± 1.69a*
Average	3.53 ± 0.62a	4.11 ± 0.76a	6.19 ± 1.37a*	7.75 ± 1.96a*
Poor	4.96 ± 1.49a	5.78 ± 1.21a*	8.54 ± 2.42a*	14.00 ± 4.63a*
Total defective grain (%)				
Good	4.35 ± 0.79a	6.00 ± 1.05a	6.77 ± 1.03a	8.17 ± 1.30a*
Average	4.22 ± 0.58a	6.56 ± 0.95a	7.77 ± 1.23a*	10.25 ± 1.87a*
Poor	5.48 ± 1.31a	8.50 ± 1.67a*	11.83 ± 2.39a*	19.83 ± 4.97a*

Data are means ± standard error. Means in the same category within a column followed by the same letter are not significantly different (*P>0.05*). Means followed by a star (*) exceed the maximum tolerable limits set by KEBS for that particular parameter(s). Means were separated using Kruskal-Nemenyi test.

4.5 Effect of storage hygiene on mold proliferation

Total mold population was slightly higher in stores characterized by poor hygiene practices throughout the experimentation period, however, the differences in the total population of molds across the treatments were not significant. Total mold population across all the storehouses did not increase significantly for the first two months of storage (χ^2 (1) = 3.33, P = 0.069). However, mold population increased significantly (χ^2 (1) = 19.43, P < 0.001); (χ^2 (1) = 11.86, P < 0.001) after four and six months of storage respectively (Figure 10).

Molds of the *Fusarium, Aspergillus* and *Penicillium* genera were cultured from the sampled grain with high frequencies (Table 11). For the first 2 months of storage, the incidence of *Aspergillus* species across the varying hygiene levels was not significantly different (F = 2.25; df = 2, 37; P =0.120 (commencement of trial) and ($\chi 2$ (2) = 0.82, P = 0.665 (2 months). Over the rest of the trial period, incidence of *Aspergillus* spp. increased in stores characterized by poor and average hygiene practices to levels that were significantly higher than those where good hygiene practices were adhered to ($\chi 2$ (2) = 12.00, P = 0.002 (4 months), (F = 20.04; df = 2, 17; $P < 0.001$ (6 months). Interaction between *Aspergillus* spp. and storage duration were highly significant ($\chi 2$ (3) = 51.81, P<0.001). Incidence levels at commencement of trial and after two months of storage were not significantly different. However, they were lower compared to those of samples collected at the fourth and sixth month of storage.

The incidence of *Fusarium* spp. across stores characterized by varying hygiene levels did not differ significantly at different sampling points throughout the trial. ($\chi 2$ (2) = 0.65, P = 0.722 (commencement of trial), (F = 0.08; df = 2, 37; P =0.919 (2 months), (F = 1.67; df = 2, 37; P =0.207 (4 months) and (F = 1.24; df = 2, 17; P = 0.314 (6 months) and the same was true for *Aspergillus* spp.

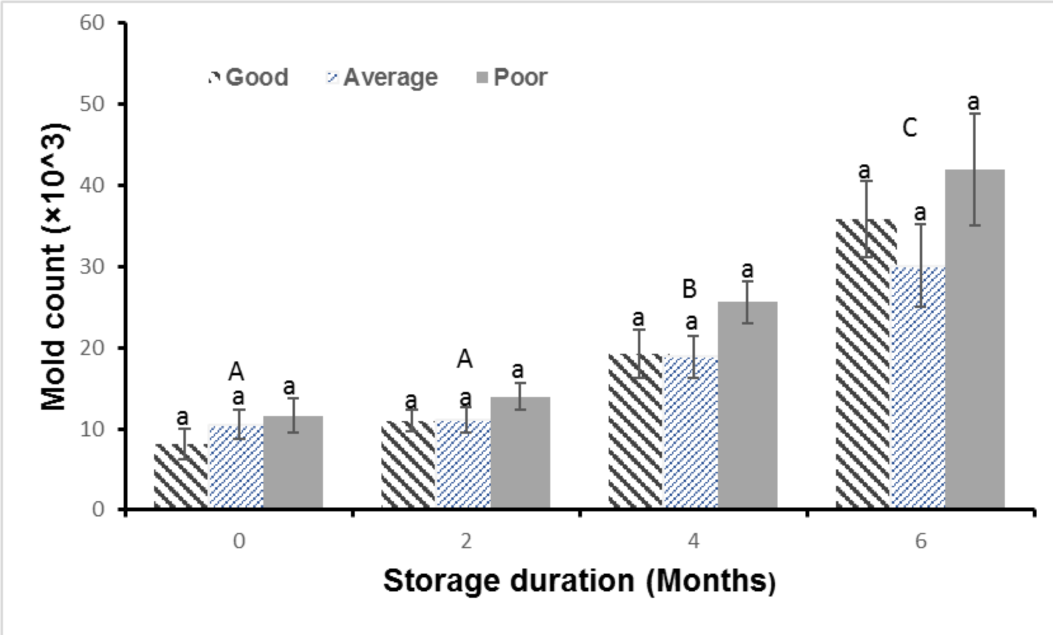

Figure 10: Total mold count of maize sampled from storage structures characterized by poor, average or good hygiene practices in Njoro and Rongai sub Counties, Nakuru County

Uppercase letters compare samples collected at different sampling points; same letters indicate no significant difference ($P > 0.05$). Lowercase letters compare different hygiene levels at the same sampling point; same letters indicate no significant difference ($P > 0.05$). Sampling was conducted between April and October 2017.

Table 11: Incidence (%) of commonly occurring molds isolated from maize sampled from stores characterized by good, average or poor hygiene practices in Njoro and Rongai sub Counties, Nakuru County

	Duration of storage (Months)			
	0	2	4	6
Aspergillus spp.				
Good	10.9 ± 2.0a	17.3 ± 2.3a	19.1 ± 2.4a	21.3 ± 1.5a
Average	14.8 ± 1.5a	20.6 ± 3.4a	36.2 ± 2.7b	44.2 ± 2.9b
Poor	17.8 ± 1.5a	23.4 ± 4.1a	38.7 ± 2.5b	47.0 ± 3.9b
Fusarium spp.				
Good	22.8 ± 4.2a	34.3 ± 5.6a	31.1 ± 3.1a	36.2 ± 3.0a
Average	21.9 ± 2.2a	35.3 ± 2.9a	30.5 ± 2.9a	29.7 ± 3.8a
Poor	18.6 ± 1.8a	33.2 ± 4.2a	37.1 ± 2.7a	35.3 ± 2.4a
Penicillium spp.				
Good	0.8 ± 0.5a	2.7 ± 1.4a	4.3 ± 1.5a	7.7 ± 1.8a
Average	2.2 ± 0.7a	4.9 ± 1.2a	4.8 ± 1.1a	8.5 ± 3.6a
Poor	1.5 ± 0.7a	4.6 ± 1.5a	5.7 ± 1.7a	13.0 ± 4.8a

Data are means ± standard error. Means in the same category within a column followed by the same letter are not significantly different ($P > 0.05$). Means were separated using Tukey's HSD or Kruskal-Nemenyi test.

