CONSTRAINTS AND OPPORTUNITIES FOR INCREASING THE ADOPTION OF TECHNOLOGIES FOR REDUCING POSTHARVEST MAIZE LOSSES IN SUB - SAHARAN AFRICA: A CASE STUDY OF ZAMBIA.

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Abstract

The annual global food wastage of 1.3 billion tons valued at US$ 2.6 trillion impedes food security and precipitates climate change. There is a need to increase food production to feed the estimated 9.1 billion people by 2050. Grain losses in sub-Saharan Africa are about 50% with an estimated value of US$ 4 billion. Reducing food wastage is one approach to increase food availability.

The inadequacy of information on postharvest losses makes Zambia suitable for such a study. Despite the availability of technologies for reducing postharvest losses, their adoption remains low among smallholder farmers in Zambia.

The study used the interpretive paradigm to investigate and explain the factors responsible for the low technology adoption by farmers. Empirical data was collected using the case study strategy. The study adopted the Unified Theory of Acceptance and Use of Technology framework. Data collected from 100 respondents was analysed using the Statistical Package for Social Scientists and the Grounded Theory approach.

The study findings are presented as factors responsible for the low adoption of technologies for reducing postharvest maize losses by farmers in Zambia. These factors include lack of information and knowledge of the available technologies and associated benefits, perceived cost, non-availability and challenges of operating the technologies.

With support from literature the study findings have been used in developing the CAD and Cooperative Postharvest Management Models for increasing technology adoption.

In terms of contribution to knowledge and practice the study played a role in developing the Food Loss and Waste Accounting and Reporting Standard. Furthermore, it strengthened the food and income security of farmers and grain traders in the region through capacity building. Additionally, it helped to increase the number of farmers using the hermetic storage technology. The study also enriched the database on the prevalence of the larger grain borer in Zambia.

LIST OF PUBLISHED PAPERS

i. Chikoye D M, Gupta N K, Kandadi K R, Application of UTAUT in understanding the adoption of technologies for reducing postharvest maize losses in Zambia, International Journal of Agriculture and Environmental Research (ISSN 2455-6939), Vol 4, No.3, 2018 pp 610-636. June 2018. Available at: www.ijaer.in/more2018.php?id=49.

ii Chikoye D M, Gupta N K, Kandadi K R, "Bags to bulk storage approach for reducing maize postharvest losses in Malawi, Mozambique and Zambia", International Journal of Agriculture and Environmental Research (ISSN 2455-6939), Vol 3, No. 4, pp 3507-519, August 2017. Available at: http://www.ijaer.in/more2.php?id=246.

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LIST OF ABBREVIATIONS AND ACRONYMS

AOATM	African Organic Agriculture Training Manual
APHLIS	African Postharvest Loss Information System
AU	African Union
AUC	African Union Commission
BCFN	Bralilla Center for Food and Nutrition
CAD	Community Agrodealer
CADPhMM	Community Agrodealer Postharvest Management Model
CABI	Centre for Agriculture and Bioscience International
CBO	Community Based Organization
CDC	Centre for Disease Control and Prevention.
CGF	Consumer Goods Forum
CIDA-PASU	Canadian International Development Agency- Project Assistance Support Unit
CIMMYT	International Maize and Wheat Improvement Centre
COL	Commonwealth of Learning
CSAM	Commodity Systems Assessment Method
DIT	Theory of Diffusion Innovation
DTPB	Decomposed Theory of Planned Behaviour
EGSP	Effective Grain Storage Project
EPA	Environmental Protection Agency
EU	European Union
FCPhMM	Farmer Cooperative Postharvest Management Model
FAO	Food and Agriculture Organization
FLW	Food Loss and Waste
FSC	Food Supply Chain
FRA	Food Reserve Agency
FSRP	Food Security Research Project.

FVC	Food Value Chain
GGGF	Global Green Growth Forum
GIZ	DeutscheGesellschaft fur Internationale Zusammnarbeit
HLPE	High Level Panel of Experts on Food Security and Nutrition
IAPRI	Indaba Agricultural Policy Research Institute
ICTs	Information Communication Technologies
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
ISTT	In-Service Training Trust
IITA	International Institute of Tropical Agriculture
KCAM	Katete Centre for Agricultural Marketing
MAO	Ministry of Agriculture
MACO	Ministry of Agriculture and Cooperatives
MAFF	Ministry of Agriculture Food and Fisheries
NRDC	Natural Resources Development College
ODL	Open and Distance learning
PHL	Postharvest Losses
PICS	Purdue Improved Crop Storage
SADC	Southern African Development Community
SADC-RFSTP	Southern African Development Community Regional Food Security Training Programme
SAP	Structural Adjustment Programme
SDC	Swiss Development Cooperation
SDGs	Sustainable Development Goals
SPSS.	Statistical Package for Social Scientists
SSA	Sub - Saharan Africa
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour
TRA	Theory of Reasonable Action
TTF	Theory of Task-Technology Fit

UN	United Nations
UNCEF	United Nations Children’s Emergence Fund
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNZA	University of Zambia
USAID	United States Agency for International Development
UTAUT	Unified Theory of Acceptance and Use of Technology
WBCSD	World Business Council for Sustainable Development
WFP	World Food Programme
WRAP	Waste and Resources Action Programme
WRI	World Resources Institute
WRS	Warehouse Receipt System
WWF	World Wide Fund for Nature
ZAMACE	Zambia Agricultural Commodity Exchange

LIST OF GLOSSARY OF TERMS

"Food means any substance, whether processed, semi-processed or raw, which is intended for human consumption, and includes drink, chewing gum and any substance that has been used in the manufacture, preparation or treatment of "food" but does not include cosmetics or tobacco or substances used only as drugs" (FAO/WHO, 2013, p. 23).

Food security. The United Nations Committee on World Food Security defines food security as "the condition in which all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO/WFP, 2010, p.8).

Food insecurity exists when people do not have adequate physical, social or economic access to food as defined above.

Food losses are defined as "the decrease in edible food mass throughout the part of the supply chain that specifically leads to a reduction in edible food for human consumption" (FAO, 2011, p.3). Food losses take place at the production, harvesting, primary handling, aggregation, storage, transport, processing, marketing, distribution and consumption segments (FAO, 2014). According to the FAO (2014) Definitional Framework of Food Loss Working Paper, 'food loss' is simply defined as "the decrease in quantity or quality of food".

Food waste refers to the food losses occurring on the demand side of the food chain (retail and final consumption) which are generally called food waste and relate to retailers and consumers' behavior **(**Parfitt *et al.,* 2010 as quoted by FAO 2011, p.3).

Food wastage refers to "any food lost by deterioration or waste and encompasses both food loss and waste" (FAO, 2011, p. 9).

Postharvest food loss refers to a decrease in quantity and /or quality of food mass on the supply side of the food chain. It is defined as "measurable qualitative and quantitative food loss along the supply chain (de Lucia & Assennato 1994 as reported by Hodges *et al., 2011,* p.38)". Therefore post-harvest is not only multidimensional but multidisciplinary involving the agriculture sector, agro-processing industry, health and nutrition sector, distribution and manufacturing sector.

