EFFECTIVENESS OF SELECTED FOOD STORAGE TECHNOLOGIES IN REDUCTION OF POST-HARVEST LOSSES OF BEANS IN SELECTED HOUSEHOLDS OF KILOSA DISTRICT, TANZANIA

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ABSTRACT

Cereal grain losses are high in sub-Saharan Africa countries, Tanzania inclusive. Information on protection of these losses is mainly reported for maize and other cereals but it is limited on bean, particularly for Kilosa district. This study was carried in Kilosa district, where by two wards (Malolo and Lumuma) were used to establish effective storage technology for bean storage and measure the level of understanding on post-harvest management. To measure effectiveness storage technology, different factors were put into consideration, e.g., ability to maintain storage moisture content of bean, ability to reduce bean damage by weevil (bruchids), price, availability and challenges on the use of particular technology. Beans from 20 farmers were kept in three different storage technologies mainly; Metal Silo, Purdue Improved Cowpea Storage (PICS) and Polypropylene bag (polypropylene bag), and stored for six months. Household survey data showed that there was little knowledge and limited awareness of the community regarding post-harvest management and the mycotoxin problem. The mean percentage bean damage were 23.6, 15.2 and 6.4% for polypropylene bag, silo and PICS, respectively. Overall results showed that PICS was the most effective in terms of beans damage reduction, price affordability and availability. During storage there were some few observations like weakness of PICS bag that made bruchids able to make holes on the two layers of polyethylene and facilitate air entrance. None had received any formal or informal training on postharvest management. The study recommends post-harvest management training of agricultural extensions officers who after the training disseminated the knowledge to farmers. Extension of the hermetic storage technology to beans seems essential. For metal silo technology to be widely adopted subsidy looks necessary to reduce its price.

DECLARATION

I, Frank M. Kaseka do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution for a degree award.

Frank M. Kaseka **Date**

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The above declaration is confirmed;

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(Supervisor)

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DEDICATION

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LIST OF ABBREVIATIONS AND ACRONYMS

AFPA	*Aspergillus flavus* and *parasiticus* Agar
AGRA	Alliance for a Green Revolution in Africa
ANOVA	Analysis of Variance
CFU/g	Colony Forming Units per gram
CO_2	Carbon dioxide
EAC	East African Community Standards
FAO	Food and Agriculture Organization of the United Nations
GAP	Good Agricultural Practices
GHI	Global Harvest Initiative
GPLP	Grain Postharvest Loss Prevention
GMP	Good Manufacturing Practices
HDPE	High Density Polyethylene
HS	Hermetic Storage
ISRA	Investigative Survey Research Approach
ISTA	International Seed Testing Association
ITC	International Trade Centre
Ksh	Kenyan Shillings
MA	Modified Atmosphere
MAFSC	Ministry of Agriculture Food Security and Cooperatives
Nd	Number of Damaged Grains
Nu	Number of Undamaged Grains
O_2	Oxygen
PHL	Post-Harvest loss
PICS	Purdue Improved Cowpea Storage

SDC	Swiss agency for Development and Cooperation
SGB	Super-Grain Bag
SPSS	Statistical Package for Social Sciences
USD	United States Dollar
VEO	Villlage Agricultural Officer
Wd	Damaged Grain Weight
WFP	World Food Programme
WHO	World Health Organization
Wu	Undamaged Grain Weight

CHAPTER ONE

1.0 Introduction

1.1 Background Information

Legumes (dry beans and other pulses) occupy an important place in human nutrition, especially among the low-income groups of people in developing countries. In Tanzania, more than one third of the population living in rural areas is poor. Eighty five percent of them are smallholder farmers who rely on agriculture as their main source of income and livelihood. Tanzanian smallholder farmers lose up to 40% of their harvests due to poor handling and storage methods (SDC, 2017). Post-Harvest Losses (PHL) are high for different crops, but are of particular concern for grains, especially cereals and pulses, which form the base for food and income of the majority. Varieties of pulses cultivated in Tanzania include common beans, cowpeas, pigeon peas, chickpeas, mung beans and bambara nuts. Their agro-ecological requirements are also very well suited to the climate in Tanzania, giving viability for commercial farming. Majority of farmers grow grain with little attention to Good Agricultural Practices (GAP), resulting in low yields of between 0.5 and 1.0 tonnes per hectare compared to the potential of producing up to 3 tonnes (standard) per hectare (SDC, 2017). The estimated production of pulses in Tanzania is currently at 1.6 million tonnes per annum, but there is potential to increase this significantly (ITC, 2016).

Post-harvest loss includes the food loss across the food supply chain from harvesting of crop until its consumption (Aulakh *et al.,* 2013). The losses can broadly be categorized as weight loss due to spoilage, quality loss, nutritional loss, seed viability loss, and commercial loss (Boxall, 2001). Magnitude of post-harvest losses in the food supply chain vary greatly among different crops, areas, and economies. In developing countries, people try to make the best use of the food produced. However, a significant amount of produce is lost in postharvest operations due to a lack of knowledge, inadequate technology and/or poor storage infrastructure. On the contrary, in developed countries, food loss in the middle stages of the supply chain is relatively low due to availability of advanced technologies and efficient crop handling and storage systems.

1.2 Post-harvest Operations That Can Compromise the Grain Quality

1.2.1 Threshing

The purpose of the threshing process is to detach the grain from the panicles. The process is achieved through rubbing, stripping, or impact action, or using a combination of these actions. The operation can be performed manually (trampling, beating), using animal power, or mechanical threshers. Manual threshing is the most common practice in the developing countries. Grain spillage, incomplete separation of the grain from chaff, grain breakage due of excessive striking, are some of the major reasons for losses during the threshing process (Khan, 2010). Delay in threshing after harvesting of crop results in significant quantity and quality loss, as the crop is exposed to atmosphere and is susceptible to rodents, birds, and insect attack (Alavi *et al.*, 2012). As in the case of harvesting, lack of mechanization is the major reason for this delay that causes significant losses. High moisture accumulations in the crop lying in the field may even lead to start of mould growth and mycotoxin production in the field.

1.2.2 Storage

Storage is an integral part of any food grain processing chain. Storage of raw and processed grains, including legumes has been used by humans since the beginning of history as a pre-requisite for ensuring food security due to off time availability and for withholding seed grain for long periods. Grain storage and handling is a major concern for pulse growers and processors worldwide. Pulses can remain in an edible condition for several years if properly stored. However, during ambient storage conditions, grains are subjected to various physical, chemical and biological changes. The basic advantage of good storage is to create environmental conditions, which protect the product from the extremes of outside temperature and relative humidity fluctuations, both diurnal and seasonal, and maintain its quality (Cox and Collins, 2002). Both pulse grain quality and quantity are affected by intrinsic and extrinsic factors and, among these, temperature and moisture content are the most important influences of shelf-life. Grain viability and reproduction of biological agents in grain are dependent to a great extent on the temperature and moisture levels (White, 1995). Improper storage conditions influence the post-harvest storability of pulses. Various pests and microorganisms attack the pulses and their products after harvest, in storage and during transportation to the market. The application of pesticides results in chemical residues in the food that are extremely hazardous to health. Establishment of efficient and effective post-production storage systems is warranted in order to minimize qualitative and quantitative losses (Mohan, *et al.,* 2011). Storage plays a vital role in the food supply chain, and several studies reported that maximum losses happen during this operation (Bala, *et al.,* 2010; Majumder, *et al.,* 2016).

In most of the places, crops are grown seasonally and after harvesting, grains are stored for short or long periods as food reserves and as seeds for next season. Studies report that in developing countries such as India, about 50–60% of the grains are stored in the traditional structures (e.g., Kanaja, Kothi, Sanduka, Gummi Kacheri) and earthen pots at the household and farm level for self-consumption and seed (Grover and Singh, 2013). The indigenous storage structures are made of locally available materials (grass, wood, mud) without any scientific design and cannot guarantee to protect crops against pests for a long time. Estimated losses as high as 59.48% in maize grains after storage for 90 days in the traditional storage structures (granary/polypropylene bags) have been reported (Costa, 2014).

1.2.2.1 Hermetic storage

Hermetic storage is a type of modified atmosphere (MA) that can be applied for the protection of grain. It is also called ‘‘sealed storage’’ or‘‘air-tight storage’’ or ‘‘sacrificial sealed storage’’ or ‘‘biogenerated MA’’. This method takes advantage of sufficiently sealed structures that enable insects and other aerobic organisms in the commodity or the commodity itself to generate the MA by reducing the O_2 and increasing the CO_2 concentrations through respiratory metabolism to prevent insect development (Navarro, 2012).

In other words, hermetic storage (HS), also known called as “sealed storage” or “airtight storage”, is gaining popularity as a storage method for cereal, pulses, coffee, and cocoa beans in developing countries, due to its effectiveness and avoidance of the use of chemicals and pesticides. The method creates an automatic modified atmosphere of high carbon dioxide concentration using sealed waterproof bags or structures. As the structures are airtight, the biotic portion of the grains (insects and aerobic microorganisms) creates a self-inhibitory atmosphere over time by increasing carbon dioxide concentration (oxygen decreases) due to its respiration metabolism. Some studies have reported that the aflatoxin production ability of *Aspergillus flavus* is also reduced at high concentrations of CO_2 (Tefera *et al.,* 2011; Adler *et al.,* 2000).

Hermetic storage has been observed to be very effective in avoiding the losses (storage losses less than 1%) during long distance (international) shipments (Villers *et al.,* 2010). Ease of installation, elimination of pesticide use, favourable costs and modest infrastructure requirements are some of the additional advantages that make the hermetic storage options attractive (GHI, 2014).

The CO_2 concentration inside the bags is usually used as an indicator of the biological activity of grains. (Cardoso *et al.,* 2008; Bartosik *et al.,* 2008). Permeability of the bag and the gas partial pressure effect the movement of gases (O_2 and CO_2) in and out, whereas the concentration of these gases inside the bag depends on the balance between these exchanges and the respiration of the biotic portion of grains. Higher initial moisture content tends to increase the CO_2 concentration because of the increased respiration, however, the change was not found to be significant (Cardoso *et al.,* 2008).

Another factor affecting the respiration rate is grain temperature. It has been observed in experimental studies that the temperature inside the bags follows the ambient temperature trend, and for every 10-degree increase in temperature, the CO_2 concentration increases by about 1.5% (Cardoso *et al.,* 2008). World Food Programme (WFP) in their Action Research Trial in Uganda and Burkina Faso found out that if properly sealed, the hermetic storage units were themselves very efficient in killing the pests and insects without any use of phosphine fumigation (Costa, 2014). Various hermetic storage options, such as metallic silos, Purdue Improved Cowpea Storage (PICS) bags, Super Grain bags, etc., have been developed and widely promoted in the last few years. These bags are being considered practical and cost-effective storage technology, and are becoming very popular in several countries (Zeigler and Truitt, 2014).

The metal silo technology is an effective method of reducing grains post-harvest losses for small and medium scale farmers. This technology provides grains protection for both short and longtime storage against pathogen damage, animal and insect pest. In some locations, the siloes are made of painted aluminium sheeting which helps prevent corrosion and improves their appearance (Yusuf and He, 2013). It is considered to be one of the key technologies which will be helpful in reducing postharvest losses and improving food security of smallholder farmers.

(a) Purdue Improved Cowpea Storage (PICS)

PIC originally developed for storage of cowpea, involves triple bagging the grains in hermetic conditions, and is widely used by farmers in sub-Saharan Africa. The grains are stored in double layer thick (80 µm) high density polyethylene (HDPE) bags and are held in a third polypropylene nylon bag. After filling with the grains, the bags are sealed airtight. This will cut off the oxygen to the weevils and hinder their metabolic pathways preventing them from producing water, and killing them by desiccation (Murdock *et al*., 2012). More than 3 million PICS bags were sold in West and Central Africa during 2007–2013. Super Grain, commercialized by Grain-Pro Inc. is another widely used water resistant and hermetic storage option. These bags are made up of a single thick layer of high-density polypropylene with a thickness of about 78µm, and used as liner along with normal polypropylene bags (Suleiman and Kurt, 2015). Zero-Fly bags are a product of Vestergaard, Switzerland. These are insecticide infused polypropylene bags designed to prevent damaging pest infestations. The bag is made with pyrethroid incorporated into polypropylene yarns.

Baoua *et al*. (2013) conducted a study to compare the performance of Super Grain bags and PICS bags, available in the West African market, to control pest infestation over the 4 months of storage. The change in temperature and relative humidity in both the bags were similar over time. The infestation level of *C. maculatus* eggs on the seeds after four months was found to be lower in Super Grain bags (18.5 eggs per 100 seeds) in comparison to PICS bag (26.1 eggs per 100 seeds). Grain damage was observed relatively lower (18.5 grains with holes per 100 tested grains) for the PICS bag compared to that in the Super Grain bags (29.5 grains with holes per 100 tested grains). Somavat *et al*. (2017), compared the effectiveness of hermetic bin bags (Grain Safe IIITM, Grain-Pro Inc., Concord, MA, USA), metallic bins and gunny bags for storage of wheat under ambient conditions in India. There was no insect infestation found in clean grains stored in hermetic bags after 9 months of storage. For the artificially infested grains, bored grain percentage remained stable at 0.33% for hermetic bags in contrast to 2% and 8% for metallic bins and gunny bags respectively. At end of storage, seed viability was found to be higher (88%) for hermetic bags compared to 82 and 73% in metallic bins and gunny bags respectively (Somavat *et al*., 2017).