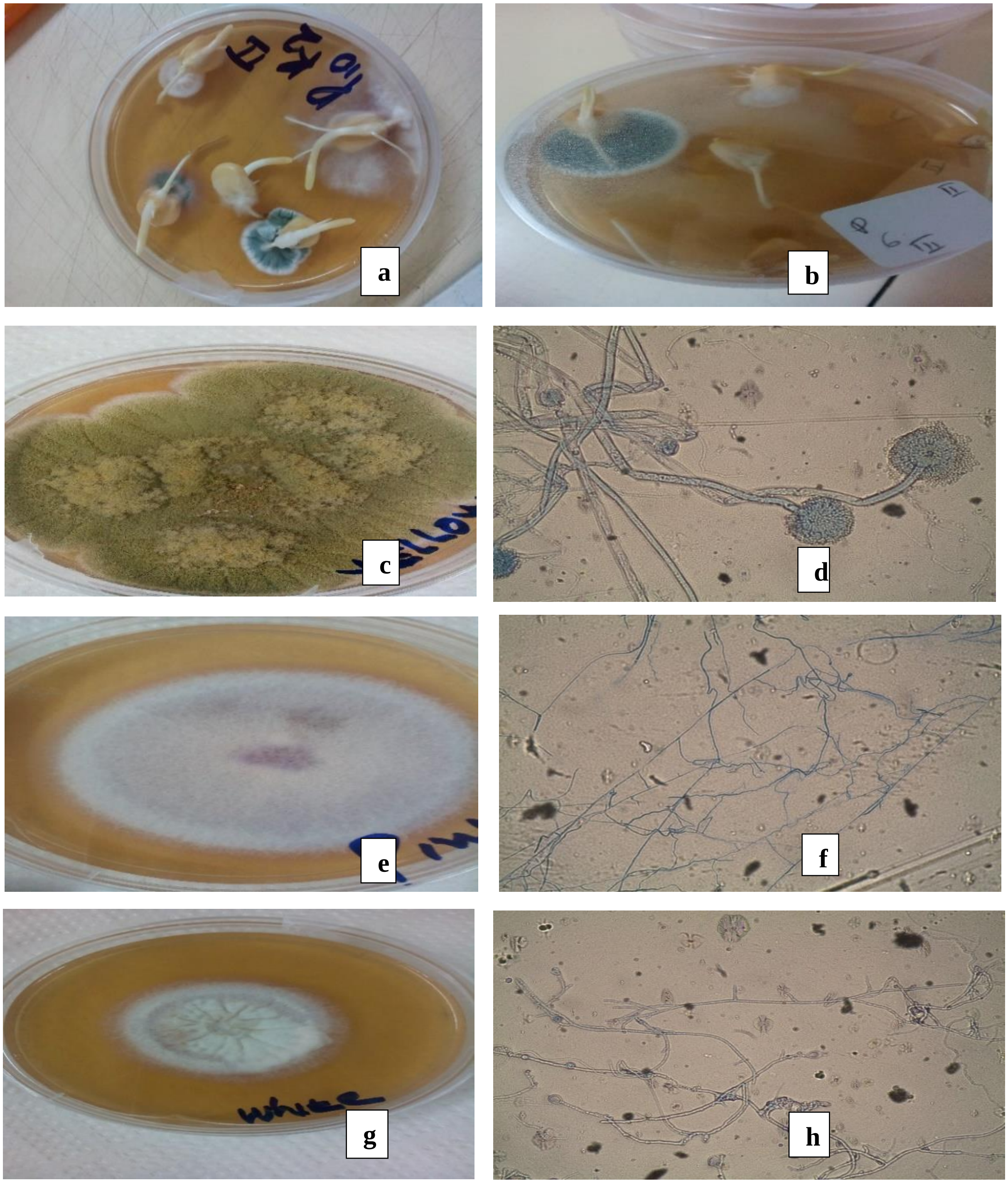

Figure 11: Fungal pathogens commonly isolated from sampled maize grains.

Fungal cultures growing from maize kernels after five days of incubation (a and b); Pure culture of *Aspergillus flavus* (c) and a microscopic slide showing structures of *Aspergillus flavus* (d; Pure culture of *Fusarium verticillioides* (e) and a microscopic slide showing structures of *Fusarium verticillioides* (f); sub-culture (g) and a microscopic slide (h) showing *Penicillium* spp. Culturing was performed on Czapek Dox Agar.

4.6 Effect of hygiene on aflatoxin contamination

Aflatoxin concentration increased gradually throughout the storage period (Table 12); however, there were no significant differences among the treatments for the first two months after commencement of trial ($\chi 2$ (2) = 0.18, *P* = 0.915 (commencement of trial), ($\chi 2$ (2) = 1.15, *P* = 0.563 (after 2 months). There were significantly higher aflatoxin levels in stores where levels of hygiene were either average or poor compared to those recorded in hygienic storehouses after four months of storage ($\chi 2$ (2) = 6.38, *P* = 0.041.) Contrastingly, there were no significant differences in aflatoxin levels at the 6th sampling point (*F* = 1.56; *df* = 2, 17; *P* = 0.24).

Aflatoxin levels increased approximately four fold for maize stored under hygienic conditions, six fold for storehouses characterized by average hygiene practices, and seven fold for grain stored under conditions of poor hygiene throughout the storage period. At the commencement of trial, 15% and 22% of samples from hygienic and unhygienic stores respectively had aflatoxin levels beyond the 10 ppb threshold set by Kenya Bureau of Standards (Figure 12). This proportion increased to 100% and 71% in unhygienic and hygienic stores respectively four months after the commencement of trial.

Table 12: Aflatoxin concentration (ppb) in maize grains stored in structures characterized by poor, average or good hygiene practices in Njoro and Rongai sub counties, Nakuru County

	Duration of storage (Months)			
	0	2	4	6
Good	5.3 ± 1.5a (0-49)	8.7 ± 2.4a (0-19)	14.9 ± 2.9a (13-64)	20.8 ± 3.9a (15-57)
Average	5.7 ± 1.1a (0-42)	12.2 ± 2.1a (0-43)	21.9 ± 3.6b (7-66)	36.5 ± 7.4ab (15-84)
Poor	4.9 ± 1.4a (0-44)	12.6 ± 3.8a (0-52)	31.7 ± 4.8b (11-60)	35.0 ± 7.8a (8-55)

Data are means ± standard error and (range). Means in the same category within a column followed by the same letter are not significantly different (*P > 0.05*). Means were separated using Tukey's HSD or Kruskal-Nemenyi test.

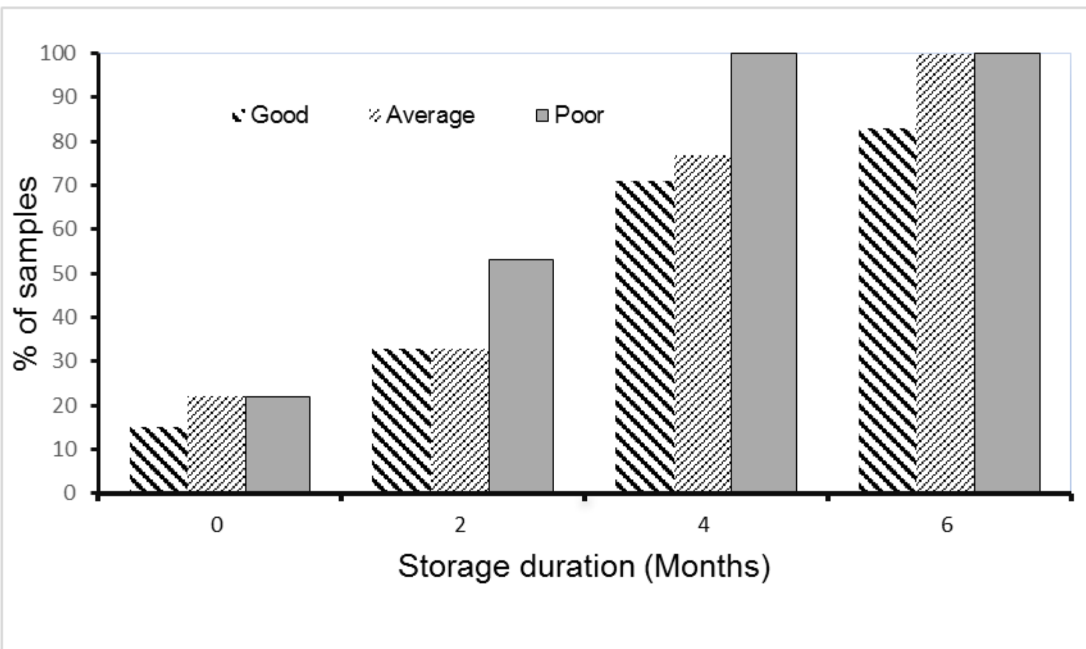

Figure 12: Proportion (%) of maize samples exceeding the 10 ppb KEBS limit.

Sampling was conducted from stores characterized by poor, average or good hygiene practices between April and October 2017 in Njoro and Rongai sub Counties, Nakuru County

4.7 Effect of hygiene on the population of adult *Sitophilus zeamais*

Varying population densities of adult *Sitophilus zeamais, Prostephanus truncatus, Tribolium castaneum* and *Citotroga cerealalella* were recovered from sampled grain. However, apart from

S. zeamais, the other insect species were present in low frequencies and for this reason, only data for *S. zeamais* is presented (Figure 13). From data collected at the commencement of the trial, initial infestations at the beginning of storage were relatively high. Out of the 40 samples collected, 32 had varying levels of *S. zeamais* infestations averaging 4.2 ± 0.9 insects per 125 grams of grain (Figure 14). This number increased steadily to 30.9 ± 7.2 insects per sample after 6 months of storage.

Marginal differences in population of *S. zeamais* were observed among treatments at each sampling point. For instance, at 6 months of storage, the population of *S. zeamais* in storehouses adhering to good hygiene practices averaged 23.3 ± 8.6 while those characterized by poor hygiene practices had an average of 60.7 ± 7.2 *S. zeamais* per 125 grams of grain. The differences in insect population at different sampling points were however not significant ($\chi 2$ (2) = 2.86, P = 0.239 (commencement of trial), ($\chi 2$ (2) = 3.32, P = 0.190 (2 months), ($\chi 2$ (2) = 3.14, P = 0.208 (4 months) and ($\chi 2$ (2) = 4.38, P = 0.112 (6 months). The overall interaction between hygiene status, population of *S. zeamais* and storage duration was highly significant (F = 13.88; df = 3, 127; P <0.001). It took 4 months of storage for mean population of *S. zeamais* to increase significantly in stores characterized by poor hygiene practices ($\chi 2$ (3) = 18.40, P < 0.001) whereas significantly higher populations of *S. zeamais* in hygienic and moderately hygienic stores were recorded after 6 months of storage ($\chi 2$ (3) = 10.09, P = 0.018 (good hygiene), ($\chi 2$ (3) = 14.50, P = 0.002 (average hygiene).