Quantitative food loss refers to the decrease in the edible food mass available for human consumption. The Definitional Framework of Food Loss Working Paper describes quantitative food losses as simply the decrease in mass of food. In physical terms, this is the grain removed from the postharvest supply chain and not consumed due to among other causes, spillage, and consumption by pests and also due to physical changes in temperature, moisture and chemical changes. The quantity lost would have either deteriorated rendering it inedible or discarded for failure to meet regulated standards to eat as food or to use as an animal feed (FAO, 2014).

Qualitative Food Loss occurs when food loses its quality attributes resulting in the deterioration in quality leading to a loss of economic, social and nutritional value. The qualitative loss can occur due to incidence of insect pests, mites, rodents and birds, or from handling, physical changes or chemical changes in fat, carbohydrates and protein, and by contamination of mycotoxins, pesticide residues, insect fragments, or excreta of rodents and birds and their dead bodies. When qualitative deterioration makes food unfit for human consumption and is rejected, this contributes to food loss (Aulakh *et al*., 2013). In many cases, the quality deterioration goes along with a significant loss of nutritional value, which might affect the health and nutrition status of the entire community (FAO, 2014).

Postharvest technology is the science and technology applied to agricultural produce after harvest for its protection, conservation, processing, packaging, distribution, marketing, and utilisation to meet the food and nutritional requirements of the humans in relation to their needs (Francis, 2010 as quoted by Nyamulinda *et al.,* 2011). Postharvest technology has to progress in tandem with the needs of a given society in order to catalyse agricultural production, prevent postharvest losses, improve nutrition and value addition to commodities. The end result should be employment creation, poverty reduction and stimulation of the allied economic sectors. The development of postharvest technology and its objective utilization calls for an inter- disciplinary and multi- dimensional approach which should embrace scientific invention, technological advancement, business entrepreneurship and institutions with the capacity to undertake wide-ranging research and development which will address the developmental needs in an integrated approach (Nyamulinda *et al.,* 2011).

Postharvest system can be described as the delivery of a crop from the time and place of harvest to the time and place of consumption with minimum loss, maximum efficiency and maximum return for all involved (Hyden Harvest, 1976 as quoted by Grolleaud, 2002). According to Grolleaud (2002), the main features of a post-harvest system include the following;

i. **Harvesting –** The time of harvesting is determined by the extent of maturity of the crop which affects subsequent operations, especially preservation and storage.
ii. **Pre-harvest drying, mostly for cereals and pulses –** Prolonged pre-harvest field drying does not only promote good preservation but increases the risks of loss arising from pest (birds, rodents and insects) and mould damage promoted by weather conditions. Conversely, harvesting prior to maturity increases the risk of rotting of certain food crops and loss due to moulds.
iii. **Transport –** A lot of care is required when transporting mature crop commodities. The place and conditions of storage will determine the collection and initial transport.
iv. **Postharvest drying and/or cold storage –** The duration for complete drying of cereals or cold chain storage of fruit and vegetables is dependent on many factors which include atmospheric conditions and weather. When using long term storage structures such as

cribs (Matala or Nkokwe) or open threshing terraces on floors, the crop commodities are exposed to free range livestock and attack by rodents, birds and small animals. Besides wastage, the droppings from these pests usually cause higher losses than what they consume. Conversely, if the moisture content of the grain is higher than what is recommended for storage, there is a risk of rotting in storage. Grain which is too dry can crack during and after threshing, hulling and milling due to brittleness.

v. **Threshing –** This operation involves the separation of grains from the cob (in the case of maize) and can be done manually or by machine. It's recommended that threshing should be done when the crop is dry enough and should not cause grain breakage. In the event where grains are threshed when still damp and then stored in bags or granary, preservation becomes limited due to susceptibility to attack from microorganisms.

vi. **Storage –** For effective lengthy storage, there should be adequate facilities, hygiene and monitoring. The control of cleanliness, temperature and humidity is of great importance in closed storage structures such as hermetic bins, warehouses and granaries. Insect pest, rodent and mould damage to structures can cause deterioration of the storage facilities resulting in losses of quality, quantity and food value.

vii. **Processing –** Grain losses can occur due to excessive hulling or threshing. Although the processing of cereal grains is not subject to stringent measures as in horticultural crops, it's still important to ensure that processed grains are safe for human consumption.

viii. **Marketing –** This is the conclusive and critical factor in the postharvest system. It occurs at several sections of the food chain and cannot be isolated from transport which is a vital connection in the system.

ix. **Supply chain –** It's a system of people, institutions, activities, information and resources concerned about the movement of products and services from supplier to the consumer.

x. **Value chain –** This is a set of actions that an organization operating in a particular trade or supply chain plays with a view to change and convey worthy merchandise to the market.

xi. **Food supply chain –** The FAO Definitional Framework of Food Loss working paper defines food supply chain as "the connected series of activities to produce, process, distribute and consume food" (FAO, 2014, p. 93).

xii. **Value addition** – It's a process involving the transformation (addition of time, place and/ or form unit) of a raw material by changing its form to produce a high quality end product which meets the needs, tastes or preferences of consumers.

CHAPTER 1: GENERAL OVERVIEW

1.1 Introduction

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them" – Sir William Bragg.

1.2 Setting the Tone

The problem of global food loss and waste is real (FAO, 2011; Lipinski *et al.*, 2013; HLPE, 2014 and WRI, 2016). Nearly one third of the food produced globally (about I.3 billion tons) eventually goes uneaten every year (FAO, 2011; Gustavsson *et al.*, 2011; The Consumer Goods Forum, 2015, Bahadur, 2016; IPFRI 2016). The lost food which has an estimated value of 2.6 trillion dollars annually is more than enough to feed all the 815 million hungry people in the world (FAO, 2014 and Green Living 2018). The environmental and social costs are approximately 700 US$ billion and 900 US$ billion respectively (ibid). Gustavsson *et al*., (2011) found that 95 -115 kgs of food per consumer is wasted annually in Europe and North America compared to a paltry 6 -11 kgs for South Asia and sub - Saharan Africa. The estimate for sub-Saharan Africa (SSA) is roughly 37 percent or 120 -170 kgs/year per capita. Lipinski *et al.,* (2013) translated the weight volumes reported into calorie terms, reducing the losses to 23 percent globally. According to FAO (2013b) the quantity of food wasted by consumers in the developed world is almost equivalent to the aggregate net food produced in sub-Saharan Africa. The annual wasted or lost food is produced on 1.4 billion hectares of land, which is about 28% of the total global agricultural area (FAO, 2013a).