Baoua *et al*. (2014). conducted a comprehensive study to investigate the effectiveness of PICS bags (50 kg capacity) for maize storage at eleven localities in Burkina Faso, Ghana, and Benin. Insect infestation in maize during storage varied from nil to highly infested. After about 196 days of storage, the PICS bags were able to maintain 100 seed grain weight, seed viability, and seed germination along with 95%–100% insect mortality at all localities. Moisture content was also observed to be unchanged during storage for most of the PICS bags. Although aflatoxin levels were observed in maize stored in both the PICS and polypropylene bags, the level of contamination was lower in the PICs bags. Similar effectiveness of the PICS bags was observed during storage of Bambara groundnut (Baoua *et al.*, 2014) maize (Njoroge *et al.,* 2014), mung bean and pigeon peas (Mutungi *et al*., 2014), pigeon peas (Vales *et al.,* 2014).

Mutungi *et al*. (2014) investigated the effectiveness of the PICs bags for mung beans and pigeon-peas. Naturally and artificially infested grains were stored in the PICS bags and polypropylene bags for 6 months. For both mung beans and pigeon peas, the oxygen levels were reduced and carbon dioxide levels rose rapidly within the two months of storage in the PICS bags. For the initial two months, the change was found to be higher in highly infested grains compared to naturally infested grains, however, at the end of storage the average change was almost the same. Insect damage and weight loss for grains remained unchanged in the PICS bags, whereas, there was 24.2–27.5 times and 21.7–43.7 times more weight loss after 6 months of storage in the polypropylene bags for mung beans and pigeon peas, respectively. Treatment of grains with Actellic Super dust before storage in the polypropylene bags did not help in reducing damage, and weight loss at the end of storage increased by factors of 20.8 and 22.5 for mung beans and pigeon peas, respectively.

(b) Metal silo

Metal silos have been found to be effective in several other studies. However, their initial high cost is a major obstacle for their adoption by smallholders. Community level silos might be an economic alternative, as the cost per unit of grains decreases with increases in the size of silos. The maintenance cost is very low in the case of silos, which can compensate for the high initial cost to some extent. Kimenju and De-Groote, (2010) conducted an economic analysis of using advanced storage structures and reported that the economic gain (extra income by avoiding losses) using a metal silo compared to polypropylene bags could be up to USD 100 per ton of grains after 12 months of storage.

However, farmers have to spend an extra USD 171 (1.8-ton capacity) to USD 316 (0.36-ton capacity) as the initial cost of silos over polypropylene bags. One of the main challenges of using hermetic bags is that the grain to be stored should be thoroughly dried to avoid mold and rotting of grains. Although these bags prevent the damage from insects, they do not provide an effective barrier from rodents. Specifically, Super Grain bags are widely used in Russia and Latin America for storage of coffee. They are also popularized in Afghanistan for wheat storage, Nepal for corn, and in Vietnam for rice conservation (Ben *et al.*, 2009). These bags are being used successfully in several Latin American countries to store all major grain crops without application of pesticides (Zeigler and Truitt, 2014) Hermetic storage structures developed by Grain-Pro Inc. are used by several commercial companies in India to store high value spices and Basmati rice (GHI, 2014).

Technology interventions and improved storage structures can significantly reduce store losses. However, it is important to understand that training of smallholders is equally as necessary as the technology dissemination (Kitinoja, 2013). Along with making these technologies available at a reduced price, the government agencies and organizations have to ensure the development of facilities to provide information and training about the use and maintenance of these technologies in the local language, for successful adaptation and effective use of these technologies.

Post-harvest development contributes to food security in several ways. Improved storage technologies such as biological pest control or controlled atmosphere storage reduce post-harvest losses, thereby increasing the amount of food available for consumption. For example, control of the larger grain borer greatly reduced maize lost in on-farm storage among smallholders in a number of African countries, heightening their food security (Goletti and Wolff, 1998). Further, post-harvest can provide income-generating opportunities for farmers in rural areas. Studies of the commercialization of smallholder producers in a number of developing countries show that producers' nutritional status is typically not compromised; income gains generally lead to higher spending on food in absolute terms (Von-Braun and Kennedy, 1994).

1.3 Problem Statement and Study Justification

Grain legumes/pulses are cultivated in many regions in Tanzania. Apart from their nutritional benefit they fix nitrogen in soil, improves soil nitrate content and saves fertilizer costs and increase yield of subsequent crops (Joshi, 1998). Being cultivated in large quantity in different regions has shown a negative relationship on their wellbeing and nutritional status (most of the families are food insecure) (SDC, 2017). Smallholder farmers in Sub-Saharan Africa face numerous challenges after their grain leaves the field. Farmers who store grain may experience significant quantity losses due to damage from rodents, insect pests, and mould, and subsequent price discounts for damaged grain (Kaminski and Christiaensen, 2014; Kadjo *et al.*, 2015; Kadjo *et al*., 2016). Deterioration of bean grain quality due to insect damage leads to rejection in the market and loss of income (Abate and Ampofo, 1996). Part of the reason quantity loss occurs is that many farmers lack access to effective and safe storage technology, such as airtight (hermetic) storage bags or metal silos. These technologies have the potential to positively impact household welfare but are currently not available in many rural settings (Gitonga *et al.*, 2015).

Despite storage technology being pointed out by many researchers in reduction of postharvest losses and improving household food security, there is a scarcity of information on beans loss. Hence this study will go deeper to assess the effectiveness of three storage technologies (metal silo, hermetic bag (PICS) and polypropylene bag, on reducing post-harvest losses and improving food security and come up with practical strategies on how to reduce post-harvest losses during storage of bean**.** Storage point was selected because it is the only stage where the grain spends a longer time after harvest waiting for the market or being used as household food, also on this stage the contact time between rodent, microorganisms, bruchids and grain is longer, therefore during storage almost all types of losses occurs (quality loss, economical loss and weight loss).

The results obtained from this study will help to come up with effective storage technology in terms of cost effectiveness and performance, which will help to reduce losses that occur during storage and hence improve food security and wellbeing (increase household income) of small-scale farmers.

1.4 Objectives

1.4.1 General objective

Assessment of effectiveness of polypropylene bags, metal silos and hermetic bags in reduction of post-harvest losses of beans at household level.

1.4.2 Specific objectives

i. To identify major challenges faced on the use of polypropylene polyethylene bags, silos and hermetic bags during beans storage

ii. To examine major types and causes of bean losses occurring in polypropylene polyethylene bags, silos and hermetic bags

iii. To evaluate the level of understanding/knowledge on post-harvest management of beans

iv. To evaluate the quality of beans stored in polypropylene polyethylene bags, silos and hermetic bags

1.5 List of Manuscripts

i. Post-harvest loss knowledge among small scale beans farmers in Malolo and Lumuma wards in Kilosa district.

ii. Effectiveness of different bean storage technologies.

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CHAPTER TWO

2.0 POST-HARVEST LOSS KNOWLEDGE AMONG SMALL SCALE BEAN FARMERS IN MALOLO AND LUMUMA WARDS IN KILOSA DISTRICT

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2.1 Abstract

Post-harvest loss knowledge among small scale farmers in Malolo and Lumuma wards of Kilosa district was evaluated using questionnaire, interview and focus group discussion. A total number of 130 households (farmers) was covered in this research. Data collected were analysed using SPSS v20 statistical programme. The results showed that, there was little understanding of post-harvest loss knowledge based on storage practices, handling practices (shelling and storage of beans), awareness of availability of effective storage technology and indicator used to determine damage. Hundred percent (100%) of the farmers interviewed had not received any formal or informal education or training concerning post-harvest management. Also, about 87.7% of the population acquired only primary school education, which affected post-harvest knowledge and practices because most of them were engaged in farming as part of their livelihood without understanding the basics of farming. Around 93% of the farmers used polypropylene bag for maize storage and they did not know anything about metal silos. Although 82% used polypropylene bag, they did not know anything about hermetic (Perdue Improved Cowpea Storage) bags. About 1.5% of the respondents used PICS while none used metal silo storage. Furthermore, 41% of farmers processed damaged beans and used them as food (*kihembe*). Therefore, knowledge of post-harvest loss was poor among Malolo and Lumuma wards of Kilosa district, implying that any education in this area could help in lowering post-harvest losses as could improve the handling and storage of beans in the district.

2.2 Introduction

Food and Agriculture Organization of the United Nations predicts that about 1.3 billion tonnes of food are globally wasted or lost per year (Gustavasson *et al*., 2011). Reduction in these losses would increase the amount of food available for human consumption. This would consequently enhance global food security, a growing concern with rising food prices due to growing consumer demand, increasing demand for biofuel and other industrial uses, and increased weather variability (Trostle, 2010). A reduction in food loss would also improve food security by increasing the real income for all the consumers (World Bank, 2011). In addition, crop production contributes significant proportion of typical incomes in certain regions of the world (70 percent in Sub-Saharan Africa) and reduces food loss, which can directly increase the real incomes of the producers (World Bank, 2011).

Food losses in the low-income countries mainly occur in the early and middle stages of the food supply chains with proportionally less amounts wasted at the consumer level. Food losses in these countries are the result of "inadvertent losses" due to the 'poor' state of their supply chains. Premature harvesting, poor storage facilities, lack of infrastructure, lack of processing facilities and inadequate market facilities are the main reasons for high food losses along the entire food supply chain (Aulakh *et al.*, 2013).

Post-harvest Food Loss (PFL) is defined as measurable, qualitative and quantitative food loss along the supply chain, starting at the time of harvest till its consumption or other end uses (De Lucia and Assennato,1994; Hodges *et al.*, 2011). Quantitative food loss can be defined as reduction in weight of edible grain or food available for human consumption. The quantitative loss is caused by the reduction in weight due to factors such as spillage, consumption by pest and also due to physical changes in temperature, moisture content and chemical changes (FAO, 1980).

From a functional point of view, the primary role of an effective post-harvest system is ensuring that the harvested produce reaches the consumer while fulfilling market/consumer expectations in terms of volume, quality and other product and transaction attributes, including nutrition, food security and product safety (World Bank, 2011). PHL can be mitigated by appropriate handling and managing of the product along the chain to minimize the effect of biological and environmental factors on product deterioration and avoid product contamination. For example, in the case of mycotoxins, the Codex Alimentarius Commission has elaborated the Code of Practice for the Prevention and Reduction of Mycotoxin Contamination in Cereals. The code presents Good Agricultural Practices (GAP) that represent the primary line of defence against contamination of cereals with mycotoxins, followed by the implementation of Good Manufacturing Practices (GMP) during postharvest stages to satisfy cereal demands for human food and animal feed (World Bank, 2011).

The aim of this study was to assess the knowledge on post-harvest management of beans and mycotoxin contamination among small scale farmers of Malolo and Lumuma wards of Kilosa District and to provide strategies to prevent postharvest losses and mycotoxins contamination among small scale bean farmers.

2.3 Materials and Methods

2.3.1 Study location

The study was conducted in two wards namely, Malolo and Lumuma in Kilosa District, Morogoro Region, Tanzania. The district lies between 6°S and 8°S, and 36°30'E and 38°E. The district experiences an average of eight months of rainfall (October–May), with the highest levels between February and March. The rainfall distribution is bimodal in good years, with short rains (October–January), followed by long rains (mid-February–May). Mean annual rainfall ranges between 1,000 and 1,400 mm in the southern flood plain. The mean annual temperature in Kilosa is about 25°C (Nduwamungu *et al*., 2004).

The wards were purposively selected because of Grain Post-harvest Loss Prevention Project (GPLP-project) that is being implemented in Kilosa District and the wards represent wards with high production of beans in the district.

2.3.2 Study design and sampling

A cross-sectional descriptive study was conducted in March 2018 in two wards of Kilosa district, i.e., Malolo and Lumuma. This design was suitable because the study was aiming to capture and collect particular information regarding handling and storage practices and awareness of post-harvest management issues from the study population from whom the farmers were to be interviewed. A preliminary survey was carried out to evaluate the level of understanding on post-harvest losses issues in the study villages. The survey was conducted in two wards, Malolo and Lumuma. A total of 130 households of small-scale farmers were randomly selected with the help of agricultural officers in the area. The survey was conducted using Investigative Survey Research Approach (ISRA) (Anazodo *et al*., 1986). Information was collected using structured questionnaire, discussion and focus group discussion. Data collected included demographic information, postharvest handling practices and food security issues.

2.3.2 Statistical analysis

Statistical Package for Social Sciences (SPSS) version 20 was used to analyse questionnaire data. The analysis involved descriptive statistics to describe the sample population, socio-demographic, awareness, handling and storage practices data, in frequency tables and percentages.

2.4 Results and Discussion

2.4.1 Demographic characteristics of farmers

Table 1 shows that bean farming in all the study villages was largely carried out by males (73.1 %).