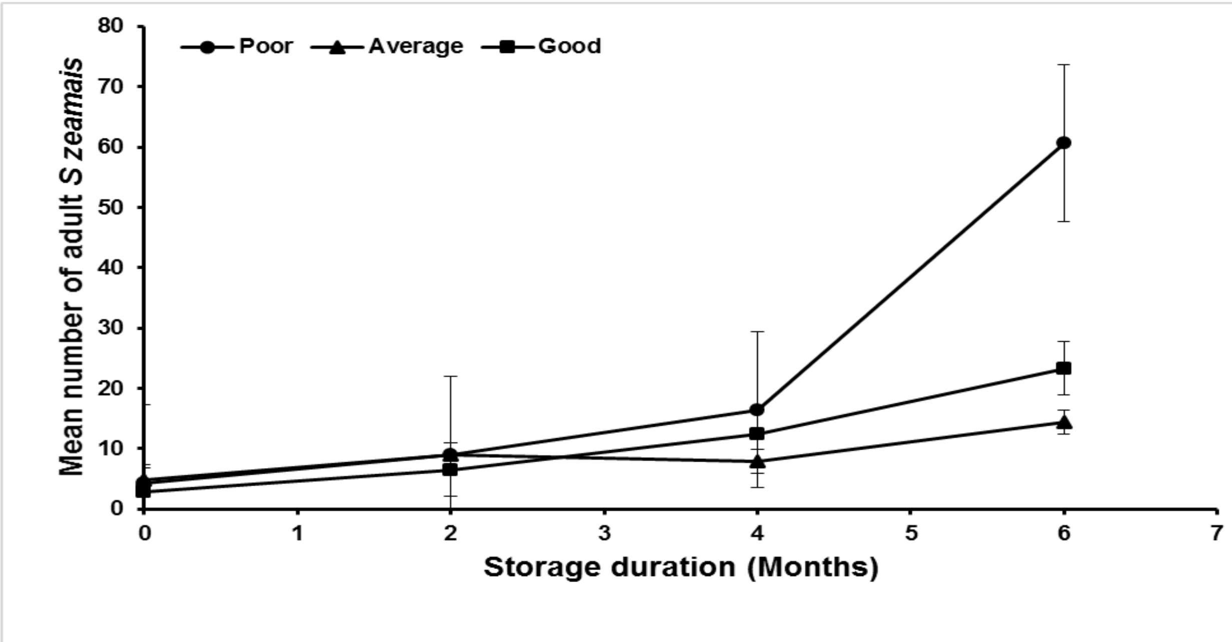

Figure 13: Total population of *Sitophilus zeamais* in 125 grams of maize sampled from maize stored in storage structures characterized by poor (●), average (▲) or good (■) hygiene practices during different sampling regimes.

Error bars represent standard error of the mean; Sampling was conducted between April and October 2017 in Njoro and Rongai sub Counties, Nakuru County

4.8 Effect of hygiene on grain damage and weight loss

At the commencement of trial, damage levels averaged 2.2 ± 0.5% (Table 13). At this point, the proportion of damaged grain across storehouses characterized with different hygiene levels was not significantly different ($\chi2$ (2) = 3.98, p = 0.136). Samples collected from storehouses characterized by poor hygiene after two and four months of storage were associated with significantly higher damage (F = 7.97; df = 2, 37; P =0.001 (2 months) and ($\chi2$ (2) = 8.49, p = 0.014 (4 months) compared to those collected from stores that were either hygienic or averagely hygienic. Contrastingly, there was no significant difference in damage levels across the different hygiene categories for samples collected at the sixth month of storage ($\chi2$ (2) = 5.72, P = 0.057). Interaction between damage levels and storage duration were highly significant ($\chi2$ (3) = 59.20, P<0.001). Particularly, damages recorded from the second month onwards were significantly higher than those of samples collected at the commencement of trial.

At the commencement of trial, average weight loss across all the storehouses sampled averaged 2.1 ± 0.4 g/125g of maize. At this point, losses incurred in storehouses characterized by different hygiene levels were not significantly different ($\chi2$ (2) = 4.25, P = 0.120). From the second month onwards, a distinct pattern with reference to the proportion of weight lost was observed; Storehouses characterized by poor hygiene experienced significantly higher losses compared to those observing good hygiene practices. Nevertheless, losses experienced in averagely hygienic stores throughout the storage period were not significantly different from either hygienic or unhygienic stores ($\chi2$ (2) = 7.42, P = 0.024 (2 months); ($\chi2$ (2) = 6.84, P = <0.033 (4 months) and ($\chi2$ (2) = 7.79, P = <0.020 (6 months). Just like in the case of damages, interaction between weight loss and storage duration were highly significant ($\chi2$ (3) = 58.49, P<0.001). Notably, weight losses accrued after the second month of storage were significantly higher than those of samples collected at the commencement of trial.

Table 13: Percentage of insect damaged grain and subsequent weight loss in maize sampled from stores characterized by good, average or poor hygiene in Njoro and Rongai sub Counties, Nakuru County

	Duration of storage (Months)			
	0	2	4	6
Damaged grain (%)				
Good	1.0 ± 0.4a	3.5 ± 0.8a	7.2 ± 2.6a	10.1 ± 2.7a
Average	2.3 ± 0.5a	5.6 ± 1.0a	9.3 ± 2.2a	19.0 ± 3.5ab
Poor	3.1 ± 1.3a	11.9 ± 2.2b	23.9 ± 4.4b	34.1 ± 8.1b
Weight loss (%)				
Good	1.0 ± 0.4a	2.7 ± 0.6a	5.8 ± 1.9a	7.4 ± 1.4a
Average	2.1 ± 0.4a	4.7 ± 0.8ab	7.9 ± 1.6ab	13.2 ± 1.9ab
Poor	2.8 ± 1.1a	7.6 ± 1.3b	13.7 ± 1.9b	22.2 ± b

Data are means ± standard error. Means in the same category within a column followed by the same letter are not significantly different (P > 0.05). Means were separated using Tukey's HSD or Kruskal-Nemenyi test.

4.9 Effect of demographic characteristics and storage hygiene practices on actual grain loss levels

The fractional response model (Table 14) estimated the correlations between the actual quantity loss caused by insect pests and the demographic characteristics of farmers and their practices. The measured losses were 5.9 ± 3.8% (range: 1 –14.5%) over an average period of 5.6 ± 1.6 months (range 3–7 months). The marginal effects measure the impact of a level change in an explanatory variable; all others held constant. Women-managed stores were associated with significantly lower losses by 2.8 percentage points than men managed stores. Likewise, farmers older than 24 years experienced significantly higher losses than their younger counterparts (<24 years) by a similar margin. However, the farmers with maize farming experience exceeding twenty years incurred significantly lower losses by a margin of 4.3 percentage points compared to farmers who had experience of less than twenty years, while training in storage did not have a significant effect on the level of losses. Farmers who bagged and stored the produce in the bedroom or living room experienced lower losses by 2.8 and 4.6 percentage points, respectively, compared to those who stored in granaries. Farmers storing in the kitchen risked higher losses by a margin of 19% compared to those who stored in granaries. Storing in woven bags or hermetic containers (bags or silo) resulted in similar loss levels. Moreover, the actual length of storage, which varied between 3–7 months, was not significant. Storing maize together with other food or non-food items resulted in higher losses by 2.7 percentage points compared to storing separately. On the contrary, inspecting and repairing the store before storage or disinfesting the store before storage were not significant. Farmers' whose stores received a higher hygiene score, however, had significantly lower losses (P = 0.043).

Table 14: Effect of farmers socio-economic characteristics, storage and hygiene practices on the magnitude of actual losses (n = 40) in shelled maize during storage in Njoro and Rongai sub Counties, Nakuru County

Variables	Estimated coefficient (SE)	Marginal effect (SE)
Socio-economic characteristics		
Gender (*dummy = 0 if male; dummy =1 if female*)	-0.516 (0.258)**	-0.028 (0.015)*
Age (*dummy =0 if age is 18 to 24 years; dummy =1 if age > 24 years*)	0.560 (0.198)***	0.028 (0.100)***
Education level (*dummy = 0 if no formal education or not gone primary education; dummy =1 if attended secondary school or tertiary education*)	-0.104 (0.186)	-0.005 (0.010)
Experience in maize farming (*dummy = 0 if ≤ 20 years; dummy =1 if > 20 years*)	-0.961 (0.241)***	-0.059 (0.017)***
Received training in grain storage protection (*dummy =0 if no; dummy =1 if yes*)	0.001 (0.203)	.000 (0.011)
Storage practices		
Location of storage device (*Granary = base category*)		
Bedroom	-0.637 (0.244)***	-0.028 (0.009)**
Special room	-0.061 (0.260)	-.003 (0.014)
Kitchen	1.676 (0.271)***	0.190 (0.050)***
Living room	-1.379 (0.699)**	-0.046 (0.014)***
Storage devices (*dummy = 0 if ordinary polypropylene bag; dummy = 1 if hermetic bag or metal silo*)	0.286 (0.331)	0.016 (0.021)
Storage duration (months)	0.078 (0.053)	0.004 (.002)
Farmer examined and repaired store before storage (*dummy = 0 if no; dummy =1 if yes*)	-0.379 (0.237)	-0.020 (0.013)
Store treated with protectants before grains introduced (*dummy = 0 if no; dummy =1 if yes*)	-0.252 (0.211)	-0.013 (0.011)
Co-storage with other products (*dummy = 0 if no; dummy =1 if yes*)	0.637 (0.305)**	0.028 (0.011)**
Hygiene score	-0.129 (0.067)**	-0.007 (0.003)**
Constant	-2.617 (0.553)	
Wald $\chi 2$ (25)	302.36	
P- value	<0.0001	