The estimated value of food wasted globally is USD 750 billion per annum (FAO, 2013a.p.55). For grains alone, the estimated value of postharvest losses (PHLs) in SSA is around USD 4 billion per annum (at 2007 prices) (Rosegrant *et al.,* 2015; World Bank, 2011). This exceeds the value of food aid received by sub-Saharan Africa during the decade 1998 - 2008 and equates to the value of cereals imported into the region during the period 2000 - 2007 (Aulakh and Regmi, 2013; World Bank, 2010). The lost food could meet the minimum annual food requirements of at least 48 million of the 220 million undernourished people in Africa (World Bank, 2011). Post-harvest losses occur both in quantitative and qualitative terms, with the former affecting food availability and nutrition security while the latter affects food use and utilization and food availability (Hodges, Buzby and Bennet, 2010; Aulakh *et al.,* 2013, as reported by and African Union Commission (AUC; 2018). Besides reducing the total quantity and quality of food available, post-harvest losses (PHLs) worsen the existing delicate poverty stricken rural economies by reducing revenue generation for the food value chain (Kikulwe *et al*., 2018; World Bank, 2011). Hence, post-harvest losses have an effect on the accessibility and sustainability of food, income and nutrition security. Generally, post-harvest losses have a remarkable influence on the entirety of food and nutrition security.

Gustavsson *et al*., (2011) report that high postharvest and processing losses are experienced in least industrialised countries due to spoilage, the lack of modern storage infrastructure, transport, finance, managerial and technical capacity under challenging climatic settings causes food spoilage. While postharvest quality losses mostly occur in developed countries (Kader, 2005), quantity losses are more common in the least developed countries (Kitinoja and Gorny, 2010) as reported by Kiaya (2014).

Consequently, reducing postharvest losses from the existing levels will have a significant bearing in reducing food insecurity in Africa. According AUC (2018) the key challenges facing the continent in implementing the Malabo Declaration includes the lack of:

a. Institutional and organisational arrangements including the lack of support for generation and dissemination of PHL best practices and knowledge;
b. Awareness of standardized postharvest loss measurement methodologies;
c. Awareness and communication on the impact or outcomes of postharvest losses;
d. Targeted policies and /or strategies at the national levels on PHLs;
e. Understanding of the economic value of PHLs and its consequences on food security;
f. Research and development including evidence based PHL assessments; and
g. Targeted financing and investment in PHL activities.

There are many reasons to reduce food loss and waste and some of these include food and nutrition security, social, economic gains and environmental sustainability (Kader 2005; Gustavsson *et al.,* 2011; Parfitt, 2010; Lipinski *et al*., 2013). The concern regarding food security relates to the challenge to provide food to estimated 9.8 billion people by 2050 (UN, 2017). Gomeiero *et al.,* (2011) and Kumar and Kalita (2017) report that available literature proposes that 70% to 100% more food will be required by 2050. The reduction of food loss and waste is considered to be an answer to guaranteeing food security (Godfray *et al*., 2010; Kummu *et al*., 2012). One of the constraints to reducing food loss and waste is that some of the institutions that have the capacity to address the problem, such as governments and businesses are not very clear about where to start from due to inadequate empirical data to guide them during policy formulation (Sheahan *et al*., 2016). Due to lack of consensus on the quantities of food lost, postharvest loss estimates vary widely (Parfitt, 2010; Sheahan *et al*., 2016). On the basis of methodological reasons, researchers and practitioners are still skeptical about FAO estimates and other aggregate numbers frequently quoted (Lipinski *et al*., 2013; Kaminski and Christiaensen, 2014; Affognon *et al*., 2015; Sheahan *et al*., 2017). Although FAO (2011) reports of an annual loss of one - third of global food production, there is lack of compromise on that ratio as the approximations vary from 10% to 50% of the total food produced globally (Parfitt *et al*., 2010). According to Elimelech *et al*., (2018) there is fragmentation and lack of consistence in the data on the amount of food which is wasted. Stenmarck *et al.,* 2016; Williams *et al.,* 2015 argue for a consensus on better metrics for food waste.

In order to have more reliable sources of data, investments have been made in the creation of institutions such as the African Postharvest Loss Information System (APHLIS), a network of experts mandated to provide accurate estimates of PHLs for grains across Eastern and Southern Africa (Hodges *et al.,* 2010; Rembold *et al*., 2011). The sheer volume and value estimates of food loss and waste raised concern among development practitioners and donors while the world food price spikes in 2008 and 2011 motivated the ongoing interest in food loss and waste (FLW) among value chain actors (Sheahan *et al*., 2016). Due to lack of well-defined objective guide, most research and interventions in PHLs is motivated by invocation of estimated magnitude of post-harvest losses and not by meaning of magnitude or its consequences (HLPE, 2014). According to Parfitt *et al*., (2010); Lipinski, *et al.,* (2013); Kaminski and Christiaensen (2014), the quantification of global food waste over the years has been motivated by somewhat the need to highlight the extent of food waste in comparison to global malnutrition. The food waste estimates have been based on extrapolation of inadequate datasets sourced from various food supply chains (FSC) at varying times. The most repeatedly quoted estimate is that, "as much as half of all food grown is lost or wasted before or after it reaches the consumer" (Lundqvist *et al*., 2008).

1.3 Description of Food Loss and Waste

There are competing descriptions or definitions of food loss and waste (IFPRI, 2016). Food loss refers to "a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption. These losses are mainly caused by inefficiencies in the food supply chains, such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, and lack of access to markets. In addition, natural disasters play a role" (FAO, 2011, p. 8). Grolleaud (2002) defines food loss as "the decrease in quantity or quality which makes it unfit for human consumption" as cited in Parfitt *et al.,* (2010).

Food waste refers to "food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry date or left to spoil. Often this is because food has spoiled or other reasons such as oversupply due to markets, or individual consumer shopping/eating habits" (FAO, 2011, p.9).

Food wastage refers to "any food lost by deterioration or waste. Thus, the term "wastage" encompasses both food loss and food waste" (FAO, 2011, p. 9).

Food waste is part of food loss and refers to discarding or alternative (non-food) use of food that is safe and nutritious for human consumption along the entire food supply chain, from primary production to household consumption (FAO, 2014). Furthermore, food waste is recognised as a distinct part of food loss because the drivers that generate it and the solutions to it are different from those of food losses (ibid).

Food losses take place during agricultural production, postharvest, and processing stages in the food supply chain where as food waste occurs at the end of the food chain (distribution, sale and final consumption) the former caused mostly by logistical and infrastructural challenges whereas the latter is mostly influenced by human behavior (FAO, 2011; FAO, 2014).

According to IFPRI (2016) food loss and waste happen at different phases along the food supply chain. There is still considerable debate concerning appropriate terminology to summarise the general theory. "Food Loss", "Postharvest", "Food Waste", and "Food loss and waste" do not necessarily describe similar features, although these expressions normally tend to be used to mean the same thing, in so doing, adding to the confusion regarding the type of loss under reference (ibid).

The Waste and Resources Action Programme (WRAP) bunches drink and food wasted by households into three categories depending of avoidability: avoidable, possibly avoidable and unavoidable (WRAP 2007). The first two groups comprise of “edible food waste” and include food discarded by consumers (e.g., pieces of beacon, bananas, and slices of bread) or food consumed or not consumed by some households (e.g. potato skins, bread crusts, mango skins). The last grouping comprises “inedible food waste” that includes waste generated from food preparation that is not normally edible (pineapple skins, egg shells, bones) (WRAP, 2007).