Table 2.1: Demographic characteristics of respondents (n=130)

Category	Description	Ward Name		Percentage (%)
		Malolo	Lumuma	
Age in years	15-24	0	24	18.46
	25-34	2	39	31.54
	35-44	2	19	16.15
	45-54	4	22	20.00
	>55	2	16	13.85
Sex	Male	9	86	73.08
	Female	1	34	26.92
Marital status	Single	0	14	10.77
	Married	10	100	84.62
	Widowed	0	2	1.54
	Divorced	0	0	0.00
	Separated	0	4	3.08
Occupation	Farmer	10	118	98.46
	Trader	0	0	0.00
	Public servant	0	0	0.00
	Entrepreneur	0	2	1.54
Number of people in the household	1-5 people	4	68	55.38
	6-10 people	6	44	38.46
	>10 people	0	8	6.15
Level of education	Uneducated	0	9	6.92
	Primary school	9	105	87.69
	O level	1	6	5.38
	A level	0	0	0.00
	College/University	0	0	0.00

Women are known to be more involved in agricultural activities than men in sub-Saharan Africa (FAO, 2010), but to these two wards the story was different, men involved more in agriculture than women. This might be their way of living whereby, women remain home to take care of children and this was observed during the time the study was conducted. Age-wise, they were widely distributed significantly between and within wards for all groups participating in beans cultivation. The study shows that people between 25-34 years of age were more engaged than other groups.

2.4.2 Packaging technology used

The results (Figure. 2.1) showed that large percent of farmers (93%) were not aware with metal silo and used normal polypropylene bag, which do not guarantee the quality of stored beans and they were generally not aware of metal silos that are also used for grain storage. Only 5% of the famers were aware of these metal silos but, were still using polypropylene bag due to high price of metal silos and problems of availability. According to the World Bank Report (2011), food losses in Tanzania due to poor quality storage facilities are in the range 23-25% and losses that occur due to lack of storage is 13% to all grains. The current tax situation in Tanzania makes purchase of the appropriate quality of sheet metal to construct SDC-style silos very expensive, implying that cost issues have to be addressed. Therefore, price of the metal silo also hindered its distribution in the area.

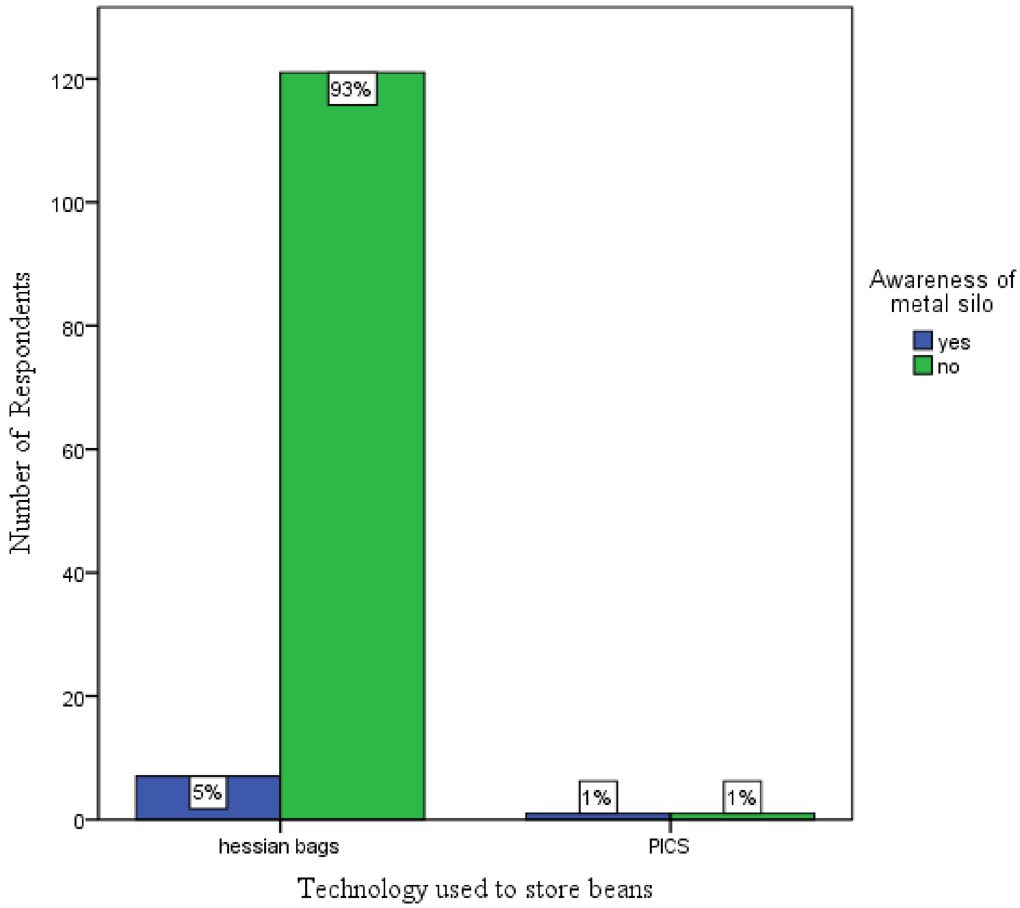

Figure 2.1 Awareness on metal silo (N=130)

The number of farmers who were interviewed with awareness of hermetic bags and still using polypropylene bag were 16%, 82% did not know about the presence of hermetic bags (Figure. 2.2). The two graphs showed well how familiar these two technologies were in the society. Hermetic bags were a bit known and distributed compared to metal silos. According to the report presented by Macharia (2015) to AGRA, the price preferences of technology had positive effect on adopting technology. When technology cost was more than 2.35 USD only 16.58% of farmers would be able to afford it while for that which cost between 0.47 and 0.94 USD 87.5% of farmers would be able to afford. Therefore, price affects positively the distribution and adoption of the technology. This supports what was seen in the present study that the most expensive technology was thus the least adopted.

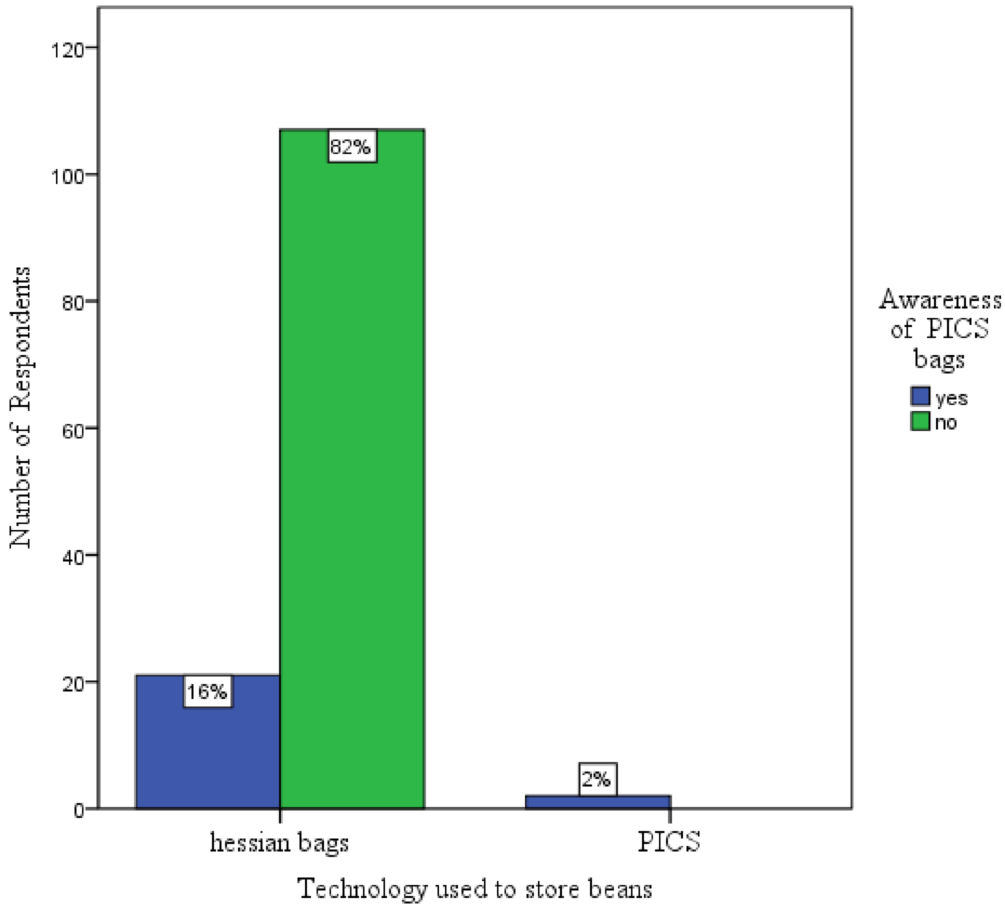

Figure 2.2: Awareness on hermetic bags (N=130)

2.4.2.1 Amount of beans lost during storage

According to the results (Figure 2.3), most of farmers stored their beans for one to three months (75%) and the remaining parcentage stored for above three months. In those three months, 45% of farmers lost up to 20% of the bags (lost 20 in 100 kg of harvest). The other 32% loose between 26 and 80 kg per 100kg of beans, which is almost the same as what has been reported above by other researchers (Costa, 2014). This means high loss occurs during the first three months of storage and increases as time goes.

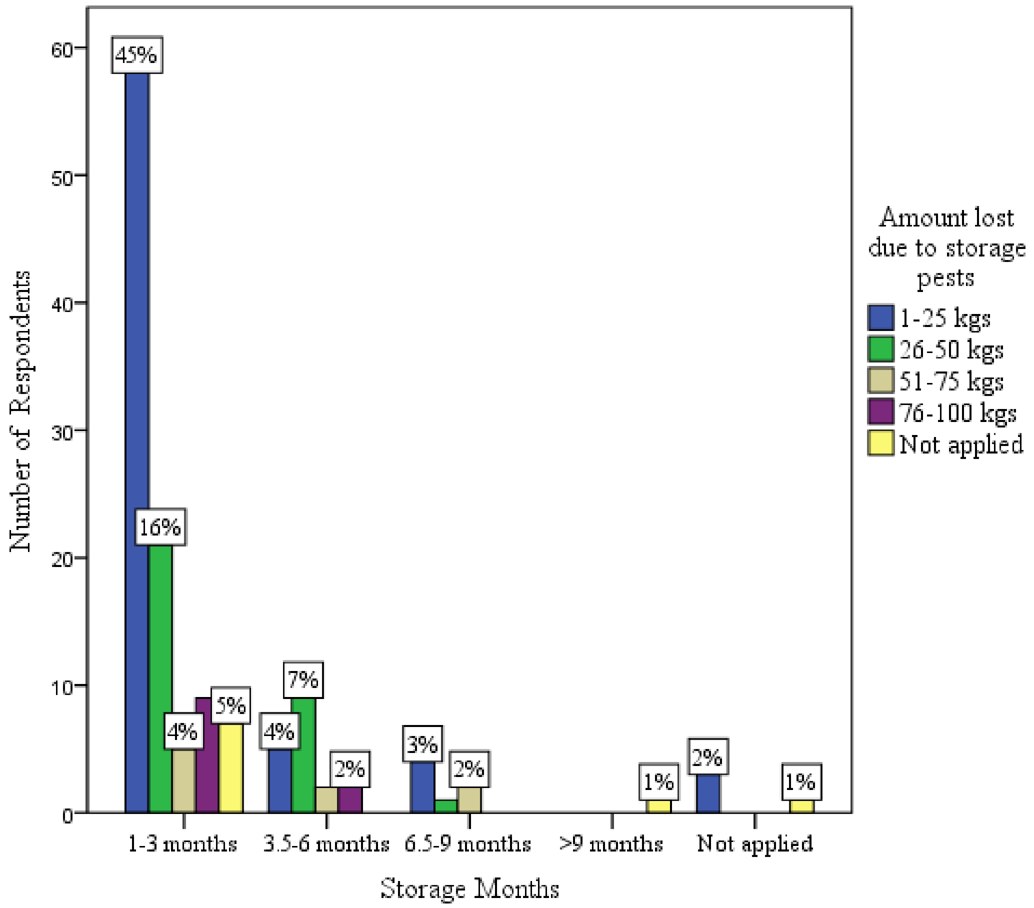

Figure 2.3: Relationship between amount lost and storage time

Beans are an important staple crop and food security as a major source of protein (20-30% in dry beans), caloric intake (32%) (Sparling and Muyaneza, 1995) and income. Deterioration of bean grain quality due to insects damage leads to rejection in the market and loss of income (Jones, 1999; Abate and Ampofo, 1996). Losses correlate directly with length of storage, the longer the beans are stored, the greater the loss. Losses caused by bruchids are known to be substantial on all continents (FAO, 1999). In Ethiopia, stored bean damage by bruchids reached up to 38% with a corresponding weight loss of about 3.2 % (Negasi, 1994). Burundi and Rwanda losses to bruchids are commonly about 30 % (Nahimana, 1992).

Figure 2.4 shows that most of the farmers whose loss was high stored their bags on the floor compared to those who stored on a pallet. The possible reason for this observation was that beans on floor were more easily accessed by pests. Also, the air between the grains in the bag and floor condensed moisture due to the rise and fall of room humidity and temperature that favoured mould growth.

This is the reason why beans on the lower part of the bag got discoloured. This was also observed by Abass *et al.* (2014) that indigenous post-harvest practices such as harvesting by hand, head-load transportation, manual processing, and storage on the floor/in the open, or in oxygen and moisture permeable bags, cribs or granaries are the dominant causes of crop losses. Some post-harvest handling practices such as the use of poor harvesting tools, storage in oxygen and moisture permeable bags and reuse of dirty and contaminated gunny bags are either unable to prevent food losses or they exacerbate post-harvest losses.