SE: Robust standard errors; *** $P < 0.01$, ** $P < 0.05$, *$P < 0.1$

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

Clean produce is the first line of defense for effective protection during storage. The present findings show that farmers who sorted out damaged maize as well as those who removed foreign matter before storage incurred significantly lower losses compared to those who did not. The proportion of farmers who sorted damaged and rotten cobs and that of farmers who dried maize before storage was equal. This may imply that sorting of cobs was done during the drying period. The high proportion of farmers who sorted out moldy grain suggests delayed harvesting which encouraged rotting as harvesting coincided with onset of short rain season. It could also be related to the maturing characteristics of cultivated varieties. Although the effect of sorting on mycotoxin levels was not determined, previous studies have shown that the practice of sorting out damaged, moldy and discoloured kernels could result in reduction of aflatoxin levels by 40-80% (Park, 2002; Fandohan *et al*., 2005) and fumonisin by 57% (Pearson *et al.*, 2010).

It was also found that shelling of maize cobs was done predominantly by use of machines. While use of motorized or manually operated machines reduces breakage and scouring of grain, incorrect setting of the machines and shelling of inadequately dried cobs could lead to higher proportion of broken or externally damaged grains, which could facilitate fungal infection (Fandohan *et al*., 2006).

Use of bags (polypropylene, improved hermetic, jute or sisal) was the predominant mode of grain storage. This could be attributed to flexibility, ease of movement, inspection and ease of sale offered by bag storage (Hodges, 2004). However, use of woven polypropylene bags was more prevalent compared to other types of bags. The woven polypropylene bags popularity may be explained by low price and that they are readily available (Mwangi *et al*., 2017). Although quality deterioration when polypropylene bags are used was not determined, spoilage resulting from accumulation of heat and moisture from grain respiration has been documented (Hodges and Farrell, 2008).

The study demonstrated that use of modern storage technologies like hermetic storage was not popular. Of the hermetic technologies, bag usage was more commonly practiced compared to metal silos. The difference in preference of these technologies by smallholder farmers could be explained by the initial high cost of metal silos (Tefera *et al.*, 2011a). Hermetic bag usage reported in this study (8.3%) compares closely with the frequency (7%) reported for smallholder cereal farmers in eastern Kenya (Njoki *et al.*, 2018). The improvement in adoption rate of hermetic storage bag technology could be attributed to the intensive promotion campaigns over the past few years (Kimenju and De Groote, 2010; Tefera *et al.*, 2011a), favorable cost, elimination of pesticide use and compatibility with existing bag storage practice (Foy and Wafula, 2016). However, unlike metal silos, hermetic bags do not offer protection against rodents. Several rodent destroyed hermetic bags were encountered during the survey. Rodent damage interferes with the hermetic properties rendering the bag unusable (Ndegwa *et al*., 2016). The affected farmers therefore lost the initial capital incurred in purchase of the bags. Good hygiene practices such as clearing storehouse surrounding, regular inspection and use of rat guards (Edoh Ognakossan *et al.,* 2016) can help regulate rodent population thereby increasing the efficiency of hermetic bags.

Whereas majority of the farmers kept bagged grain in granaries, there was a marked tendency to store bagged grain either in a store room in the house or bedroom. The practice of storing grain in dwelling houses could be attributed to widespread theft (Bunei and Rono, 2014). However, dwelling rooms are not purposively constructed for grain storage and the poor aeration within the rooms may promote proliferation of molds if grains are inadequately dried. Some storage structures have been found to provide more conducive environment for fungal proliferation and mycotoxin production (Hell *et al.,* 2000). For instance, Maina *et al*. (2016) reported high population of *Aspergillus* species in stored maize. They attributed this occurrence to widespread use of polypropylene bags as well as storage in dwelling houses.

The current study revealed that most farmers swept and sprayed their stores with Actellic® super dust before loading newly harvested grain. Dust formulations are contact insecticides labelled for direct application to stored maize and are not effective in treatment of empty structures (Hagstrum *et al.,* 2012). In a study elsewhere, significantly lower insect densities were recorded in wheat samples collected from bins that had been cleaned preceding grain filling compared to those that had not (Reed *et al.,* 2003).

At the beginning of the trial, moisture content across stores distinguished by different hygiene levels exhibited slight variations but was within the recommended moisture level for safe storage of grain (i.e. below 13.5%). Moisture content of maize stored under unhygienic and moderately hygienic conditions increased with storage duration. The woven polypropylene bags used by majority of the farmers are incapable of maintaining good moisture barrier properties and therefore, they predispose stored grain to fluctuations in moisture content (Ng'ang'a *et al.*, 2016). Marginal moisture losses were observed in grain stored under hygienic conditions whereas marginal gains were observed in stores where moderate hygiene practices were observed. However, in stores associated with poor hygiene practices, significant increase in moisture content throughout the trial period was observed. Mean moisture levels rose above the recommended 13.5% for safe storage of maize in stores characterized by poor hygiene beginning the fourth month of trial. Moisture content of stored grain can change with variations in humidity and temperature (Angelovič *et al.,* 2018). Increase in moisture to such high levels can result into rapid deterioration by promoting growth of molds and insects (Ekechukwu and Norton, 1999). Significant increase in moisture to unsafe levels during storage can lead to loss of grain that was otherwise deemed safe for storage. Observations of increase in moisture levels in stored grain have been made in other studies (Compton *et al.,* 1998; Njoroge *et al*., 2014; Likhayo *et al.,* 2016). The rise in moisture content would also have been occasioned by heavy insect infestation (Njoroge *et al.,* 2014) or heavy fungal proliferation (Compton *et al.,* 1998).

Respiration by insects produces heat and moisture, which promote growth of microorganisms which in turn undergo respiration producing additional moisture. Braga-Caneppele *et al.* (2003) investigated the effect of different infestation levels on the physical, physiological and sanitary conditions of stored maize. They observed that increase in infestation levels was accompanied with proportional increases in the moisture content of the stored grain. These results demonstrate the effect of metabolic activity of insects on moisture content of grain.

Insects may also contribute to increase in moisture by exposing the endosperm as they feed on the grain. Endosperm exposure promotes moisture absorption by hygroscopic carbohydrates. Brewbaker (2003) emphasised the significance of the role played by moisture in storage of grain. He observed that when grain has more moisture, respiration by living organisms within the grain (insects and molds) and thermal heat produced by the grain itself enhance water vapour production leading to further deterioration of grain (Hagstrum *et al.*, 2012). Such observations point to the need for regular grain monitoring and inspection.

In the current study, incidence of mold from grain sampled at harvest was high. Similar observations have been made elsewhere (Ng'ang'a *et al.*, 2016; Maina *et al.*, 2017). Maina *et al*. (2017) attributed high *Fusarium* infections at the beginning of storage to pre-harvest infections, improper drying as well as unhygienic handling conditions. Incidence of *Aspergillus* spp., as well as Aflatoxin levels were significantly higher in unhygienic and moderately hygienic stores four months after commencement of trial. Maize in these stores was mostly stored alongside other grains. Other grains stored together in the same store could be a source of spores that contaminate newly harvested maize. Fungal cross contamination and higher aflatoxin levels in maize stored together with sorghum or cowpea have been reported (Hell *et al.,* 2000). High *Aspergillus* and aflatoxin levels in unhygienic stores could also have resulted from failure to isolate damaged and moldy grain. Studies have shown that separation of moldy and discoloured kernels could result in reduction of aflatoxin in stored grains (Park, 2002; Fandohan *et al*., 2005). Failure to clean and dust the stores before loading the grain could be another source of high mold infection contributing to high aflatoxin levels in unhygienic stores. Tangni and Pussemier (2011) investigated the impact of dust on contamination of stored wheat with mycotoxins. They found that incorporation of grain dust in stored wheat contributed to increase in concentration of mycotoxin. They attributed the increase on the dust that had settled from previous storage acting as a contaminant and a source of inoculum (Tangni and Pussemier, 2011).