Parfitt *et al.,* (2010) associate food waste to retail, and consumption phases of the supply chain which are usually associated with consumer behavior. Spoilage / food losses are applied to food supply chain systems (harvesting, drying, processing, transportation, storage) which entail infrastructure financing (Parfitt *et al*., 2010).

Although food waste is mainly defined at retailing and consumption stages where agricultural products are predominately meant for human consumption, waste takes place at different stages of the food supply chain (Lipinski *et al*., 2013). In comparison to other agricultural commodities, food is a biological substance subject to deterioration and with different nutritional value (Parfitt *et al.,* 2010). Food waste is associated with moral and economic dimensions; the degree to which food crops are used to meet the universal human needs directly or converted into livestock feed and other by-products such as biofuels and livestock feed (ibid).

According to de Gorter (2014) food loss refers to any food lost by producers or in distribution, while food waste is the food lost at consumer stage of the food supply chain. Bellemare *et al*., (2017) argue that defining food loss and waste on the basis of food life cycle does not contextualize rural households in sub-Saharan Africa who play a dual role of both producer and consumer. De Gorter (2014) explains that the boundaries in the definition are marked mainly for convenience’s sake and become distorted in the context of rural households in SSA who usually operate both as producers and consumers. From both a data and literature perspective, there is lack of clarity and commonly acknowledged appreciation of what amounts to food loss or waste (Bellemare, Cakir, Peterson, Novak & Rudi, 2017) as quoted by UN (2017). In addition, there is no mutual agreement whether food loss or waste is a normal thing expected to happen as part of agricultural production or a challenge which needs addressing (ibid). This study will adopt the approach proposed by Sheahan *et al*., (2017) which uses food loss and waste, as an expression used interchangeably with PHLs.

Post-harvest losses (PHLs) describe the losses of crops after the harvest and at all phases of the onward supply of the crop to markets (the post-harvest chain) (Hodges *et al*., 2010; Buzby and Hyman, 2012). Nonetheless, qualitative losses also happen in crops between harvest and consumption (Tyler and Gilman, 1979) as cited in (Kok *et al*., 2019). Reduction of postharvest losses could raise income for 470 million smallholder farmers globally, signifying a gigantic action forward in global endeavors to end poverty and enhance food security and sustainability (Schuster and Torero, 2016).

Postharvest losses are caused by many factors which include; poor harvesting methods, poor handling, processing and storage, destruction by insect pests, rodents and microorganisms such as bacteria and fungi (Kumar and Kalita, 2017). The problem of postharvest maize losses in Zambia, similar to other African countries, is significant because it has an implication on national food security as this grain is the main staple food for the country (McCann, 2007).

Post-harvest system encompasses the delivery of crop from the time and place of harvest to the time and place of consumption with minimum loss and maximum efficiency and returns for all involved (Hodges *et al*., 2011). According to Spurgeon "the post-harvest system should be thought of as encompassing the delivery of a crop from the time and place of harvest to the time and place of consumption, with minimum loss, maximum efficiency and maximum return for all involved" (Spurgeon, 1976, p. 15).

A good postharvest system has several benefits which include the creation of an environment needed to encourage farmers to produce food beyond their requirements (Spurgeon, 1976). It has the additional benefits such as reduction of food spoilage, enhancement of acceptability, utility and nutritional quality of food crops and could contribute to the establishment of new food industries (ibid). A good postharvest system could lead to the creation of a conducive environment for farmers to increase food production beyond their requirements. If well planned and executed a postharvest system can assist in ensuring a consistent supply of food crops which could result in a reduction in food prices due to consistent supply of commodities (ibid). A good postharvest system could offer many opportunities for enhanced rural and urban employment in the harvesting, grading, storage, transportation, processing and marketing of crops and construction of postharvest facilities (Spurgeon, 1976).

In view of the fact that food loss and waste reduces net food supply available for human consumption, it's envisaged that the reduction of food losses and waste would contribute to increasing net food supply, which subsequently could lower food prices locally and globally (Lipinski *et al*., 2013; FAO, 2011; Lundqvist, de Fraiture and Moulden, 2008). The impact of lower prices, however, would be felt differently by the various actors along the food value chain (FVC). As described by Sheahan *et al.*, (2016), the reduction of food losses increases the supply which in turn can reduce the necessity to source additional supplies through transfer programs (household level), food imports or food aid donations (national level). Under normal circumstances, increased food supply should translate into a fall in food prices, thereby improving access. It's therefore not a coincidence that recent interest in food loss and waste reduction emerged from the global food price spikes of 2008 and 2011 (FAO, 2017; Rosegrant *et al*., 2015).

According to de Gorter (2014) as reported by Sheahan *et al*., (2016) it's very expensive to eliminate PHLs even when using the best available technologies and institutional arrangements. Due to the fact that some form of contamination and spoilage cannot be avoided, improvements in the food supply inevitably results in incurring quality losses. Prior to designing interventions, it's important to understand the underlying microeconomic justification of reducing PHLs (de Gorter 2014; Goldsmith, Martins, Moura 2015; Waterfield and Zilberman 2012). When a certain level of PHLs is considered economical, value chain actors will not invest in loss reduction. There are many examples whereby PHLs are tolerated as the case of soybean farmers in Brazil who increase PHLs at harvest (through increasing combine speed) to facilitate early planting in the first season and create time for a second crop where they maximize profits (Goldsmith *et al.,* 2015).

In Africa, an increase in retained food can be of great importance in regions where there is a sharp increase in the price of crops just a few months after harvest period, as it increases food access when food insecure households are most vulnerable (Sheahan *et al*., 2017). The retention of low quality food products could disproportionately benefit the poor where there are price distortions associated with the quality of food (Sheahan *et al*., 2017; Kadjo, and Ricker-Gilbert alexander, 2006). Market principles regulate both tradability and variations of prices of maize (IFPRI 2010). When a food commodity plays a crucial role in diets of households as the case is of maize in most sub-Saharan African countries, variations in tradability and prices can have severe consequences for food and nutrition security. As a matter of fact, price fluctuations are essential for the survival of a market because it creates the incentives that entice market players to transact in response to price increases. Consequently, it's not price fluctuations per se that should be of concern to policy makers, but rather the excessive variability or in certain instances the little or a lack of price fluctuations of staple foods. The extreme price fluctuation is indicative of the absence of market integration. In addition, little or lack of price fluctuations is usually an outcome of policy intervention such as pan-territorial pricing, which was practiced in most African countries in the 1970s and 1980s (IFPRI, 2010). The food price stages in future will be dependent upon the response of production to resource challenges and climate change. As a result of the high likelihood of climate change negating the increase in agricultural production in certain parts of the world, there might be a spike in prices FAO (2017).