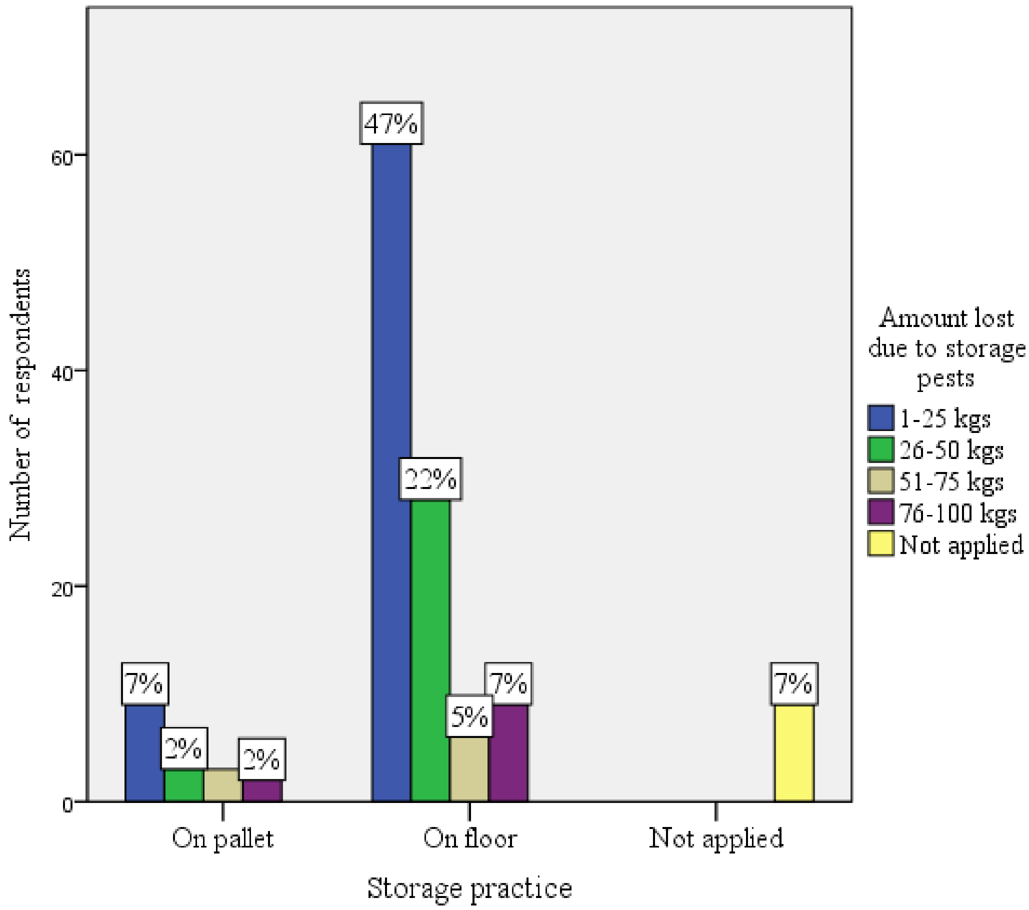

Figure 2.4: Relationship between storage practice and amount of beans lost due to storage pest

2.4.2.2 Indicator for damage

Damage is shown in the circular holes or "windows" left in the bean when bruchids emerge (FAO, 1999). Most of farmers (46%) used insect development as the sign of their beans being damaged (Figure 2.5). According to the labaratory obeservations, insect develepment was a later sign after formation of holes. It means, they could save some amount of beans if they could have used hole formation as a sign of beans damage and exposing beans to the sun (solarization), which is also a very common and local way of killing insects.

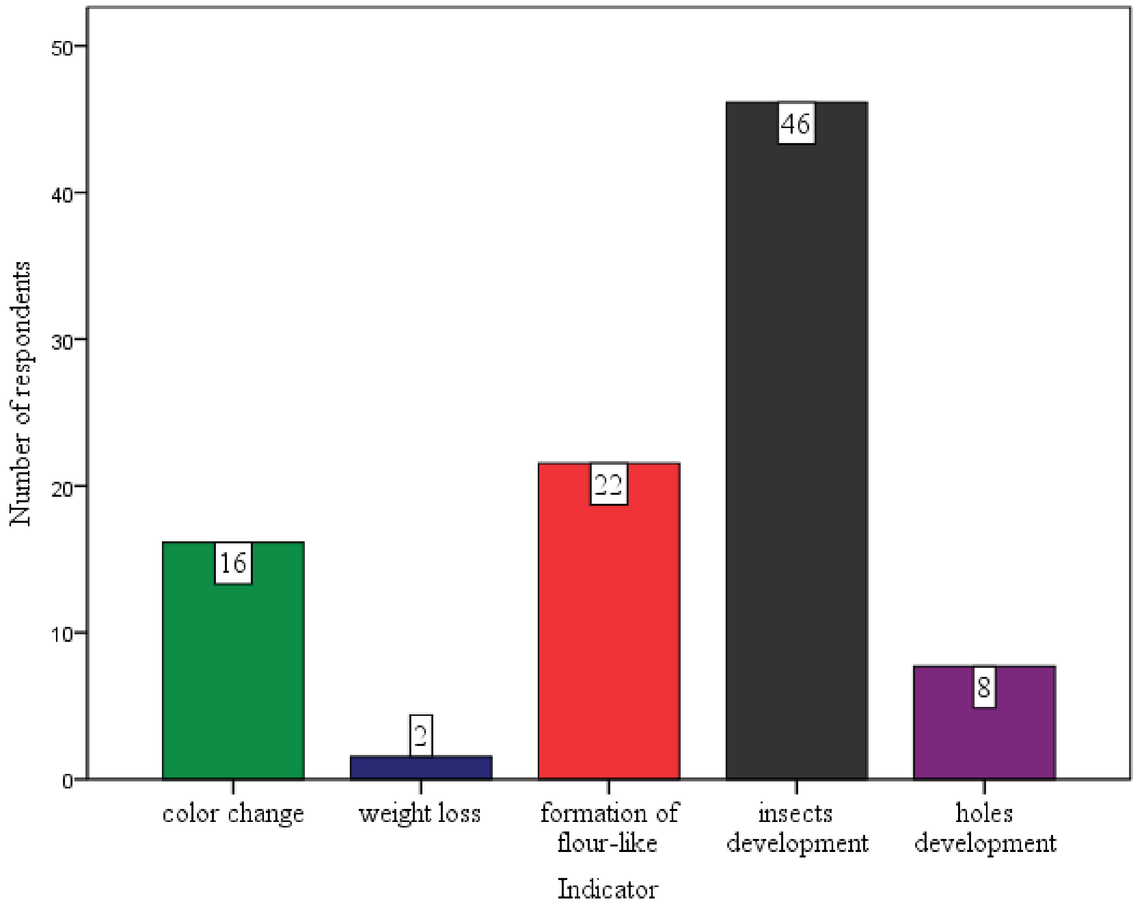

Figure 2.5: Indicators used in identifying beans attack by storage pest

2.4.2.3 Losses due to poor practices

(i) Shelling of beans

In Figure 2.6, almost the entire population (99%) removed beans from their pods using sticks (by beating). This is the most common method used by most of small-scale farmers, a practice that injures beans hence make them easy to be attacked by pests and also affects appearance and thus quality of the beans. Most of the farmers used this method because it was easy, cheap and it is used by family members to cut down costs of threshing at family/household level. This method also contributes to the loss but farmers did not seem to be concerned.

Post-harvest losses can be caused by mechanical damage and injury, physiological processes, poor handling, lack of processing, inadequate packaging, poor logistics and sub-optimal storage conditions (Chakraverty *et al.*, 2003).

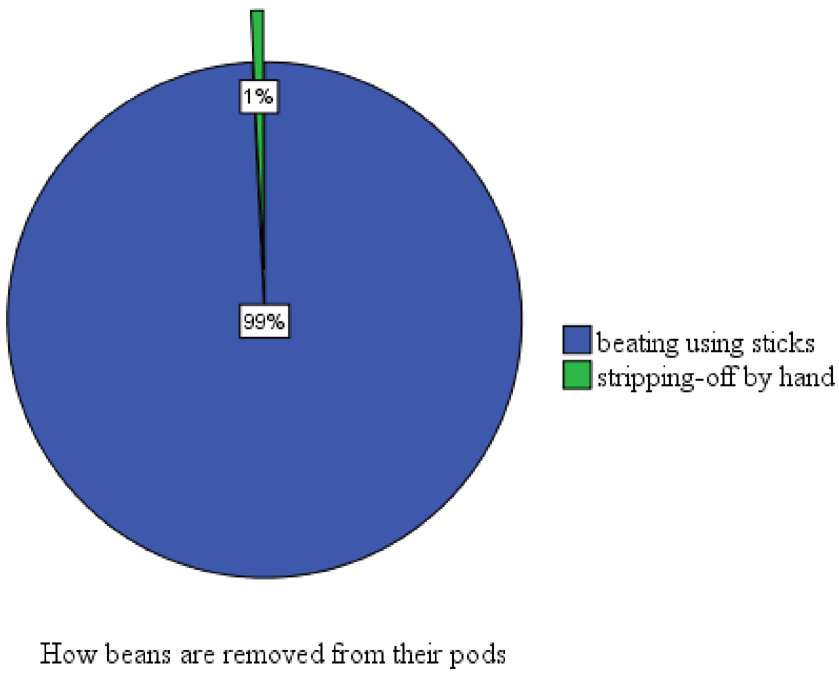

Figure 2.6: Handling practice of threshing beans

2.4.3 Storage technology used

According to the results (Figure 2.7), most of farmers used polypropylene bag (98%). Using this type of storage makes food loss inevitable. This type of storage technology does not guarantee quality and quantity of stored beans. It does not control air between beans and environment hence when relative humidity and temperature increase, the stored grains get affected, hence encouraging growth of moulds.

Storage structures (either traditional or modern) have been described as physical environment, medium or containers within which agricultural produce can be preserved against theft, pest and diseases for a desirable period of time (Agboola, 1999). Most new improved technological innovation packages are improperly set up and also very expensive for small rural farmers in Nigeria (Agboola, 2001).

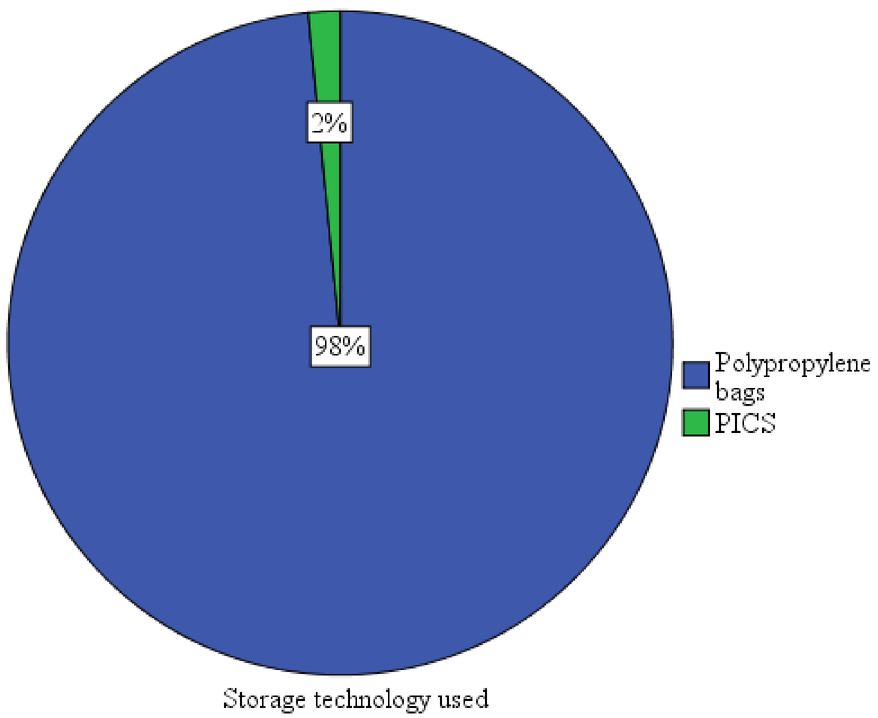

Figure 2.7: Technology used to store beans

2.4.4 Food security

Food and Agriculture Organization of U.N. predicts that about 1.3 billion tons of food are globally wasted or lost per year (Gustavasson, *et al.*, 2011). A reduction in food loss also improves food security by increasing the real income for all the consumers (World Bank, 2011).

2.4.4.1 Factors influencing access to food

From Figure **2.**8, it was shown that only 28% of all households interviewed were engaging in other economic activities, like animal keeping. This means, if farming goes bad, this may be due to natural disasters, like floods or drought where 72% of the families will likely become food insecure. Also, the results show there is inverse relationship between economic activities and number of household members. We do expect families with large number of members to have other economic activities so as to meet family needs, but it was not so for Malolo and Lumuma wards. Access to food depends upon income available to the household, distribution of income within the household and price of food (FAO, 2003).