Percentage of samples possessing aflatoxin levels beyond the threshold set by the Kenya Bureau of Standards (KEBS) increased throughout the storage duration. At the beginning of the trial, 15% of tested samples had aflatoxin levels beyond the 10 ppb threshold. High levels of aflatoxin concentration at the beginning of storage may point to field contamination. Such high levels of aflatoxin in stored maize portend a problem to millers and consumers since aflatoxin is not destroyed by cooking or grinding of contaminated maize. In a survey of aflatoxin and fumonisin contamination in milled maize samples in western Kenya, aflatoxin contamination was detected in 49% of samples and was above the regulatory (10 ppb) in 15% of the samples (Mutiga *et al.*, 2015). Consequently, animals that feed on contaminated grains can accumulate the toxin and pass it on to people through products such as milk, eggs and meat.

Samples collected at the beginning of the trial had relatively high *S. zeamais* infestations. This may point to the possibility of infestations beginning in the field since *S. zeamais* attacks maize in the field or before storage (Golob and Hanks, 1990). High initial infestations in the field lead to higher subsequent infestations in storage (Demissie *et al.,* 2008). Good storage hygiene practices mostly target exclusion of pests that may be harbored in the stores before or during the course of storage. These initial infestations therefore cannot be controlled even by adherence to recommended hygiene practices. This implies that good hygiene practices cannot be relied on solely for protection of maize against insect pests. A broad integrated insect control strategy that includes hygiene as part of its IPM should be adopted if meaningful reductions in postharvest losses are to be realized.

This study reported significant increase in population of *S. zeamais* throughout the storage duration. However, it took a shorter duration for the population of *S. zeamais* to increase significantly in stores characterized by poor hygiene practices compared to other hygiene levels. A probable reason behind the explosion could be failure to clean the storehouses by most farmers whose stores were categorized as poorly hygienic. Reed *et al.* (2003) compared insect populations in bins that had been cleaned before grain filling vis-a-vis those that had not been cleaned. Newly stored wheat from discharge sprouts was sampled from the bins. They found mean insect densities to be significantly lower in bins that had been cleaned before being filled with wheat. Failure to clean grain residues from the stores once grain is depleted provides the insects with food as they await the new harvest to be loaded. Availability of food may help insects survive insecticide exposure even under application of store disinfestants. Additionally, in unclean stores, application of store protectants may not provide effective insect control because the dirt, dust and grain remnants may absorb the applied insecticide and very little is available for insect contact (Toews and Subramanyam, 2002).

This study has revealed significantly higher weight loss and insect damage in stores exhibiting poor hygiene practices compared to those where good hygiene practices are adhered to. The increase in weight loss and damage over storage duration corresponds to increase in insect population. The rapid overall increase in insect population and subsequent weight loss indicate that low initial infestations can result into economically important weight losses over a short duration of storage. Results from this study revealed that farmers stored shelled maize grain with varying degrees of foreign and inorganic material. This is despite the fact that majority of the farmers reported cleaning their grain before storage. The result may point to use of ineffective grain cleaning methods. Levels of foreign material continued to increase throughout the storage duration presumably due to feeding activity of insect pests. Feeding by insects produces flour consequently increasing the proportion of foreign material. Tefera *et al.* (2011b) reported flour production by *P. truncatus* and *S. zeamais* after 90 days of storage. Similar results were reported by Bbosa, (2014). High levels of foreign material are associated with increased rates of mold proliferation. Sone, (2001) found the amount of broken corn and foreign material to significantly affect the final infection levels of *Fusarium verticillioides* in maize stored at 13% and 16% moisture content after 80days of storage. This may have resulted from grain heating associated with increased foreign matter content.

The proportion of broken kernels recorded throughout the storage trial was within the acceptable levels. The low degrees of broken kernels may point to the decreased damage associated with machine threshing which was the preferred mode of shelling among farmers from whom maize was sampled.

Majority of the farmers did not practice sorting of damaged grains before storage. This could have been be responsible for the high proportion of rotten, diseased and discolored grain from samples collected at commencement of trial. Further, continued increase in the percentage of rotten, diseased and discolored grain could have resulted from mycelia of contaminating fungi (Chuck-Hernández, 2012). Likhayo *et al.* (2016) reported marginal increases in percentage of discolored grain and attributed the increase in discoloration to high storage moisture and temperature among other factors.

Farmers experienced storage problems mainly from insects and rodent infestations that resulted in perceived loss estimated at 7.2%. There were no differences in losses due to insects (3.9%)

and those due to rodents (3.3%). This was in contrast with significantly higher insect losses reported by Edoh Ognakossan *et al.* (2016). Most farmers who stored grain in dwelling houses cleaned the rooms weekly which suggested that good hygiene practices were observed. On the contrary, granaries were mostly cleaned every six months indicating that satisfactory hygiene practices were not achieved.

Contrary to expectations, disinfestation of the store prior to introducing the new harvest did not lead to lower losses. Mwangi *et al*. (2017) reported a similar observation in off-farm stores. A plausible reason is that the majority of the farmers used dust-based insecticides to disinfest their granaries or store rooms. These insecticides do not penetrate into the cracks and crevices. Hence, adult insects, larvae, or eggs hidden in these places escape insecticide exposure (Toews and Subramanyam, 2002). A further explanation may be related to the nature of the surfaces. According to Gwinner *et al.* (1996), the activity of insecticides on dirty surfaces tends to be short-lived irrespective of the formulations or the active ingredient. The potency of residual insecticides applied to wood, brick, or concrete attenuates within a short time due to the absorptive capacity of these surfaces (Jankov *et al.*, 2013). Morrison *et al.* (2019) reviewed the effects of sanitation on chemical control of insect pests and found a 1.3–fold reduction of efficacy of grain protectants in low sanitation conditions. The efficacy reduction was 11–fold for residual insecticides and 1.6–fold for passive methods such as hermetic storage. Hence, while store disinfestation is a good practice, cleaning the store before, would enhance the efficacy by removing dust and debris that bind or dilute the disinfectant, besides directly reducing carry-over of pests from the previous season. Findings elsewhere showed significantly lower losses by 3.1 percentage points for farmers who disinfested their store prior grain storage in Tanzania (Chegere, 2018). The nature, formulation, or ingredients of the chemicals used for disinfestation were, however, not expounded on.

Storing bagged maize in the bedroom or living room was associated with lower actual (measured) losses by margins of 2.8 and 4.6%, respectively, compared to storage in granaries. However, the storage of the bagged grain in the kitchen was associated with significantly higher losses by a margin of 19 percentage points. The warmer temperature and higher relative humidity in the kitchen environment, which would favor insect proliferation (Throne, 1994), are possible reasons for this observation. Co-storing maize with other farm produce and equipment resulted in significantly higher losses by a margin of 2.8%. Whereas the majority of storage insects prefer to attack particular grain types, most insects can feed on different types of grains (Golob, 2009). However, the co-storage of produce with other farm implements and products such as hay, onions, potatoes, old bags, and clothes would also encourage pest harborage and make store cleaning operations difficult and ineffective. The practice may contaminate the new harvest or create favourable conditions for pests and pathogens to thrive, e.g., commodities such as onions and potatoes can increase the humidity in storage spaces. Some authors (Hell *et al.*, 2000), for instance, reported higher aflatoxin levels in maize stored together with sorghum or cowpea.

The use of either ordinary polypropylene bags or improved air-tight containers (bags or metal silos) did not result in different loss levels. Chegere (2018) reported similar findings. Hermetic containers such as the purdue improved crop storage (PICs) bags suffocates and dehydrates weevils by maintaining a good air barrier between the bag and the surrounding environment (Obeng-Ofori, 2011). Respiration from storage insect pests causes a decrease in oxygen levels and a corresponding increase in levels of carbon dioxide leading to suffocation and dehydration of pests (Navarro *et al*., 1994). When oxygen levels become sufficiently low, pests in the bag stop feeding, become inactive, and eventually die of asphyxiation (Moreno-Martinez *et al*., 2000) or desiccation (Murdock *et al.*, 2012).

Although the hermetic technologies are effective in protecting stored maize against insect pests in East Africa (Tefera *et al.,* 2011a; Ng'ang'a *et al.,* 2016), their usefulness depends on the farmers' ability to seal them in a manner that ensures sustained hermeticity. During this survey, hermetic devices in the majority of farmers' stores were either left open, improperly sealed, or were damaged. Many of the farmers who used ordinary polypropylene bags applied pest control measures, including insecticides, wood ash, plant leaves, sieving or exposing the grain to sun. The appropriate application of insecticides in particular, is equally as effective against storage insect pests as hermetic containers (Abass *et al.,* 2018). A higher hygiene score was associated with lower losses by a margin of 1%. Thus, storing clean produce in externally and internally, well-maintained clean stores contributed to lower pest infestations by limiting the shelter, food, and chances of development. These practices, together with improved postharvest storage technologies, should be encouraged as part of better pest management in farmers' stores.