Maize is the second most important food crop after cassava in Africa, which provides nutrients for humans and animals and also serves as a basic raw material for the production of starch, oil and protein, alcoholic beverages (McCann, 2006; CIMMYT & IITA, 2016). In sub-Saharan Africa, maize is the source of nearly 30% of the calorific intake of the population. The crop accounts for more than 50% of the calorific intake in Lesotho, Malawi and Zambia (McCann, 2005). Zambia is more dependent on maize as a source of calories (49.4%) than any other country in Eastern and Southern Africa (FAO, 2013; Minot, 2011).

The dearth of infrastructure and poor production and harvesting techniques in many third world countries are bound to remain key factors in the creation of food losses (FAO, 2019; Ambuko, 2017; Aulakh, and Regmi, 2013). Although the reduction of postharvest losses is acknowledged as a cardinal element of improved food and nutrition security (Godfray *et al*., 2010; Kummu *et al*., 2012; Nellemann *et al.,* 2009), less than five percent of the funding for agricultural research is apportioned to postharvest systems (Kumar and Kalita, 2017; Kitinoja, *et al*., 2011; and Kader, 2005).

While there may be other technologies for preventing postharvest losses in existence or under research, most discussion in literature is skewed towards the hermetic storage structures (Tefera *et al*., 2012). The experimentation on use of acoustics to detect pest outbreaks in storage indicates that further innovations for preventing postharvest loss reduction is on the way (Sheahan *et al*., 2017). Arising from the compounding effect of crop deterioration accrued from the field, consideration should be given to interventions which reduce postharvest losses prior to harvesting of the crop (Ippolito and Nigro, 2000). Food loss and waste researchers and practitioners should consider going beyond PHLs and tackle pre-harvest losses as well (John, 2014). Variety selection and development is one of the important measures for mitigating losses in the field (ibid).

In sub Saharan Africa, postharvest loss reduction can contribute to improving the livelihoods of smallholder farmers and agribusiness while the motive of private sector value chain actors to reduce postharvest losses is to increase revenue in order to meet profit maximization goals (Halloran *et a*l., (2014). Hodges *et al.,* (2010) argue that postharvest losses usually arise at or around the farm in developing countries. They further contend that the best strategies for the reduction of food losses include farmer training, improved infrastructure for food storage, enhanced access to markets for smallholder farmers, and the development of opportunities for group marketing. There are two overarching themes on food loss and waste; while the socio-economic and technological causes of food waste are very important, they differ greatly across regions (Martinez *et al*., 2014; FAO, 2016; Schanes *et al*., 2018). Since one third of the food produced globally is wasted (FAO, 2011; Gustavsson *et al*., 2011; The Consumer Goods Forum, 2015, Bahadur, 2016; IPFRI 2016), reduction of food waste is a major strategy which can assist in the reduction of the impact of agriculture on the environment whilst addressing the global food needs (Godfray *et al*., 2010 and Kummu *et al*., 2012).

The challenge of increased food insecurity in regions such as sub-Saharan Africa is caused by agricultural productivity and the effect of climate change which contributes to increased reliance on food aid (Masipa, 2017; Thompson *et al*., 2010). The situation is exacerbated by the poor postharvest management by the value chain actors such as producers and consumers. Therefore, addressing the problem of postharvest losses can provide a solution for promotion of food security and wise use of the scarce production resources (Parfitt, 2010). FAO (2010) posits that 'reducing postharvest losses along food chains can provide a more cost-effective and environmentally sustainable means of promoting food and nutrition security than investments focusing on increasing production'.

The opportunities for reducing postharvest losses are evidenced by the development and availability of technology, renewed world interest among policy makers, international community, academics, researchers and private sector in addressing losses in response to the food crisis experienced during 2006-2011 (FAO, 2011; Rosegrant, 2015). In recent years there has been an increase in funding of initiatives for reducing postharvest losses. For example, a number of international organisations such as the World Food Programme (2014), Rockefeller Foundation (FAO 2018, and SDC, 2015) have initiated projects which aim at reducing post-harvest food losses. In addition, a variety of technologies have been developed for reducing postharvest losses, and some of these include crop protectants and storage containers such as hermetically sealed bags (PICS) and metal silos (Abass *et al*., 2017).

The greatest potential for food waste reduction lies in the implementation of sustainable solutions along the food supply chain. In developing countries this would require market-led large scale investment in agricultural infrastructure, technical skills and knowledge, storage, transport and distribution (Kitinoja *et al.,* 2011; and WBCSD, 2017). As such, the application of innovative technology along the food supply chain in the developing countries can contribute to the reduction of food waste (Torres-León *et al*., 2018). Therefore, the use of technology to mitigate postharvest maize losses is one of the promising strategies that could be used to address food insecurity in Zambia and other sub-Saharan African countries (FAO, 2010; FAO 2016; Parfitt, 2010).

Although there are many factors which contribute to post-harvest losses, the lack of knowledge in postharvest management and equipment for implementing comprehensive grain handling and storage practices among smallholder farmers and traders are considered to be the primary causes (WFP, 2015). Postharvest food loss is a resolvable problem in sub-Saharan Africa (Sheahan 2017; Rutten 2013; World Bank, 2010). This, however, is dependent upon the extent to which the existing challenges can be addressed through supportive government policies, collaboration from development agencies and the international community in backing the implementation of proven interventions (ibid).

The findings of the study were that the factors responsible for the low adoption of technologies for reducing postharvest maize losses by the smallholder farmers included the lack of awareness and knowledge of the available technologies, lack of knowledge about the benefits of using technology, the perceived cost of the technology, non-availability of the technologies locally and difficulties to operate some of the technologies.

The study further established the inedaquate provisions in the national agriculture policy to address PHLs. The 2016 - 2025 Zambia National Agriculture Policy does not provide adequate strategies regarding the reduction of PHLs. Since the policy was developed after the Malabo Declaration and Sustainable Development Goal target 12.3 were endorsed by the continental and world leaders respectively, the agricultural policy should have provided a clear road map towards the reduction of PHLs.

There was inadequate integration of postharvest management in the agricultural extension service. Notwithstanding the fact that a number of projects on postharvest management implemented in the past had involved the participation of district agricultural staff, there was lack of continuity of post-harvest activities after closure of the projects. This could partly have been driven by the too much emphasis on increased productivity and production of maize and the low numbers of extension workers skilled in postharvest management.

The study noted the inadequate knowledge in chemical pest control among some agrodealers resulting in poor advice to farmers on application of chemicals recommended for protection of grain from pest attack. The re-infestation of grain previously treated by chemicals, made some famers to lose faith in the chemical control method. The consequence of the poor performance of the chemicals made some farmers to abandon chemical control of storage insect pests. Furthermore, there was exposure of farmers to harmful chemicals such as aluminum phosphide which ordinarily is supposed to be handled by trained personnel.

The study is proposing a production to postharvest management (P2Ph) approach when planning crop production projects and/or programmes. This approach calls for provision of a postharvest loss reducing component when planning the implementation of projects or programmes. The study is proposing the Farmer Cooperative Postharvest Management (FCPhM) and the Community Agrodealer Postharvest Management (CADPhM) Models for increasing the adoption of postharvest loss reduction technologies.