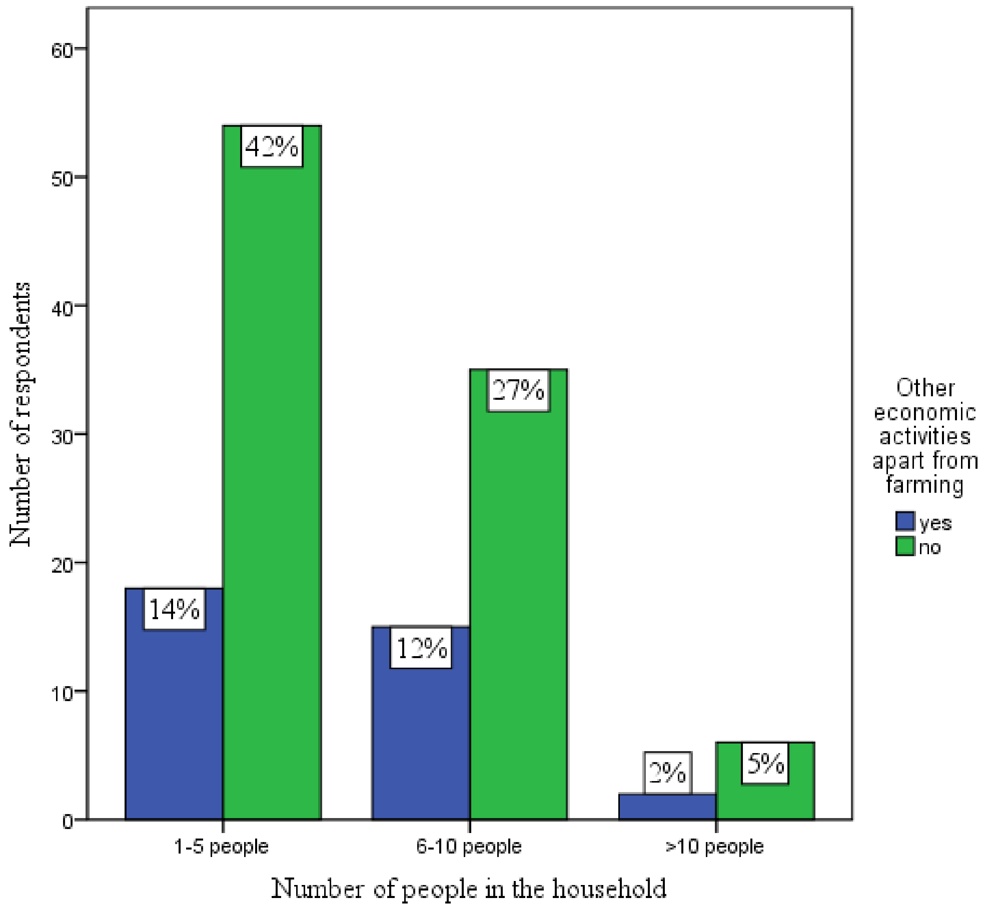

Figure 2.8: Relationship between number of people in the house and other economic activities apart from farming

According to the information received from Villlage Agricultural Officer (VEO), one acre produces 5-7 bags of beans, but results (Figure 2.9) showed that most farmers cultivated at most 1 acre and harvested 1 to 2 bags of beans. This affected access to food as they used a lot of input to cultivate but realized poor harvest hence loss of income. This loss looked normal to the society, because they considered agriculture as part of their life rather than agribusiness. They did not take precautions like the use of fertilizers or crop rotation.

According to Abass *et al*. (2014), during focus group discussions, low crop outputs were identified as a factor responsible for food insecurity. Also, 70% of the surveyed households attributed the low crop output to weather changes. Weather changes were described as erratic rainfall and low amount of rain with poor distribution, which negatively affected crop performance. In some occasions another factor was the planting of seeds close to the onset of rainfall, which did not guarantee good yield because the rainfall was inadequate to support crop growth. Again, weather changes were noted to aggravate postharvest losses; sometimes when mature crops needed to dry, suddenly rainfall was experienced. This caused significant food losses and reduced both the quantity and quality, in terms of nutrients and taste and significantly diminished the market value.

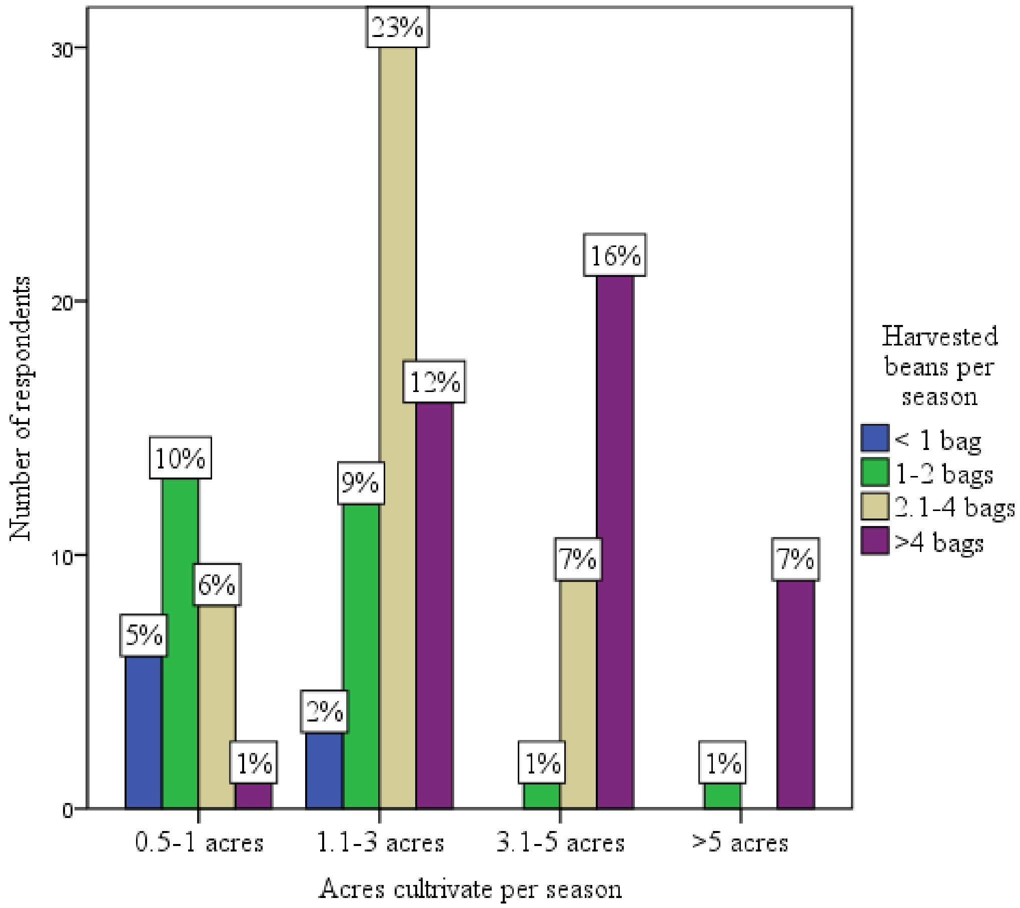

Figure 2.9: Relationship between land cultivated and amount harvested

Figures 2.10, 2.11 and 2.12 show the relationship between how much has been harvested and amount being stored with reference to the number of household members. Looking at the graphs there seems to be no relationship between amount stored and amount harvested with respect to the number of people in the household. Some harvested more but stored little for home consumption while others harvested more and stored more while they had few people in their households. This implies that there is little understanding on the issues of food security in the society.

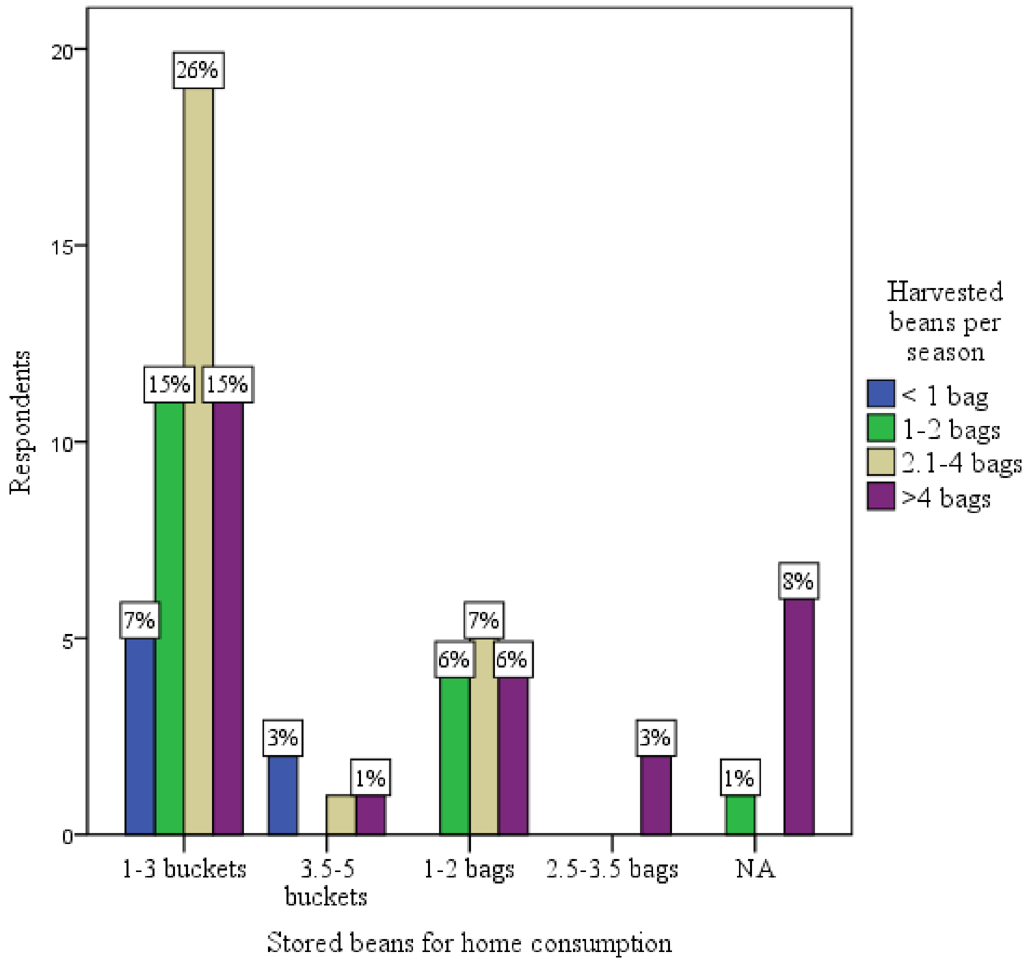

Figure 2.10: Amount of beans stored for home consumption with respect to the number of people (1-5 people)

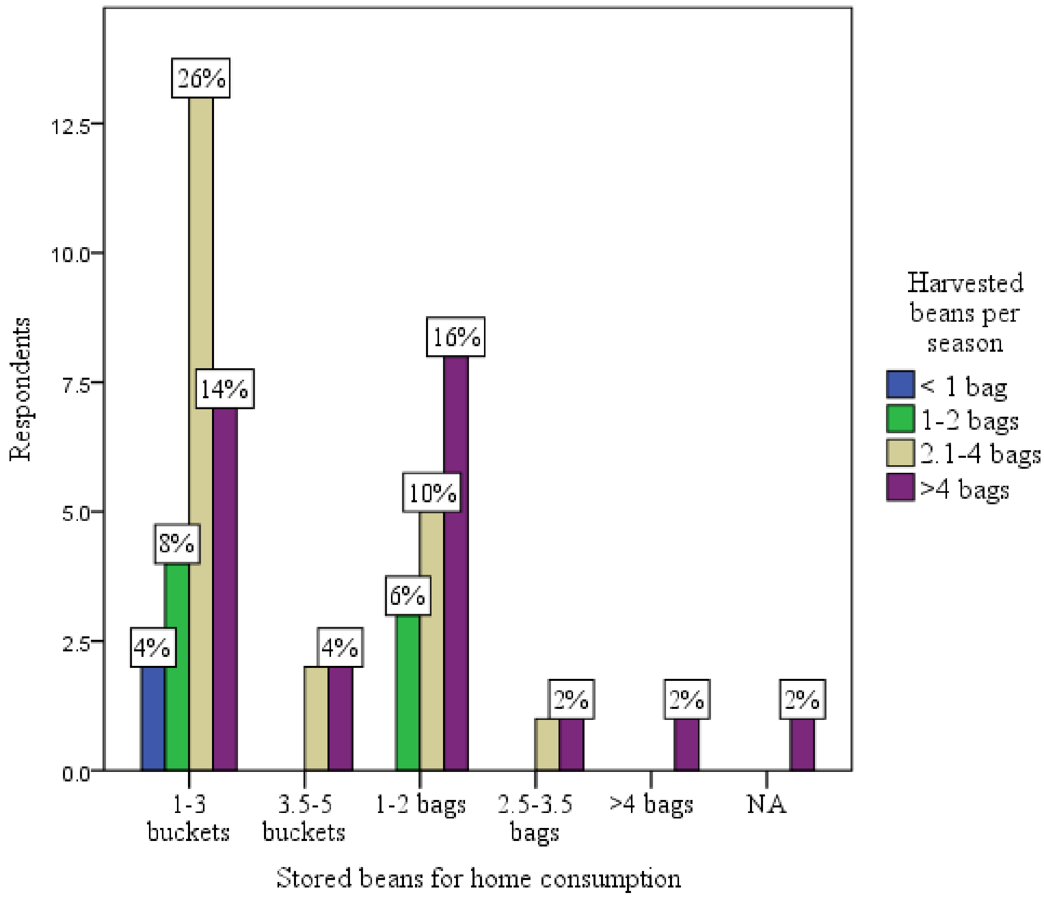

Figure 2.11: Amount of beans stored for home consumption with respect to the number of people (6-10 people)