Finally, this study revealed that socio-economic factors influenced the implementation of proper postharvest practices in farm stores. The stores of households in which women were responsible for making majority of the decisions on postharvest handling activities were associated with lower actual losses. From a sanitation and hygiene point of view, women play a greater role in the household and may, therefore, attend better to storage hygiene practices. Moreover, lower losses were associated with more experience in maize farming (> 20 years), suggesting that farmers mastered better techniques over time to manage storage pests. These findings agree with the observations of an earlier study (Edoh Ognakossan *et al.*, 2016). In contrast, the younger farmers in the present study incurred significantly lower losses. One possible reason is that the stores owned by the younger farmers are quite pristine and devoid of years of pest accumulation. Other authors (Midega *et al.*, 2016) also reported a trend where young farmers seem to be abandoning traditional storage methods in favor of modern ones partly due to a lack of knowledge and ability to construct and manage traditional structures. These findings highlight the need for integrating greater understanding of the socio-economic perspectives into interventions targeting the protection of stored produce in farm stores.

5.2 Conclusion

The findings of this study revealed that majority of the smallholder farmers in Nakuru County mostly harvested, dried and threshed their maize grain using mechanical threshers. Threshed grain was then loaded into polypropylene bags and stored in granaries or rooms within the dwelling house. Adherence to the recommended storage hygiene practices varied among the surveyed farmers. Majority of the farmers cleaned and disinfested their storehouses preceding grain storage. However, farmers mostly used traditional and ineffective cleaning and disinfestation methods. These methods fail to accord requisite protection to the stored grain resulting in gradual increase in pest and pathogen population throughout the storage period.

Insect pests; primarily *S zeamais*, storage molds from genera *Fusarium*, *Aspergillus* and *Penicillium* and aflatoxin contamination were detected at the onset of grain storage. Presence of aflatoxin contamination at the onset of storage and its subsequent increase throughout the storage duration implies the risk of long term exposure among unsuspecting maize consumers. Long term consumption of aflatoxin contaminated maize can cause impaired immune functions, malnutrition and stunted growth in children. Moreover, storage problems arising from fungal infection, aflatoxin contamination and pest infestation threaten food and nutritional security for smallholder farmers in sub Saharan Africa. An important economic driver would be sensitization of farmers on the importance of growing the right maize varieties as a measure to preventing pre-harvest insect pests, molds and aflatoxin contamination.

Failure to adhere to good hygiene and postharvest handling practices contributed to higher pest populations, mold infection and aflatoxin contamination. Adherence to recommended hygiene practices can create unfavorable conditions for mold proliferation, consequently lowering the rate of aflatoxin accumulation. Application of good hygiene practices at the onset of storage can help retard pest and mold populations even before more robust control measures are initiated. These practices, together with the new effective postharvest storage technologies should form part of a joint integrated pest management (IPM) strategy for mitigation of postharvest losses.

5.3 Recommendations

Based on the findings of this study, the following are recommended:

i. Farmers and Extension Officers should be trained on good storage hygiene practices and their contribution to effective grain storage.
ii. Future research should investigate the differences in levels of grain damage when various threshing methods are used.
iii. The importance of drying grain adequately before storage and subsequently monitoring the moisture levels during storage should be emphasized.
iv. Investigation of the conditions of the stores at the period between harvest depletion and loading of new harvests could provide insightful information on the cycle of storage fungal pathogens and insect pests in the absence of grain.
v. Future research where experimental storehouses adhering to recommended hygiene conditions and devoid of other control measures are set up on-farm could shed more light on the actual role played by hygiene in stored product protection.

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APPENDICES

Appendix I: Questionnaire on maize farmers' storage hygiene practices in Nakuru County, Kenya

01. Questionnaire No:	
02. Interviewers' Name:	
03. Date:	
04. County:	
05. Sub County	
06. Location:	
07. Village:	
08. GPS coordinates:	______________________ ______________________
09. Altitude:	______________________M

I. Demographic and socio-economic characteristics of the farmers.

1. Name of the Farmer ____

2. Phone Number ____

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

4. Age range (in years)

   (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 [ ]

   (4) Completed tertiary education [ ]

6. For how long have you been practicing maize cultivation?

   (0) 1— 5 Years [ ]

   (1) 6— 10 Years [ ]

   (2) 11 — 15 Years [ ]

   (3) 16 — 20 Years [ ]

   (4) Above 20 Years [ ]

II. Grain harvesting condition and storage practices.

7. How do you usually know that your maize is ready for harvesting?

   (0) Calendar (time of the year) [ ]

   (1) When leaves dry up [ ]

(2) When dry cobs and husks droop [ ]

(3) When kernels cannot be scratched by a fingernail [ ]

(4) When the husks dry up completely [ ]

(5) Others, specify ____

8. How do you harvest your maize?

(0) Cutting the entire stalk [ ]

(1) Harvesting husked cobs [ ]

(2) De husking before harvesting [ ]

(3) Bending the stalk upside down to let it dry completely before harvesting [ ]

(4) Others, Please list ____

8.1 Why do you harvest this way?

(0) To prevent insect attack [ ]

(1) To dry the cobs completely [ ]

(2) To give time for land preparation [ ]

(3) Others, please list ____

8.2 How long did the harvesting process take? ________________________(in weeks)

9. How many maize growing seasons do you have?

(0) One [ ] / (1) Two [ ]

10. Did you sort out damaged cobs after harvesting?

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

If yes,

10.1 What is your sorting criterion?

(0) Color [ ]

(1) Cob size [ ]

(2) Grain size [ ]

(3) Physical damage [ ]

(4) Others, specify ____

10.2 What types of damage do you sort out?

(0) Insects [ ]

(1) Molds (discoloration) [ ]

(2) Rodents [ ]

(3) Birds [ ]

(4) Others, specify ____

10.3 What did you do with the damaged maize cobs?

(0) Threw them away [ ]

(1) Fed them to livestock [ ] Which animals __________________________

(2) Consumed them [ ]

(3) Sold them [ ]

(4) Others, specify ____

11. Did you dry your maize before storage?

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

If yes,

11.1 Where did you dry your maize before storage?

(0) Field [ ]

(1) Homestead [ ]

(2) Both [ ]

(3) Others, specify__________________________________

11.2 In which form did you dry your maize before storage?

(0) As cobs in the husks [ ]

(1) De husked cobs [ ]

(2) Only shelled maize grain [ ]

(3) Both cobs and shelled maize grain [ ]

11.3 What did you use to dry your maize before storage?

(0) Sun [ ]

(1) Fire [ ]

(2) Mechanical dryers [ ]

(3) Others, please list ___________________________________

11.4 Where did you place your maize grain to dry?

(0) On bare earth [ ]

(1) On tarpaulins [ ]

(2) Concrete drying floor [ ]

(3) On other drying platforms [ ] Please list _________________________

11.5 How long did your grain take to dry up and be ready for storage?

(0) Less than one week [ ]

(1) 2-3 weeks [ ]

(2) 3-4 weeks [ ]

(3) More than four weeks [ ]

11.6 How were you able to ascertain that your grain is completely dry?

(0) Cannot be scratched by fingernail [ ]

(1) Sound made by dry maize when shaken on the palm [ ]

(2) Produces a cracking sound when chewed [ ]

(3) Moisture meter [ ] Reference moisture value ____________________

Brand of the meter ____

12. Did you isolate any kind of damaged cobs after drying? (NB: *for farmers who dry cobs or a combination of cobs and shelled grains only*)

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

If yes,

12.1 What were your sorting criteria?

(0) Color [ ]

(1) Cob size [ ]

(2) Grain size [ ]

(3) Physical damage [ ]

(4) Others, please list ____

12.2 What types of damage did you sort out?

(0) Insect [ ]

(1) Mold (Discoloration) [ ]

(2) Rodent [ ]

(3) Birds [ ]

(4) Others, specify ____

12.3 What did you do with the damaged cobs?

(0) Threw them away [ ]

(1) Fed them to the livestock [ ] Which Animals ________________________

(2) Consumed them [ ]

(3) Sold them [ ]

(4) Others, specify ____

13. How did you separate grains from the cobs (threshing)?

(0)Use of hands alone [ ]

(1) Beating bare cobs with clubs [ ]

(2) Beating the cobs with clubs in a sack [ ]

(1) Using threshing machines [ ]

(2) Others, Specify ____

14. Did you remove excess particulate matter from shelled maize grain before storing?

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

If yes,

14.1 What types of particulate matter did you remove from the shelled maize grain?

(0) Weed seeds [ ]

(1) Chaff [ ]

(2) Sand [ ]

(3) Dust [ ]

(4) Others, please list ____

14.2 What mechanism did you use to remove the particulate matter from the grain?

(0) Sieving [ ]

(1) Winnowing [ ]

(2) Removing with hands [ ]

(3) Others, specify ____

15. Did you remove any other materials that remained in the maize grain after sieving and/or winnowing?

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

If yes,

15.1 What other materials did you encounter in the maize grain?

(0) Stones [ ]

(1) Shriveled grains [ ]

(2) Wild seeds [ ] Please list ______________________________

(3) Broken or cracked maize kernels [ ]

(4) Other edible grains [ ] Please list _________________________

(5) Others, please list ____

15.2 What mechanism did you use to remove these materials from the maize grain?

(0) Hand picking [ ]

(1) Sieving [ ]