1.4 Motivation for the Study

The principal motivation for this study was to develop a framework for increasing the adoption of strategies, technologies and practices for reducing postharvest maize losses along the value chain. The study identified barriers to the adoption of technologies and practices for reducing maize losses among smallholder farmers. The additional motivation was the desire to contribute to new knowledge by Identifying opportunities for increased adoption of technologies for reducing postharvest maize losses by smallholder farmers.

1.5 Theoretical Background

In order to situate this study in a broader perspective regarding the topic of PHLs, this section provides conceptual and theoretical frameworks for the significance of adoption of PHL reducing technologies. Conceptual frameworks offer a standard for interaction among variables which might or might not entail a specific theoretical standpoint, with the rationale of proving an explanation to phenomena (Berman, 2013; Knight *et al.,* 2010 and Yamauchi *et al*., 2017). According to Miles and Huberman (1994) and Robson (2011) a conceptual framework is a system of concepts, assumptions, expectations, beliefs, and theories that support and informs research. Miles and Huberman (1994) defined a conceptual framework as a visual or written product, one that "explains, either graphically or in narrative form, the main things to be studied - the key factors, concepts, or variables - and the presumed relationships among them" (p. 18).

A theoretical framework in a study is based on an existing theory or theories (Grant and Osanloo, 2014). According to Labaree (2009), "a theoretical framework is a structure that can hold or support a theory of a research study. Theories are formulated to explain, predict and understand phenomena and, in many cases, to challenge and extend existing knowledge within the limits of critical bounding assumptions". Eisenhart (1991, p. 205) defined a theoretical framework as "a structure that guides research by relying on a formal theory … constructed by using an established, coherent explanation of certain phenomena and relationships" as quoted by Grant and Osanloo (2014, p. 13). A theory is a "set of interrelated constructs, definitions, and propositions that presents a systematic view of phenomena by specifying relations among variables, with the purpose of explaining and predicting phenomena" (Ker linger, 1986, p.9) as reported by Yamauchi *et al*., (2017, p. 11). Maxwell (2012) argues that a theoretical framework can be used to distinguish and clarify data which originally may appear irrelevant or unconnected to other data. Furthermore, theory offers assistance in explaining what is being studied.

The purpose of a theoretical framework is to stimulate research and test theories, it makes research findings important and generalisable. It helps to predict and control situations and establishes orderly connections between examination and facts (Labaree, 2009). In order to situate this study in a broader perspective regarding the topic of PHLs, this section provides a theoretical framework for the significance of adoption of PHL reducing technologies. The theoretical framework for estimation of PHLs enables impartial documentation of exact losses and causative factors. This framework provides the road map for plotting interventions and policies on PHL solutions (ibid).

The difference between conceptual and theoretical frameworks is that where as a theoretical framework is grounded on already established hypotheses a conceptual framework is a structure used to clarify the normal evolution of phenomena (Camp 2001). According to Maxwell (2012) whereas conceptual frameworks are in the class of provisional or transitional theories which tries to link several features of the study, theoretical framework describes the phenomena.

Since the rationale for conducting this research was to establish the reasons or factors for the low technology adoption, the study adopted the Unified Theory of Acceptance and Use of Technology (UTAUT) model. This model was selected because it is more versatile than the other eight theories used in adoption research such as the popular Technology adoption Model (TAM), Theory of Diffusion Innovation (DIT), Theory of Reasonable Action (TRA), Theory of Task-Technology Fit (TTF), Theory of Planned Behavior (TPB) and Decomposed Theory of Planned Behaviour (DTPB) among others.

1.6 Contextual Background

The study was founded on the conceptualization that although technologies for reducing postharvest are available their adoption by small-scale farmers in Zambia remains low. According to The World Bank (2011), a broad range of technologies exist, which if adopted, would support smallholder and larger farmers to maintain the quality and quantity of maize grain during the postharvest handling and storage periods. Furthermore, Kumar and Kalita (2017), report that the application of modern technology can reduce postharvest losses of cereal grains in developing countries from 50% - 60% to 1% - 2%. However, the application of technology and other innovative methods is dependent upon awareness creation among the smallholder farmers and capacity strengthening in postharvest management (AUC-FAO, 2012). Katinoja *et al*., (2011) cautions that although several useful postharvest technologies appropriate for developing countries have been developed, there is still scanty information regarding the cost aspect and financial benefits from investing into postharvest technologies. Rosegrant (2015) argues that the benefits of using postharvest technologies differ in size and period for recovery of the returns to investment. However, it's important to consider the fact that application of certain technologies entails large amount of production thereby preventing the accessibility to small-scale producers. A study conducted by Colverson (2015) established that if the technology is appropriate for their needs, it can be adopted by smallholder farmers.

In this study the postharvest technologies were analysed in terms of awareness of availability, benefits of using the technology, reasons for the low adoption and cost of acquiring the technology.

1.7 Research Problem

Sub - Saharan Africa experiences postharvest maize losses exceeding 30% of the annual production in spite the availability of technologies for preventing food losses at the global level. This research, therefore, attempted to interrogate the constraints and identified opportunities for increasing the adoption of technologies for reducing postharvest maize losses in sub - Saharan Africa, a case study of Zambia.

1.8 Research Goal

The goal of the study was to develop a framework for increasing the adoption of strategies, technologies and practices for reducing postharvest maize losses along the value chain.

1.9 Research Objectives

This research study addressed the following objectives:

i. To review government policies towards postharvest food losses and establish the extent to which these policies addressed the availability and promotion of technologies for reducing postharvest maize losses among smallholder farmers in Zambia.
ii. To investigate barriers to the adoption of technologies and practices for reducing maize losses among smallholder farmers in Zambia;
iii. Document the technologies and practices used by smallholder farmers in Zambia in mitigating postharvest maize losses; and
iv. To identify and analyse opportunities which exist for adopting technologies for reducing postharvest maize losses among smallholder farmers in Zambia.

1.10 Research Questions

The research questions for this study were as follows:

i What are the government policies towards postharvest food losses in Zambia?
ii. What is the impact of government policies on development, availability and promotion of technologies for reducing postharvest maize losses among smallholder farmers in Zambia?
iii. Which technologies and practices are available to smallholder farmers in Zambia for reducing postharvest maize losses?
iv. Which are the common technologies and practices used by smallholder farmers in Zambia to mitigate postharvest maize losses?
v. What are the barriers faced by smallholder farmers in Zambia in adopting technologies for reducing postharvest maize losses?
vi. What opportunities exist for the adoption of technologies for reducing postharvest maize losses among smallholder farmers in Zambia?