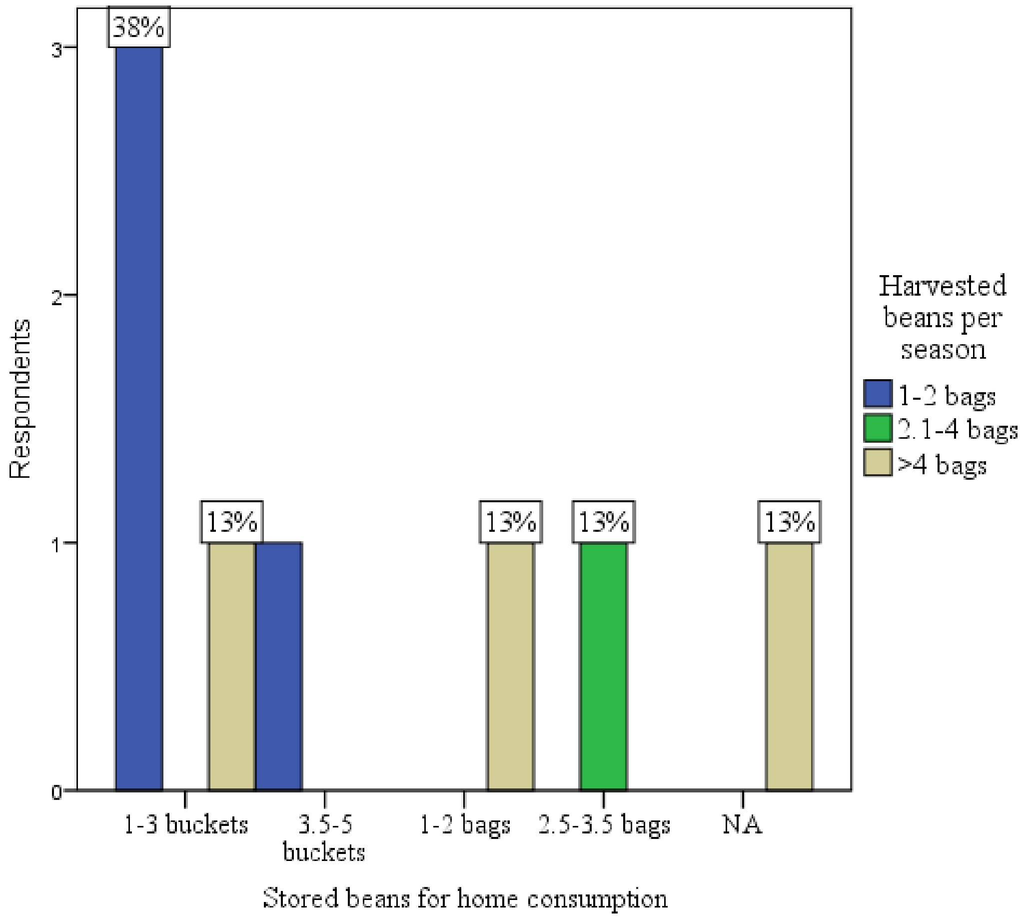

Figure 2.12: Amount of beans stored for home consumption with respect to the number of people (6-10 people)

2.4.5 Trainings and education on post-harvest management

Large number of the population seems not to receive formal or informal trainings about post-harvest management and food security issues. All farmers who were interviewed had not received any formal or informal training on post-harvest management (Figure 2.13). This has impact on both post-harvest loss reduction and food security among farmers' households. Extension officers mainly based on providing knowledge regarding good agricultural practices (GAP) and overlooked the issue of post-harvest loss, which has impact on agricultural yield and food security.

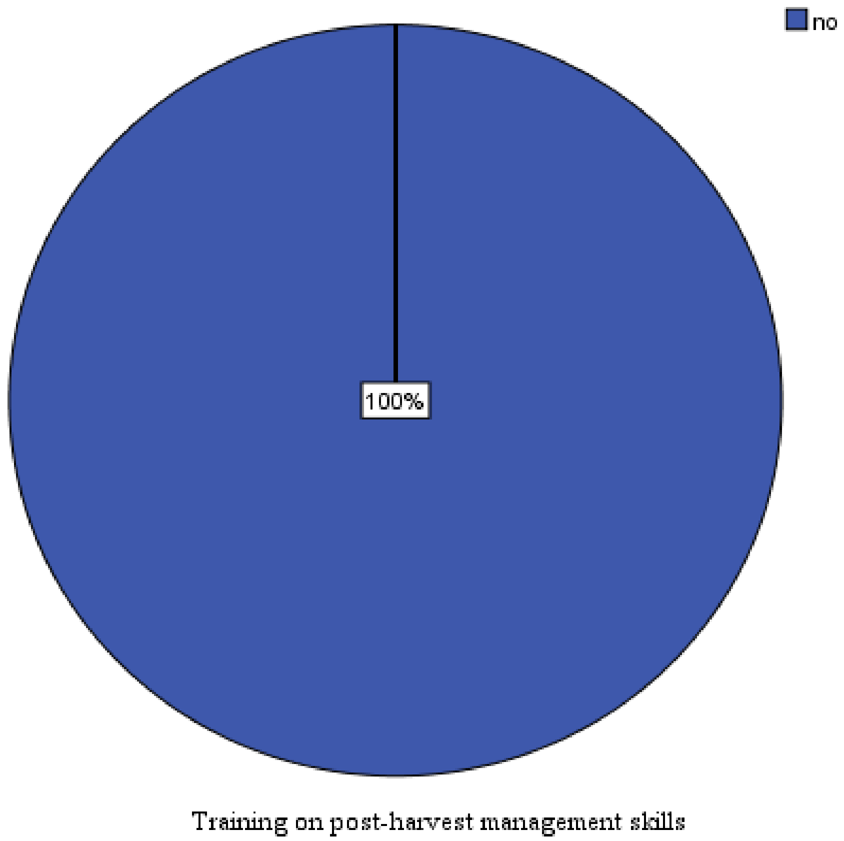

Figure 2.13: Training on post-harvest management

2.4.5.1 Knowledge on mycotoxin contamination

From Figure 2.14, almost half (46%) of the entire population indicated little understanding on the issue of mycotoxin, as 41% processed the damaged beans to food (*kihembe*) and 5% gave damaged beans to chickens. These two groups are in danger of food intoxication because the damaged beans could be potential sources of mycotoxins. These results show that there was little knowledge on the issues of mycotoxin contamination and other complications associated with consumption of cereals which are damaged by moulds.

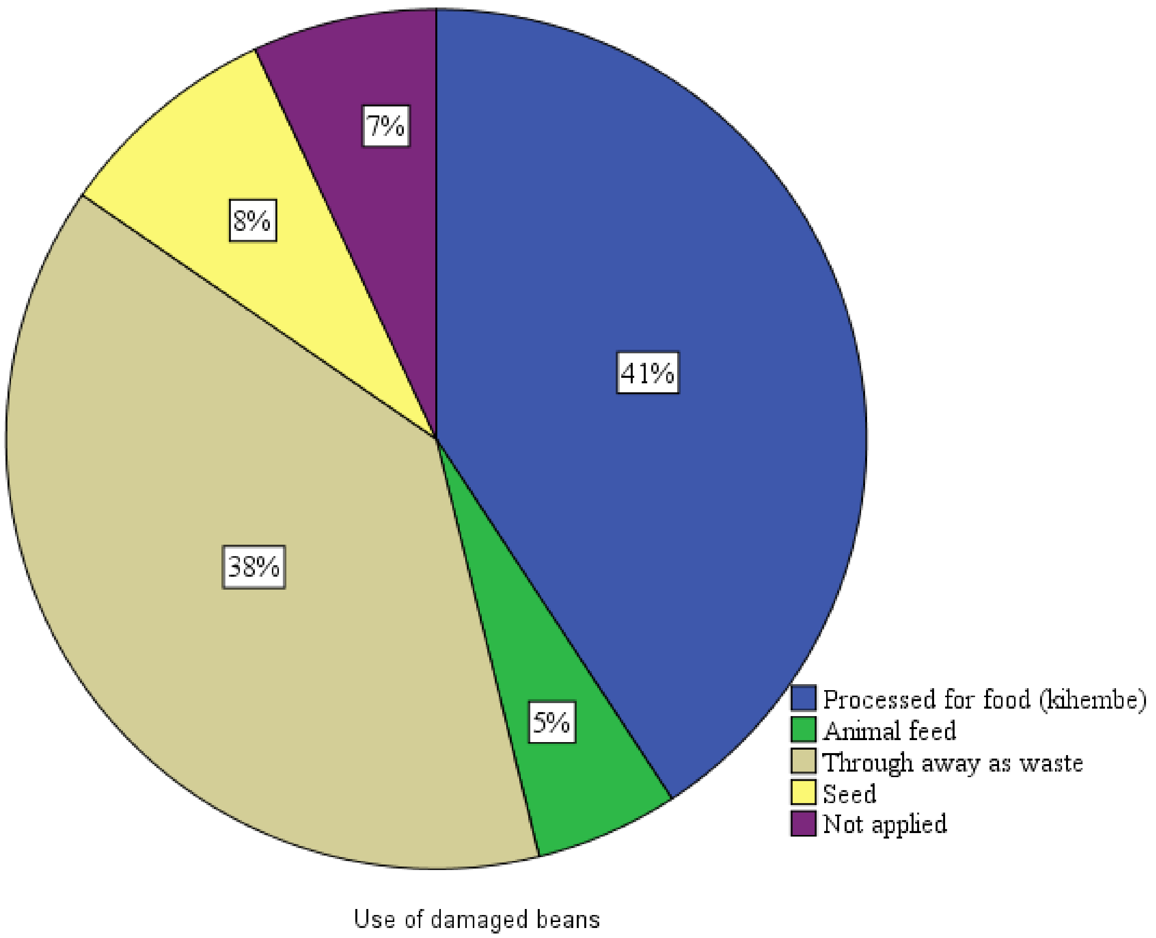

Figure 2.14: Use of damaged beans

2.5 Conclusions and Recommendations

Post-harvest loss knowledge among farmers of Malolo and Lumuma wards in Kilosa district was poor although there were some operations they performed that reduced loss, for example drying beans after harvesting. Metal silo technology was new to a large percent of farmers when compared to that on hermetic bags. Therefore, more efforts are needed to spread these hermetic technologies among small scale farmers to rescue post-harvest losses.

One of the observations showed that community processed damaged beans and used as food (*kihembe*). These damaged beans could be a source of mycotoxins. The poor knowledge on the issue of aflatoxin, coupled with poor post-harvest loss knowledge put this community at the risk of contamination and a threat to health as well as food insecurity resulting from post-harvest losses.

From this study, it is recommended that knowledge in post-harvest management and mycotoxins need to be availed to farmers in the study wards. Hermetic storage proved more effective than other technologies used in bean storage. GPLP project need to explore possibility of introducing these hermetic storage technologies to these wards to help farmers in extending shelf life of beans stored in the households. Proper drying of beans to recommended moisture level seems essential in suppressing microbial growth that could consequently encourage mycotoxin production and health problems to bean consumers.

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CHAPTER THREE

3.0 EFFECTIVENESS OF DIFFERENT STORAGE TECHNOLOGIES OF BEANS

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3.1 Abstract

Effectiveness of different storage technologies (metal silo, polypropylene bag and Purdue Improved Cowpea Storage (PICS)) in beans storage was evaluated using laboratory analysis, whereby three technologies were compared with reference to percentage bean damage, low moisture level maintenance and challenges on the use of technology. Beans were kept for six months and analysis was based on the interval of three months. Data were analysed using SPSS v20 and Microsoft Excel 2016. In the first three months, there was no significant difference ($P<0.05$) in moisture content between three technologies, however variation in moisture content started to occur beyond three months of storage. The overall results based on low moisture level maintenance showed that metal silo performed better than PICS and polypropylene bag with the average mean of 14, 15 and 15.7 % respectively. The mean percentage bean damage were 23.6, 15.2 and 6.4% for polypropylene bag, silo and PICS, respectively. After 180 days of storage all samples from three technologies were found contaminated by aflatoxin producing microorganisms with average mean of 3.1×10^4 for PICS, 5.0×10^4 for Silo and 2.8×10^5 for Polypropylene bag CFU/g. Therefore, farmers should be provided with technology that is effective but also affordable and safe. According to the results, PICS is recommended for use to reduce losses that will positive effect in assisting fighting against hunger. Metal silo also showed good results but the issue of price and other challenges on the use, required farmers to produce large amounts of grains so as to counter the issue of price and headspace challenges need to be addressed as well.