(2) Others, please list ____

16. Did you experience/notice moldy (discolored) shelled kernels before storage?

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

If Yes,

16.1 What did you do to discolored kernels?

(0) Stored them together with other sound grain [ ]

(1) Sorted them out from the batch of the sound grain [ ]

16.2 In case you sorted the moldy grain out, what did you do with them?

(0) Consumed them [ ]

(1) Burnt them [ ]

(2) Buried them [ ]

(3) Gave them to livestock [ ] Specify the animal(s) _______________________

(4) Others, please list ____

17. Did you remove old grain from previous maize harvests before introduction of maize from the current harvest?

    (0) Removed old stock of grain [   ]

    (1) Stored the new and the old stock together [   ]

    (2) Old stock was depleted at the time of storage [   ]

III. Storage structures for shelled maize.

18. What storage structure do you use to store your shelled grain?

(0) Bags [ ]

a) Specify the bag type ;

(0) Ordinary polypropylene [ ]

(1) Jute or sisal [ ]

(2) Both poly and sisal/jute [ ]

(3) Improved Hermetic [ ] Specify the brand ______________________________

(1) Metal grain silo [ ] Specify the brand ____________________________________

(2) Plastic grain silo [ ] Specify the brand ____________________________________

(3) Drums [ ]

(4) Directly on the floor in the room [ ]

(5) Directly on the floor in the Granary [ ]

(6) Others, please list ____

19. Do you use new bags for each new seasons harvest or do you recycle bags that had stored previous season's harvest?

(0)Recycles bags [ ]

(1) Uses new bags for each harvest [ ]

(2) Uses both new and recycled bags [ ]

20. If you recycle bags, do you treat them before loading them with new maize grain?

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

If yes,

20.1 What do you use to treat the bags before loading them with maize?

(0) Chemicals [ ] Specify the chemical _________________________________

(1) Put them in boiling water [ ]

(2) Others, specify ____

21. After putting grains in the bags, in which place do you store the bags?

(0) Living room [ ]

(1) Bed room [ ]

(2) Kitchen [ ]

(3) Special store room [ ]

(4) Granary [ ] Specify the type _______________________________________

(5) Others, please list ____

22. Do you place your bags on pallets, tarpaulins or other raised platforms?

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

23. What quantity of grain (in 90 Kg bags) can your storage structure hold? _____ Bags.

24. For how many month(s) do you store your maize grain before the stock is completely exhausted?

(0) Less than one month [ ]

(1) Between one and two months [ ]

(2) Three to four months [ ]

(3) Four to five months [ ]

(4) Six months and above [ ]

25. What material did you use to construct your storage facility?

<u>Granary</u>

Wall:

(0) Wood [ ] / (1) iron sheets [ ] / (2) Mud [ ] / (3) Concrete [ ] /

(4)Others, specify____

Roof:

(0) Thatch [ ] / (1) Iron sheet [ ] / (2) Concrete [ ] /

(3) Others (specify)____

Floor:

(0) Mud [ ] / (1) Concrete [ ] / (2) wood [ ] /

(3) Others, specify ____

Room

Wall:

(0) Wood [ ] / (1) Iron sheets [ ] / (2) Mud [ ] / (3) Concrete [ ] /

(4)Others, specify____

Roof:

(0) Thatch [ ] / (1) Iron sheet [ ] / (2) Cemented slab [ ] /

(3) Others (specify)____

Floor:

(0) Earthen [ ] / (1) Cemented [ ] / (2) wood [ ] /

(3) Others, specify ____

26. Do you store other products together with shelled maize grain?

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

If yes above,

26.1 What else do you store together with shelled maize grain?

(0) Straw [ ]

(1) Animal Feeds [ ]

(2) Empty sacks [ ]

(3) Empty Containers [ ]

(4) Agrochemicals (pesticides and fertilizers) [ ]

(5) Other grains [ ] Please list ____

(6) Others, Please list ____

IV. Hygiene and Sanitation.

27. Did you clean the storehouse (cribs, granaries, living room, others) before storing the new harvest?

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

If yes, describe how the cleaning was done? (Narrative)

____

____

28. Did you treat your storehouse with any protectant(s) before introducing the new harvest?

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

If yes above, what protectant(s) do you use?

Narrative ____

29. Did you clean the storehouse after the new harvest had been stored?

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

If yes,

29.1 How do you clean your storehouse?

(0)Sweeping [ ]

(1) Dusting [ ]

(2) Mopping [ ]

(3) Others, Specify ____________________________

29.2 How often do you clean the store?

(0) Daily [ ]

(1) Weekly [ ]

(2) Once after every 2 weeks [ ]

(3) Monthly [ ]

(4) Others, Specify ____

30. Did you clean your handling equipment before using them to handle newly harvested maize?

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

30.1 1 If yes, how did you go about it?

(0) Washing [ ]

(1) Disinfecting [ ]Specify the disinfectant ___________________________________

(2) Dusting [ ]

(3) Others, Specify____

31. Do you clean the following hard to reach surfaces;

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

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

(2) Below the pallets or beneath other raised platforms. (0) No [ ] / (1) Yes [ ]

32. Do you remove the dust accumulating around the walls of the storage facility?

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

33. Is your storehouse fitted with a mechanism to facilitate aeration? (0)No [ ] / (1) Yes [ ]

33.1 If yes, what form of aeration do you deploy?

(0) Natural [ ]

(1) Forced [ ]

(2) Both (Natural +Forced) [ ]

34. Do you inspect the stored maize grain for÷

(0) Insect proliferation [ ]

(1) Mold contamination [ ]

(2) Rodent infestation [ ]

(3) Spillages [ ]

(4) Others, please list ____

34.1 If yes, how often do you do so?

(0) Daily [ ]

(1) Weekly [ ]

(2) Once every two weeks [ ]

(3) Monthly [ ]

(4) Others, please list ____

34.2 In case you encounter insect damage/mold proliferation, what action do you take?

(0) Apply insecticides [ ] specify the insecticide ________________________

(1) Get the maize out to the sun to dry [ ]

(2) Sell the infested lot [ ]

(3) Others, please list ____

35. How often do you handle the stored maize grain? (i.e move from place to place, transfer from one bin/sack into another, spread out in the sun to dry, e.t.c)

(0) Never [ ]

(1) Once every two weeks [ ]

(2) Monthly [ ]

(3) Once every two months [ ]

(4) Others, Specify____

36. Are there grains scattered on the floor of the facility?

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

If yes,

36.1 What causes the scattering?

(0) Tearing of bags [ ]

(1) Rodents [ ]

(2) Mishandling of grain [ ]

(4) Others, please list ____

37. Do you seal cracks on the walls or holes in the roof of your storage facility?

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

V. Storage problems

38. Do you experience any storage problems/ challenges?

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

If yes,

38.1 What is/are the cause(s) of the challenge (s) you experience?

(0) Infestation by Insects [ ]

(1) Proliferation of molds [ ]

(2) Infestation by Rodents (Rats and mice) [ ]

(3) Theft [ ]

(4) Others (Please List) ____

38.2 List in order of importance, the challenges you experience in your store. (Please rank in order of importance: 1, 2, 3, 4. 1 = Most important /, 2 = Important /, 3 = moderately important/, 4 = of little importance)

Storage problem	Order of importance (1, 2, 3, 4)
Insects	
Mold (Discoloration)	
Rodents (Rats and mice)	
Other (specify) __________________________ ______________________________________	

39. Approximately, how many Kgs of maize grain do you lose due to storage problems? _________________________Kgs

40. In your own estimation, how many Kgs of the lost maize grain would you attribute to;

(0) Insects __________________________

(1) Molds _________________________

(2) Rodents _________________________

(3) Theft ___________________________

(4) Others, specify____________________

41. When did you observe proliferation of insect on stored maize grain?

(0) At the beginning of storage [ ]

(1) One month after storage [ ]

(2) Three month after storage [ ]

(3) At the end of storage [ ]

42. When do you observe mold growth (Discoloration) on your grain during storage?

(0) At the beginning of storage [ ]

(1) One month after storage [ ]

(2) Three months after storage [ ]

(3) At the end of storage [ ]

VI. Strategies to cope with storage problems

43. If you experience insect or mold problems, do you take any measures to control them?

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

If Yes,

43.1 What do you do to solve storage problems caused by insects?

(0) Apply insecticides [ ] state the name ____

(1) Apply wood ash [ ]

(2) Use plant leaves [ ] Name of the plant _________________________________

(3) Wood ash [ ]

(4) Exposure to sun [ ]

(5) Others, please list ____

43.2 What do you do to solve storage problems caused by molds?

(0) Expose the grains to the sun [ ]

(1) Clean the grain to remove surface fungal growth [ ]

(2) Careful sorting to remove visibly mold infected kernels [ ]

44. Have you received any training on protection of stored maize grain?

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

If yes,

44.1 who provided the training?