1.11 Research Methodology

Research methodology is fundamentally a way or technique for data collection (Bryman & Bell., 2007). Research methodology provides backing to the categories of questions that can be attempted and the kind of evidence collected (Clark, 1984) as cited in Al Zefeit & Mohamad (2015). In this study the interpretivist paradigm was selected because it helps to “gain full access to the knowledge and meaning of the phenomenon” (Collis and Hussey, 2009, p.65). In addition, the Interpretive paradigm was considered to be appropriate for this study because it is related to “an inductive process where patterns and /or theories are developed in order to understand phenomena” (Collis and Hussey, 2009, p.74). “A research paradigm is a philosophical framework which guides how scientific research should be conducted” (Collis and Hussey, 2009, p.55).

The inductive research approach was used because the data collected allows for the generation of theories and explanations to the phenomena discovered through the research findings (Charmaz, 2008; and Thulesius, 2009). They further argue that this approach is usually associated with the social constructivist paradigm which emphasises the socially constructed nature of reality. It is about recording, analysing and attempting to uncover the deeper meaning and significance of human behavior and experience, including contradictory beliefs, behaviours and emotions (ibid).

The case study strategy was chosen due to its superiority in enabling an investigation into the issues, the collection of large amounts of data, and the easy analysis of information (Yin, 2003). As defined by Robson (2002:178), "Case study is a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence" (cited in Saunders *et al.,* 2009; pp.145-146).

The grounded theory approach was used in data analysis. Grounded theory is commonly used in the analysis of qualitative data (Creswell, 2014; Corbin and Strauss, 2008; Charmaz, 2006 and Samik-Ibrahim, 2000). Glaser and Strauss (1967) argue that grounded theory can be considered as the best example of the inductive approach, much as this might appear rather basic.

1.12 Thesis Structure

The thesis is organised in 7 chapters namely: general overview; literature review; research design and methodology; study findings and discussion; models or frameworks for increasing the adoption of technologies for reducing postharvest maize losses among smallholder farmers; recommendations from the study and conclusion and further research work.

1.12.1 Chapter 1: General overview

This chapter provides a general overview of contemporary issues in food loss and waste (FLW). The chapter debates the motivation, topical developments, challenges and research directions in food loss and waste. Furthermore, the chapter provides a theoretical framework and research questions underpinning this research work.

1.12.2 Chapter 2: Literature review

Chapter 2 presents a review of literature in food loss and waste. This review covered books, case studies, conference papers, refereed journals in food loss and waste.

1.12.3 Chapter 3: Research methodology and design

This chapter gives a detailed argument about the philosophical and methodological groundwork for this research work. It provides the rationale for the choice of the research philosophy and methodologies for sample selection, data collection and analysis

The chapter further presents a far reaching narration of the motivation for the research methodology adopted for this study. It is based on detailed argument about the philosophical and methodological groundwork for this research work.

1.12.4 Chapter 4: Research findings and discussion

In Chapter 4, the research findings are analysed and discussed. The results are evaluated against work done by other researchers which is found in literature. The findings from the study are used to develop a framework or model for increasing the adoption of technologies for reducing postharvest maize losses.

1.12.5 Chapter 5: Models or frameworks for increasing the adoption of postharvest technologies

Chapter 5 provides models or frameworks which can be applied in increasing the adoption of technologies for reducing postharvest maize losses among smallholder farmers. The models or frameworks were developed from the research findings with support from literature.

1.12.6 Chapter 6: Recommendations from the study

This chapter presents recommendations which can assist strengthen the adoption of technologies for reducing postharvest maize losses among smallholder farmers in Zambia

1.12.7 Chapter 7: Conclusion and further research work

Chapter 7 presents a summary of the research findings and limitations to the study. Further debated herein is the contribution of this research to knowledge and practice of postharvest management. In addition, the chapter provides propositions on further research to strengthen the outcomes of this work.

1.12.8 Appendix A: Research instrument

This is where the research questionnaire used in this study is presented.

1.12.9 Appendix B: Selected papers

Copies of two journal publications accepted in the International Journal of Agriculture and Environmental Research are attached.

Summary

Chapter 1 gave an overview of food loss and waste and postharvest management by establishing the tone for this thesis. Furthermore, the chapter outlined the research problem, aim and objectives and limitation of the research work. The philosophical and methodological groundwork for this research work is also provided in this chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

“The difficulty of literature is not to write but to write what you mean; not to affect your reader, but to affect him precisely as you wish” - Robert Lewis Stevenson

This chapter gives a comprehensive narration of the motivation for the research methodology adopted for this study. It is based on detailed argument about the philosophical and methodological groundwork for this research work. The main challenge facing agriculture in the 21st century will be the production of safe food to feed the human population predicted to reach 9.1 billion by 2050 (FAO, 2009; Kummu, 2012; Pelletier and Tyedmers, 2010; UN 2014 and WWF, 2016). Agricultural production needs to increase by 60-70% to meet this target (FAO, 2009; Parfitt *et al.,* 2010). It is estimated that approximately one third of the total food produced globally is lost or wasted (FAO 2011; Gustavsson *et al.,* 2011; HLPE, 2014; Prusky, 2011 and UNRIC, 2016). This represents a loss of 1.3 billion tons of food per year on a planet where nearly 1 billion people are hungry and undernourished (FAO, 2009; Gustavsson et al., 2011; Tilman *et al*., 2011; Hoering, 2012; WWF, 2016).

Food loss and waste is much higher at the immediate postharvest stages in developing countries while in the developed world, consumer food waste accounts for the greatest overall food losses (Parfitt *et al.,* 2010). Food wastage occurs at all segments of the food supply chain for a number of reasons which are influenced by the prevailing conditions within a given country (Ibid). The pattern is clearly more visible at global level, as in developed countries, the quantities of wasted food are higher during processing, distribution and consumption while in developing countries, food losses occur in the production and postharvest stages (FAO, 2011; Parfitt *et al.,* 2010; Kummu *et al*., 2012). Furthermore, Bond *et al*., (2013) argued that losses in the early stages of the food supply chain are food losses. This type of loss is associated with low earnings and occurs at pre-harvest, harvesting, storage and transportation stages of the supply chain. Food losses in superior earnings phases such as retail and consumption are referred to as food waste (Martinez *et al*., 2014).

Food loss and waste has a significant impact on the efforts to protect the environment, combat hunger, raise incomes and improve food security especially among the world’s poorest countries (Gustavsson *et al.,* 2011). Other scholars report that food waste is an issue of significant importance to world food security and good environmental governance, directly connected to economic (e.g. resource efficiency, price volatility, increasing costs, consumption, waste management, commodity markets), the environment (e.g. energy, climate change, availability of resources) and social impacts (e.g. health, equality) (Stenmarck *et al.,* 2016). On the basis of producer prices the global direct economic cost of food waste of agricultural commodities (excluding fish and seafood) is estimated to be US$ 750 billion (FAO, 2014). Rosegrant (2015) found that the estimated value of PHLs reported by APHLIS for Eastern and Southern Africa was US$ 1.6 billion per year.