3.2 Introduction

World population has been predicted to reach 9.1 billion by 2050 and this will require a 70% increase in food production. Almost all of this growth will occur in less developed countries including Africa. However, Africa is suffering from 20-30% post-harvest losses of cereals valued at 4 billion dollars annually (Word Bank, 2011). Traditional storage practices in developing countries cannot guarantee protection against major storage pests of staple food crops like maize. The lack of suitable storage structures for grain storage and absence of storage management technologies often force the smallholder farmers to sell their produce immediately after harvest. Consequently, farmers receive low market prices for any surplus grain they may produce (Kimenju *et al.,* 2010). Safe storage of maize at the farm level is crucial, as it directly impact on poverty alleviation, food and income security and prosperity for the smallholder farmers. Without appropriate grain storage technologies, farmers are forced to sell maize when prices are low, to avoid post-harvest losses from storage pests and pathogens. For this reason, they cannot use their harvest as collateral to access credit and ultimately their food security is undermined (Semple *et al.,* 1992). Therefore, food security and safe storage at the farmer level go hand-in-hand. As well as providing food security at times of scarcity, effective grain storage is an inflation-proof savings bank whereby grains can be cashed as needed or used directly as a medium of exchange (i.e., in payment for work such as field clearing and weeding) (Thamaga-Chitja *et al.,* 2004).

Adoption of appropriate and effective methods of grain storage can significantly improve the quality and quantity of grain at outturn. For this reason, there has been a strong focus on the extension/modification of existing store types as well as on the introduction of new storage types. Modified farm stores can provide solutions to long-standing storage problems in Africa and elsewhere. While grain storage structures help to protect against crop losses from insects, rodents, moulds, theft, and fire, traditional designs are not always effective, and building them is difficult for poor communities where the hardwood supply is limited due to deforestation (World Bank, 2011).

3.3 Materials and Methods

3.3.1 Study area

The study was conducted in two wards namely, Malolo and Lumuma in Kilosa District, Morogoro Region, Tanzania. The district lies between 6°S and 8°S, and 36°30’E and 38°E. The district experiences an average of eight months of rainfall (October–May), with the highest levels between February and March. The rainfall distribution is bimodal in good years, with short rains (October–January), followed by long rains (mid-February–May). Mean annual rainfall ranges between 1,000 and 1,400 mm in the southern flood plain. The mean annual temperature in Kilosa is about 25°C (Nduwamungu *et al*., 2004). The wards were purposively selected because of Grain Post-harvest Loss Prevention Project (GPLP-project) that is being implemented in Kilosa District and the wards represent wards with high production of beans in the district.

3.3.2 Study design and sample collection

A longitudinal study design was employed in this study, whereby the samples were studied over a period of six months. This design is suitable for this study because the objective of the research was to identify and relate beans moisture content, seed damage and aflatoxin producing microorganisms in metal silo, polypropylene bag and PICS over a period of six months.

Samples of harvested beans were selected randomly from farmers of Malolo and Lumuma wards. A total sample of 500 kg of beans was collected, dried for 3 days and sorted to remove damaged grains prior to storage (six months). Beans were mixed manually using hands to reduce bias and errors since beans were taken from different farmers.

3.3.3 Data collection

3.3.3.1 Moisture content

Moisture content of beans was obtained as per International Seed Testing Association (ISTA) (2017), using high oven drying method, whereby beans from three storage technologies (metal silo, polypropylene bag and PICS) were randomly picked from their respective technology and size reduced by using grinder, then sieved to the required coarseness to pass through 4 mm sieve as per this standard method and measured the weight of 5 g from this sample (W_2). This sample was placed in an empty pre-dried container (W_1). Then, the bean sample was oven dried for one hour at 130^0C. Thereafter, the container and dried sample were cooled and weighed (W_3). The moisture content was calculated by;

$$Moisture\ content = \frac{\{W2-W3\}}{\{W3-W1\}}\ X\ 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textbf{(equation 1)}$$

3.3.3.2 Weight loss

The count and weigh method is the most common method to measure loss by insect pests in storage (Adams and Schulten, 1978). The weight loss in the sample is estimated by calculating the average loss per damaged grain. This is determined by the difference between the average undamaged grain weight (Wu) and the average damaged grain weight (Wd) and multiplying this by the number of damaged grains (Nd). The percentage loss is calculated as the weight loss over the estimated weight of the sample if none of the grains was damaged. This in turn, is determined by multiplying the average undamaged grain weight by the total number of grains in the sample, damaged as well as undamaged (Nu) (Harris and Lindblad, 1978).

$$\%weight\ loss = \frac{(\mathrm{Wu} - \mathrm{Wd})\mathrm{Nd}}{\mathrm{Wu}(\mathrm{Nu} + \mathrm{Nd})} \quad \ldots\ldots\ldots.. \qquad (\textbf{equation 2})$$

Boxall (1986) developed another formula which involve correction factor because the count and weigh method tends to underestimate loss at low levels of infestation;

$correction\ factor = \frac{\%\ \text{grain damage}}{\%\ weight\ loss}$ ……………………...................................**(equation 3)**

$\%\ grain\ damage = \frac{\text{No of damaged beans}}{\text{Total No.of beans}}\ x\ 100\%$ **………………………….. (equation 4)**

in this study percentage grain damage was used to determine weight loss since so far there is no documented correction factor for pulses (beans).

3.3.4 Analysis of aflatoxin producing microorganisms

3.3.4.1 Sample preparation

Dried beans were ground and sieved (using 0.5 mm sieve) to obtain fine powder. Thereafter, 1 g of flour was mixed with 5 mL of 0.1% peptone water. The 0.1 % peptone water was prepared by dissolving 0.1 g of peptone powder to 100 mL of distilled sterilized water as per media preparation protocol. Serial dilutions were performed for all samples, whereby 0.5 ml of sample solution was mixed with 4.5 mL of 0.1% peptone water for 3 serial dilutions.

3.3.4.2 Media preparation, inoculation and incubation

Aspergillus flavus and *parasiticus* agar (AFPA) (22.75g) was suspended in 500 ml of distilled water and heated to dissolve completely. Then the mixture was autoclaved at 121 °C for 15 minutes. Thereafter, the mixture was cooled to 50°C, then 1 ml of 50 mg/ml sterilized chloramphenicol solution was added as per media preparation protocol. Then, the mixture was poured into the petri dishes followed by inoculation of samples. Samples were incubated for 3 days at 28-30^{0}C. After incubation, colonies were counted and presented in CFU/g as per Nyirahakizimana (2013). The expression was as shown in equation 5.

$$\mathbf{CFU/g} = \frac{\text{colony counts}}{\text{(volume plated x dilution factor)}}$$ .... (*equation 5*)

$$\mathbf{D}\boldsymbol{ilution\ Factor} = \frac{\text{initial volume}}{\text{final volume}}$$ .... (*equation 6*)

3.4 Statistical Analysis

Data were analysed using SPSS v. 20 and Microsoft excel. One-way ANOVA was used to determined significant variation between assessed parameters and graphs were plotted using Microsoft excel.

3.5 Results and Discussion

3.5.1 Moisture content

Results (Table 3.1) showed that, after three months of storage there was significant ($P<0.05$) difference among the three storage technologies (silo, hermetic bag and polypropylene bag).

Table 3.1: ANOVA table of moisture content comparison among different storage technologies after three months of storage

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	237.9497	2	118.9749	85.17303	7.53E-18	3.158843
Within Groups	79.62106	57	1.396861			
Total	317.5708	59				

The results show (Table 3.2) metal silo maintained the level of moisture by 90%, hermetic bag (PICS) by 92% and polypropylene bag (86 %). The trend is shown in Figure 3.2.

Table 3.2: Percentage moisture level maintenance

Technology	Day	Average moisture content	Moisture maintenance (a/b)*100%
Silo	0 (a)	13.44660071	
	180 (b)	14.99009924	90
Polypropylene bag	0 (a)	13.32083406	
	180 (b)	15.47702271	86
PICS	0 (a)	14.16433081	
	180 (b)	15.46746096	92

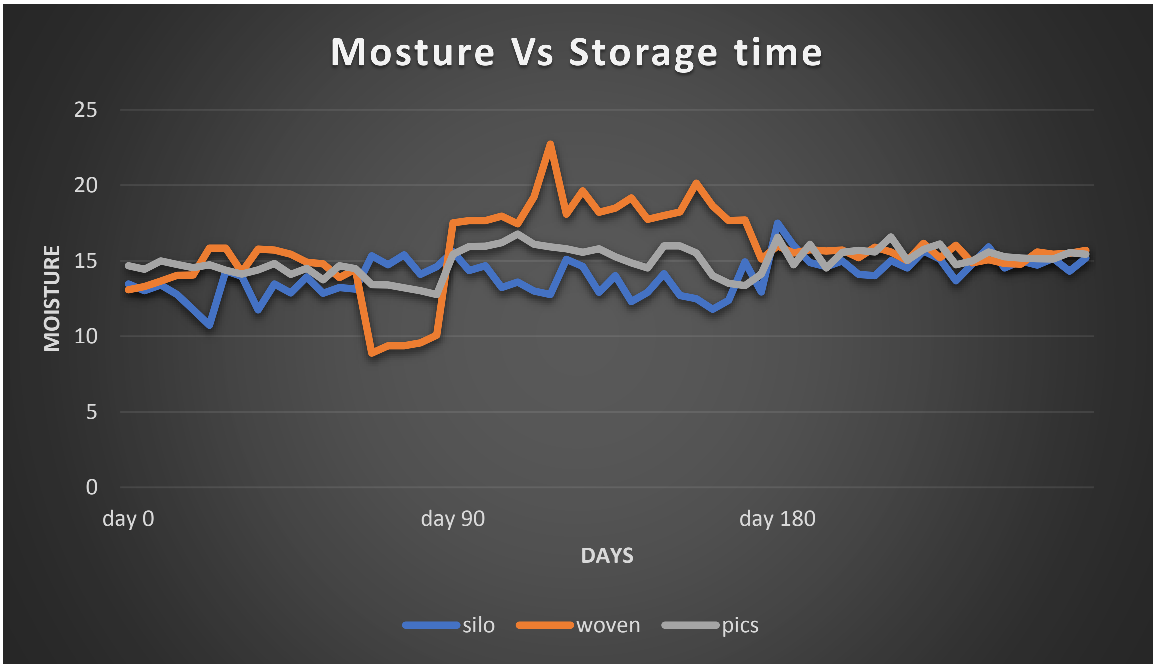

Figure 3.1: Moisture content level trend in 180 days

After 180 days, the performance of all storage technologies appeared to be similar, although after running statistical analysis there was significant difference in moisture content at $p<0.05$ between polypropylene bag and metal silo; metal silo and PICS. However, there was no significant difference between PICS and polypropylene bags (Table 3.3).

Table 3.3: ANOVA table of moisture content comparison among different storage technologies

Dependent Variable			Mean Difference (I-J)	Std. Error	Sig.
Moisture_content_day_180	Silo	Polypropylene bag	-.48692*	.19959	.018
		PICS	-.47712*	.19959	.020
	Polypropylene	Silo	.48692*	.19959	.018
		PICS	.00980	.19959	.961
	PICS	Silo	.47712*	.19959	.020
		Polypropylene bag	-.00980	.19959	.961

*. The mean difference is significant at the 0.05 level.

PICS and silo were expected to perform similarly but the outcome was different. This can be explained by the fact that during sample taking from the silos for analysis, silos were opened and inevitably allowed air to flow in. To remove the air in PICS (headspace) was easier than for metal silo. Therefore, enough air was retained in the metal silo, which led to the growth of bruchids resulting to moisture and temperature rise due to their respiratory activities. For the case of polypropylene bag, the moisture content seemed to decrease. This can also be explained based on the humidity of the surroundings. There were changes in humidity from 0.96 (i.e., 96%) to 0.86 (i.e., 86%) during storage time. As a matter of fact, polypropylene bags were affected by the external factors (temperature and humidity).

This was also observed by Chigoverah and Mvumi (2016), whereby the moisture content decreased with time in non-hermetic treatments (untreated control and synthetic pesticide) regardless of the mode of infestation. A fairly constant pattern was observed in hermetic treatments (metal silo and Super Grain Bag (SGB)) although slight fluctuations were observed between four and eight months of storage. Non-hermetic treatments allow interaction of stored grain with dynamic external environment (Baoua *et al*., 2014), hence, experience continuous moisture sorption and loss cycles in attempt to achieve equilibrium moisture content with the environment (Chigoverah, and Mvumi, 2016). Therefore, due to the rapid fall of humidity (from 0.96 to 0.86), the moisture content of beans fell simultaneously to the extent that there was no significant difference between polypropylene bag and PICS after 180 days. This is also consistent with the study results obtained by Abbas *et al.* (2017).

3.5.2 Weight loss

Results obtained were calculated in terms of percentage beans damage (equation 4), which is proportional (mathematically) to weight loss. Statistically, there was a significant difference between three groups (Silo, PICS and Polypropylene bag) at $p<0.05$. The mean percentage bean damage was 23.6, 17.4 and 6.4% for polypropylene bag, silo and PICS, respectively. Polypropylene bags caused more damage compared to PICS and silo (Fig. 3.2). There was statistical difference between the group means $p= 0.000546$ (Table 3.3). Silo seemed to cause more beans damage compared to PICS. Quality grain damage usually refers to physical spoilage or the apparent evidence of deterioration such as holes, cracks and discolouration. It is of a qualitative nature and is usually reported as a percentage of grains damaged in a sample. Grain weight loss, on the other hand, refers to the disappearance of food and is usually expressed as a percentage weight loss (Boxall, 2002). Chigoverah and Mvumi (2016) reported that at the end of the storage period, the effectiveness of treatments in controlling weight loss was as follows metal silo (<7%), Super Grain Bag (SGB) (<12%), untreated control (<27%) and synthetic pesticide (>34%). There were no significant differences between hermetic treatments (silo and SGB) regardless of the mode of infestation.