(0) Government officers [ ]

(1) ICIPE staff [ ]

(2) Farmer to farmer [ ]

(3) Any other organization [ ] Specify____

44.2 Did the training help you in managing stored grain pests?

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

VII. Production, consumption and sale of grains.

45. How much land does your household own? ____________________ (in acres)

46. How much land has your household allocated for maize cultivation ___________ (in acres)

47. On average, how many bags of maize do you harvest annually? __________ (90 Kg bags)

48. What are the end uses of the harvested grain?

(0) Consumption [ ] Number of bags reserved ______________________________________

(1) Sale [ ] Number of bags sold ____

(2) Seed for planting the following season [ ]. No. of bags reserved _____________________

49. At what time do you sell the portion of maize that is meant for sale?

(0) Immediately after threshing/shelling [ ]

(1) One month after threshing [ ]

(2) Between one and two months after threshing [ ]

(3) Between two to four months after threshing [ ]

(4) Four to six months after threshing [ ]

(5) Others, Please list ____

50. How long does the proportion meant for consumption last your household before its depleted?

(0) Less than one month [ ]

(1) One to two months [ ]

(2) Three to four months [ ]

(3) Five to six months [ ]

(4) Seven to eight months [ ]

(5) Others, Please list ____

Appendix II: Checklist on maize farmers' storage hygiene

Hygiene assessment Checklist for maize farmers' storehouses, Nakuru County, Kenya

Name of the Farmer ___________________________

Location: ____________________________________

GPS coordinates.

____

Type of store: ________________________________

Products stored: ______________________________

____

____

Capacity of the store: __________________________

Amount stored: ________________________________

Date Checked _________________________________

Key; Tick (✓) appropriately

1. **Condition of storehouse surrounding**

	Yes	**No**	**N/A**
a) Is the surrounding of the storehouse free of accumulation of discarded grains, old bags and cobs?			
b) Is the storehouse located away from domestic waste pits or trash dumping sites?			
c) Is the surrounding of the storehouse free of weeds, tall grasses and bushes?			
d) Is the surrounding of the storehouse free of rodents or evidence of their existence (droppings, burrows, rodent gnawed grains, e.t.c)?			
e) Is the vicinity of the storehouse free of pools of stagnant water?			
f) Is the storehouse located in a well ventilated area devoid of obstruction by other buildings?			

2. **Condition of exterior of the storehouse**

	Yes	**No**	**N/A**

a) Is the roof intact (without perforations)?			
b) Is the water drainage system intact?			
c) Is the storehouse sufficiently raised (at least 30 cm high) to prevent flooding in case of flash floods?			
d) Are the walls without holes or cracks?			
e) Are the ventilation openings protected against penetration of rodents, insects and birds?			
f) Is the store fitted with rat guards?			
g) Are the external walls free of dust, cobwebs and other debris?			

3. **Condition of the interior of the storehouse**

	Yes	**No**	**N/A**
a) Are the walls, the door and the roof undamaged?			
b) Have all holes and cracks been filled so as not to provide hiding places for pests?			
c) Is there an effective and functional ventilation system that allows good circulation of air in the storehouse?			
d) Is the store free of residues or agrochemicals (empty insecticide containers, empty fertilizer sacks, empty rodent baits, etc.)			

4. **Storage practices**

	Yes	**No**	**N/A**
a) Are all loaded bags stored on pallets/ raised platforms?			
b) Are all bags in the stacks without perforations?			
c) Are the bags stored at least 50 centimeters from the wall?			
d) Does the stacking of the bags allow adequate ventilation?			
e) Are insecticides, fertilizer, old bags, tarpaulins and other products/grains stored separately from shelled maize grain?			
f) Are all the bags used for storage of shelled maize grain new?			
g) Is the storehouse free of evidence of presence of domestic animals			

such as cats, dogs, chicken e.t.c?			
h) Are old stocks of grain from previous harvests stored separately from the new harvest?			

5. Hygiene Practices

	Yes	No	N/A
a) Are the walls, floors, windows and the roof of the storehouse generally clean?			
b) Are the walls and the roof free of accumulation of dust, dirt, spillages, debris, cobwebs, flour, e.t.c?			
c) Is any grain handling equipment within the storehouse clean?			
d) Is the floor free of spilled grain, dirt, and trash?			
e) Are difficult to reach areas (such as corners, crevices, below the pallets, behind the doors, e.t.c) adequately cleaned?			
f) Is the toilet or latrine located at least 20 meters away from the storehouse?			
g) Is the surrounding of the storehouse free of animal or bird droppings?			

6. **Presence of pests**

	Yes	No	N/A
a) Are the surfaces of the bags, tarpaulins and/or bins free of flying/crawling insect pests?			
b) Are the walls, floor and the ceiling free of crawling insects, larvae and pupae?			
c) Is the store free of traces of rodents (hair, droppings, smell, e.t.c)?			
d) Is the store free of traces of birds?			
e) Is the store free of moldy smell, dampness,(discolored) walls/ceilings?			

7. **Pest control**

	Yes	No	N/A
a) Has any pest control treatment been done shortly before or during the visit?			
b) Are there rodent traps or bait stations within the storehouse?			
c) Are insect infested grains separated from the healthy ones?			
d) Are doors, windows and ventilation openings protected against penetration of insects, rodents and birds?			

8**. Physical condition of the grain**

	Yes	No	N/A
a) Are damaged cobs not stored together with the produce?			
b) Is stored maize free of foreign matter (pieces of cobs, sheaths, dust, filth)?			
c) Is the stored produce free of signs of rewetting (e.g. water marks on bags)?			
d) Is the stored produce characterized with normal smell, color and appearance (rotten/diseased/moldy grain)?			
e) Is the stored produce free of live insects?			
Total responses			

— (1); (2) (3) produce has no signs of rewetting (e.g. water marks on bags); (4); (5)

Notes on any other striking features related to storehouse architecture, hygiene, storage pests and pest control.

Appendix III: Publication

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The importance of store hygiene for reducing post-harvest losses in smallholder farmers' stores: Evidence from a maize-based farming system in Kenya

Kobia J. Makinya [a, b, f], John M. Wagacha [b], Judith A. Odhiambo [b], Paddy Likhayo [c], Kukom Edoh-Ognakossan [d], Tadele Tefera [e], Adebayo Abass [f], Christopher M. Mutungi [f, *]

[a] International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya
[b] School of Biological Sciences, University of Nairobi, Kenya
[c] Kenya Agricultural and Livestock Research Organization (KALRO), Nairobi, Kenya
[d] World Vegetable Center, West & Central Africa-Dry Regions, Bamako, Mali
[e] International Centre of Insect Physiology and Ecology (ICIPE), Addis Ababa, Ethiopia
[f] International Institute of Tropical Agriculture (IITA), Dar es Salaam, Tanzania

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A B S T R A C T

Knowledge of the role of hygiene in reducing food loss in farm stores is limited among extensionists, researchers, and farmers. Store hygiene practices during post-harvest handling and storage of maize were assessed using a cross-sectional survey of 342 farmers, with regular follow-up of 40 farmers' stores over seven months to measure losses caused by insects, and to score the hygiene levels using a standard checklist. Fractional Response Model was used to evaluate the associations between hygiene practices and the losses. Farmers stored their produce in sacks (98.2%) kept in outside granaries (60.1%), or rooms in dwelling houses (39.9%). Co-storage with other items — stover or animal feed (29%), old storage containers (41%), farm implements (30%), other crops (65%) and recycling of old storage bags (40%) were common practices. Nine out of ten farmers cleaned their stores before introducing the new harvest, but only half cleaned their stores during the course of storage. High hygiene scores correlated significantly with lower losses. Storing in the bedroom or living room correlated with lower losses by 2.8 and 4.6 percentage points, respectively, compared to storing it in granaries, while storage in the kitchen correlated with higher losses by 19 percentage points margin. Co-storage was associated with higher losses by 2.8 percentage points. Repairing or disinfesting the store before introducing a new harvest did not significantly reduce losses. Training in grain storage did not have a significant effect either, while maize farming experience and younger age were associated with lower losses by 2.8 and 5.9 percentage points, respectively. Stores where majority of the post-harvest handling decisions were made by women had lower losses by 2.8 percent points. These findings are pointers for the need to strengthen education and mechanisms that enable farmers to put knowledge into practice for effective integrated pest management in farm stores.

1. Introduction

The productivity of smallholder farmers must increase sustainably in order to address the challenge of food and nutrition insecurity. An essential component of sustainable food production is the prevention of loss of harvested produce, and the retention of its nutritional value and safety. Maize is a food and income-generating crop for millions of rural farmers in East and Southern Africa. In Kenya, the annual per capita consumption is 79 kg, accounting for 30.7% of the recommended daily calorie intake (FAOSTAT 2017). However, poor post-harvest management results in approximately 15–25% grain loss, which is equivalent to US$ 180–240 million in forfeited incomes or the grain required to feed close to 2 million households each year (C. Mutungi, personal communication). Preliminary operations including harvesting,

* Corresponding author.
E-mail addresses: chrismutungi@yaoo.co.uk, c.mutungi@cgiar.org (C.M. Mutungi).

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