Table 3.4:ANOVA table for percentage beans damage

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3041.886	2	1520.943	8.595051	0.000546	3.158843
Within Groups	10086.47	57	176.9557			
Total	13128.36	59				

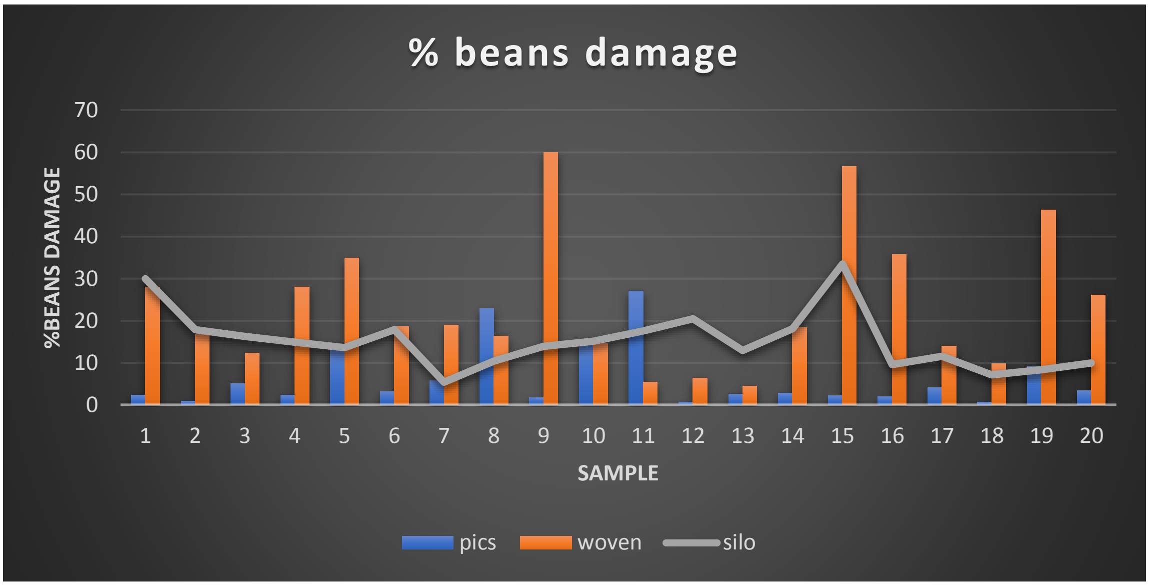

Figure 3.2: Percentage beans damage in three storage technologies

According to Chigoverah, and Mvumi (2016), hermetic treatments were equally effective in suppressing grain damage and were more effective than non-hermetic treatments (polypropylene bag). Both metal silo and super grain bag treatments with lower grain damage levels managed to suppress grain dust production compared to non-hermetic treatments. The methods of assessing weight losses caused by insects can be used for assessing losses due to mould, and inevitably, the estimates of losses due to insects often include an element of loss due to mould (Boxall, 1986). Therefore, losses that were caused by growth of mould were incorporated in weight loss due to insects as explained above.

3.5.3 Aflatoxin occurrence

The results showed that, the average CFU/g after 180 days of storage were 3.1 x 10^4 for PICS, 5.0 x 10^4 for Silo and 2.8 x 10^5 for Polypropylene bag. According to the research conducted by Nyirahakizimana (2013) on raw peanuts, the relationship between the level of aflatoxin and the number of microorganisms was demonstrated by the graph equation $y=0.032x + 31.49$ which was obtained from a graph of the population (CFU/g peanuts) of *Aspergillus flavus* (L and S strains) and *A. parasiticus* against aflatoxin level in raw peanuts, where x= CFU/g and y= aflatoxin level. If the same equation to find the level of aflatoxin in the beans samples from different storage technologies is applied, the results would be 1.0 x 10^3 µg/kg for PICS, 1.6 x 10^3 µg/kg for Silo and 9.1 x 10^3 µg/kg for polypropylene bag. The maximum tolerance level of aflatoxin in beans as per East African Community standards (EAC) is 10 µg/kg (EAC, 2011). Therefore, all the samples were out of tolerance level. However, presence of aflatoxin producing microorganisms gives a warning to take precautions and that there is a high possibility of beans to be contaminated with aflatoxin. Aflatoxins are a group of mycotoxins that adversely affect food safety, mainly of grains and peanuts, as well as trade and human and animal health. Aflatoxins are the most toxic and carcinogenic compounds among the known mycotoxins and are mainly produced by *Aspergillus flavus* and *A. parasiticus* (Yu *et al.*, 2005 and Paterson and Lima, 2010).

3.5.4 Challenges on the use of technologies

3.5.4.1 Metal silo

The on-station results showed that metal silos are effective in bringing the losses to zero if properly used. The proper usage includes testing grain moisture content and depletion of oxygen by burning candle inside the silo. Therefore, the most important prerequisite for effective storage of the grains in the metal silo is checking the moisture content of the grain (International Maize and Wheat Improvement Center, 2011). Although they work well and have potential in improving household food security and income from maize, metal silos are expensive, going to KSh 18,000 (US$ 210) for a 1-ton silo, the size that is commonly ordered by the farmers and the smallest size is considered to be cost effective (Kimenju and Groote, 2009). As a result, most farmers are not able to buy them unless subsidized or through group credits (Ndegwa *et al*., 2015).

During storage, one of the most challenging experiences was air penetration. According to observations during the study, this was caused by poor design of the silo and material used to make the structure airtight (using cellotape). Cellotape does not guarantee to coherence to the silo throughout the storage time. Therefore, air penetrates and disturbs air equilibrium inside the silo resulting into bruchid growth and moisture rise. Also, the price of metal silo was higher compared to the other technologies. This hinders its adoption by small scale farmers. This has also been observed by other researchers (Maonga *et al*., 2013). Lastly, silos have to be filled to the top, otherwise, if head space remains, the air in the headspace will support the growth of bruchids, which will damage the beans. Abbas *et al.* (2017) reported that, effectiveness of the metal silo under the farmers' conditions could be affected, taking into account the farmers' practice of repeatedly opening their storage containers to withdraw household food.

3.5.4.2 PICS bag

During storage there were some few observations as weak point of PICS bag. Bruchids were able to make holes on the two layers of polyethylene, hence compromise the concentration of air inside the bag, in few bags. De Groote *et al.* (2013) reported the same issue of perforation of bags in maize, caused by grain borer. Damage by rodents on the outer polypropylene bags was common and was reported by roughly a quarter of the participating farmers, substantially more by the control farmers (35%) than by the treatment farmers (20%) (Ndegwa *et al*., 2015).

PICS bag is a simple, low-cost triple bagging technology originally developed for post-harvest storage of cowpea but had been evaluated for applicability to maize storage mainly in West Africa (Baoua, *et al*., 2014). The three layers include an outer polypropylene bag and two inner linings of high-density polyethylene (HDPE). Trials have shown that PICS bags can be used for maize storage even in areas with high prevalence of larger grain borer, but storage of maize should begin soon after harvest and drying to minimize bag damage that can occur when very high numbers of larger grain borers are present (Baoua *et al*., 2014).

The issue of price and availability of these bags is also a challenge to most of farmers. Most of the farmers used the same polypropylene bag for harvesting, winnowing and storage. PICS bags cannot be used for harvesting and winnowing and still remain good for storage. Low availability of the technology limits farmers access to it. Therefore, farmers who are willing to use it, cannot access it easily.

3.5.4.3 Polypropylene bags

According to observations from this study, polypropylene bags were just for short time storage and not otherwise, like using them for transportation. Polypropylene bags face many challenges when used as a long-term storage technology. These bags are highly supportive to growth of both micro- and macro-organisms, hence compromise quality of grain. During the middle part of storage time, the storage room was full of bruchids from polypropylene bags. This was because these bags allowed free flow of air in and out of the bag. Both temperature and moisture affected the grain since there was no effective barrier.

Grain damage of maize in untreated polypropylene bag was high reaching 58.3% compared to all the hermetic storage treatments that were in the range of 7.0 to 10.9%. However, no significant differences were observed among the remaining treatments, irrespective of the use of insecticide whether combined with hermetic storage or not (Abbas *et al.*, 2017).

3.5 Conclusions and Recommendations

Effectiveness of different storage technologies on beans showed future promise on post-harvest loss prevention. Effectiveness was measured by considering different factors (moisture content, weight loss, beans quality and challenge on the use). Performance of metal silo and PICS bags provided good results compared to polypropylene bag (polypropylene) despite of their weaknesses. PICS bags performed better than silo, price was affordable and they were easy to find. Metal silos can be good to farmers whose production is high and who can afford the price. To make metal silo widely accepted provision of subsidy looks necessary. Education on mycotoxins and their effects on consumers' health need to be provided to the community to increase their awareness and knowledge of post-harvest management of beans.

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APPENDICES

Appendix 1: Questionnaire

Personal information

Name……………………..……….. Ward…….………. Village…………..……

Occupation 1= farmer 2= trader 3= public servant 4= entrepreneur

Age 1= (15-24), 2= (25-34), 3= (35-44), 4= (45-54), 5= (55 and above)

Sex: male ( ). Female ( )

Marital status 1= Single, 2 = Married, 3= Widowed 4= Divorced 5= Separated

Education level 1=Uneducated 2=Primary school 3=O-level 4=A-level 5=Collage/University

1. How many acres of beans do you cultivate per season 1= 0.5-1 acre, 2= 2-3 acres, 3= 4-5 acres, 4= 6 and above
2. Do you cultivate beans for? 1= Food 2= cash 3= cash and food 4= specify
3. How much beans do you harvest per season 1= 1-25 kg 2= 25-50 kg, 3= 50-100 kg, 4= 100-200 kg 5= 200 and above.
4. Do you sell beans immediately after harvesting? 1=Yes 2=No
5. If no how much do you store for home consumption? 1= 1-25 kg 2= 25-50 kg, 3= 50-100 kg, 4= 100-200 kg 5= 200 and above.
6. If yes how much do you sell? 1= 1-25 kg 2= 25-50 kg, 3= 50-100 kg, 4= 100-200 kg 5= 200 and above.
7. Why do you sell such amount? 1= I have surplus 2= difficult in storage 3= Poverty 4= specify
8. Which technical method do you use in threshing your beans? 1= Machine, 2= beating using sticks 3= strips-off by hands 4= if others, specify
9. How long do you take to harvest your beans when are fully matured? 1= 0-1 month, 2= 1-2 months 3= 2-3 months
10. Do you dry your beans after harvesting? 1=Yes 2=No

11. If the answer is no why? 1= already dried 2=lack of drying materials 3= ate by birds and rodents 4= other specify
12. If the answer is yes, how long do you dry 1= 1-7 days, 2=7-14 days 3= 14-21 days 4= 21-28 days 5= 30 days and above
13. Why do you dry your beans 1= for longer storage 2= To reduce weight 3=for milling 4= specify
14. How do you know the beans are dried and ready for safe storage? 1=chewing 2=observing 3=time used for drying 4=pounding 5= if other specify
15. How long do the beans store in the protected form before spoilage starts? 1=1-2 months 2= 3-4 months 3=5-6 months 4= above 6 months
16. Do you experience beans damage in storage every year? 1= yes 2 = No
17. What are the main agents of deterioration 1= bruchids/insects 2= rodents 3= moulds 4= specify
18. What indicator do you use to show you that your beans has been attacked 1= colour change, 2=weight loss, 3=formation of flour like 4= bruchids development 5= specify
19. For how long after beans storage do you observe pest, rodent and mold attacks 1= 1-3 months, 2= 3-6 months 3=6-9 months 4=specify
20. How much do you lost due storage pest, rodent and mold 1=1-20 kg 2=20-30 kg 3=30-40 kg 4=40-50 kg 5=specify
21. For what purpose do the damage beans be used 1= processed for food 2=animal feed 3= through away as waste 4=specify
22. Which storage technology do you use to store your beans? 1= polypropylene bag 2=buckets 3=traditional silo 4= specify
23. Why do you use such technology (xii) 1= It is cheap, 2= It is effective 3= I have no other option 4=specify

24. Do you know the presence of other effective technologies like metal silo? 1=Yes 2=No
25. Do you know the presence of other effective technologies like hermetic bags? 1=Yes 2=No
26. If the answer is yes in (24) have you ever tried to use one of them? 1=Yes 2=No
27. Do you still using the technology? 1=Yes 2=No
28. If no in (27) why? 1= It is expensive 2= Not available to our area 3= specify
29. If the answer is no in (24 and 25), are you interested to know about those technologies? 1=Yes 2= No
30. What kind of treatment method do you use to store your beans? 1=traditional 2=chemical
31. If tradition, which material do you use 1=wood ash 2=rice husk 3= neem 4=specify
32. If chemicals, which type do you use 1= Actellic super dust 2=shumba 3=actellic liquid 4= specify
33. For how long do you keep/store your beans before selling or using for food, 1=1-3 months 2=3-6 months 3= 6-9 moths 4=specify
34. Why do you store in such storage time 1= lack of food 2= surplus of food 3=no storage facilities/destroyed by pests and rodents 4=income instability 5= specify
35. Have you received any form of training on postharvest management of beans? 1= Yes 2=No
36. If yes, for how long you were trained?
37. Was it beneficial? 1= yes 2=No