Estimates of food loss are dependent upon location and handling method (Parfitt, *et al.,* 2010). In developed countries consumers are responsible for waste while in developing countries the majority of losses happen between the farm and the consumer (Dou *et al*., 2016). In the case of cereals, microorganisms such moulds and bacteria, insects and rodents are responsible for most of the losses (Kumar and Kalita, 2017; Lipinski *et al*., 2013; and World Bank, 2011). According to Lipinsky *et al*., (2013) 44% of the total food loss occurs in developing countries whereas industrialized countries and industrialized Asian countries are responsible for 56%. Furthermore, Pachón (2013) found that 36.7% of the global food losses experienced in 2011 were during the consumption stage. In sub Saharan Africa, higher food losses occur during the production phase (Martinez *et al*., 2014). Figure 2.1 shows the relationship involving "food loss", "food waste" and "food wastage".

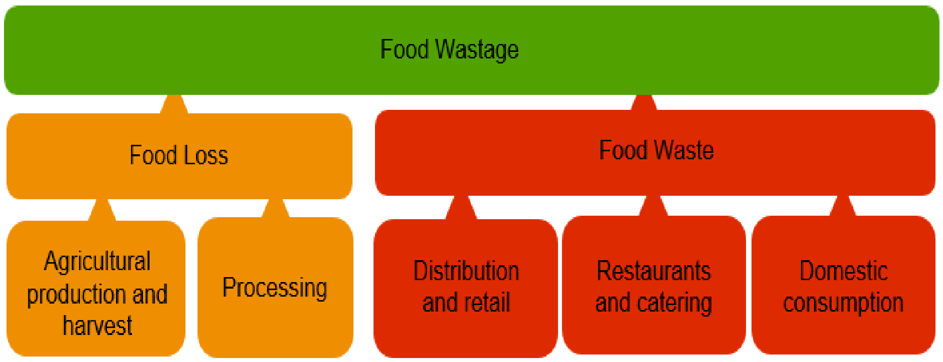

Figure 2. 1: Relationship between food loss, food waste and food wastage. Source: Every Crumb. Counts: https://everycrumbcounts.eu/ (2019)

One challenge with the estimates of food waste is that only part of the picture is taken into consideration. If we consider food waste as a product of the food system, there is the demand side and then supply causes (IPCC, 2019). Since food waste cannot go beyond food available for consumption, therefore food waste by consumers is controlled by an upper perimeter which is determined by the available food, as dictated by supply side dynamics (Verma *et al.,* 2020). They further report that the FAO methodology for calculating food waste does not take into account the role of consumers in determining food waste. As a way of accounting for the demand side there is a need to consider how the food available for human consumption is used (including consumer waste) as well as the determining factors of food wasted by consumers (Verma *et al.,* 2020).

In recent years food security has gained prominence on the international political agenda due to the volatile food prices experienced in 2006-2008, converting of crop land for biofuels as well as use of food crops as biofuels and fodder and the recurring droughts (Donner, 2007; Godfray *et al.,* 2010; Naylor, 2011; Naylor and Falcon, 2010; and Rosegrant *et al.,* 2009). With regard to food security and nutrition, nearly one billion people globally suffer from hunger and are undernourished. That is one person in every nine on the globe suffers from hunger (FAO, 2010). A reduction in post-harvest losses is considered critical in the promotion of food security, alleviation of poverty, creation of income generation opportunities as well as to foster economic growth in African countries (Kikulwe *et al.,* 2018; Kaminski and Christiaensen 2014; FAO, 2013 and FAO/World Bank, 2011).

Table 2.1: Percentage share of total food available globally that is lost or wasted. Source: FAO (2011)

Food value chain	**Regions of the world**						
	North America and Oceania	Industrialized Asia	Europe	North Africa, West and Central Asia	Latin America	South and South East Asia	Sub-Saharan Africa
Production	17	17	23	23	28	32	39
Handling and storage	6	23	12	21	17	37	37
Processing	9	2	5	4	6	4	7
Distribution/ marketing	7	11	9	18	22	15	13
Consumption	61	46	52	34	28	13	5

When a comparison is made across the regions of the world, North America and Oceania (61%), Europe (52%) and Industrialized Asia (46%) experience highest levels of food loss and waste during consumption while in sub - Saharan Africa (39%) and South and South East Asia (32%) food wastage is mainly during production, handling and storage (FAO, 2011). The lowest levels of food loss and waste occur during processing, followed by distribution and marketing across all regions of the world. Table 2.1 gives detailed information on percentage share of total food available globally that is lost or wasted.

2.2 Causes of Postharvest Losses

According to Gustavsson *et al.,* (2011) there are five stages in the food supply chain where food losses or waste occur. These segments include:

Agricultural production; losses caused by mechanical damage/ and or spillage during harvesting, crop sorting, threshing and winnowing.

Postharvest handling: losses caused by spillage and degradation during handling, storage and transportation from farm to distribution centres.

Processing: losses caused by spillage during processing. Losses may occur when crops are sorted out if found to be of inferior grade.

Distribution: Losses and waste occur in the marketing system, for example, wholesale markets, supermarkets, and retailing.

Consumption: Losses and waste during consumption at household level.

A summary of examples of food waste along the food supply chain is provided in Table 2.2.

Table 2. 2: Generic food supply chain and examples of food waste. Source: Parfitt *et al.,* (2010)

#	Stage	Examples of Waste
1	Harvesting, handling at harvesting	Edible crops left in field, ploughed into soil, eaten by pests; timing of harvest not optimal; crop damaged during harvesting
2	Threshing	Loss due to poor technique
3	Drying, transport and distribution	Quality and quantity loss during drying, poor transport infrastructure; loss owing to spoiling/bruising
4	Storage	Storage pests and disease attacks, spillage, contamination; natural drying-out of food
5	Primary processing, cleaning, classification, hulling, pounding, grinding, packaging, soaking, winnowing, drying, sieving, milling	Process losses; contamination in processing causing loss of quality.
6	Secondary processing, mixing, cooking, frying, moulding, cutting, extrusion	Process losses; contamination in process causing loss of quality
7	Product evaluation and quality control	Product discarded /out-grades in supply chain
8	Packaging	Inappropriate packaging damages produce; grain spillage from sacks; attack by pests
9	Marketing, selling, distribution	Damage during transport; spoilage; poor handling; losses caused by poor storage
10	Post-consumer	Poor storage/stock management; discarded before serving; poor food preparation; expiration
11	End of life disposal of food waste/loss at different stages in supply chain.	Food waste discarded may be separately treated, fed to animals, mixed with other wastes/landfilled

Post-harvest losses are caused by several factors which include inappropriate handling or bio-deterioration by micro-organisms, insects, rodents or birds (Grolleaud 1997; Boxall, 2002) as reported by Hodges *et al*., (2010). In the developed world, large quantities of food produced is wasted for reasons such as passing of expiry date including that food which remains on the plate after meals (Hodges *et al*., 2010 and WRAP, 2007). Food losses and waste in developing countries are caused by financial, managerial, and technical constraints in harvesting methods, handling, storage, cold chain infrastructure, packaging and marketing. The causes of food losses and waste in developed countries are mostly associated with consumer behavior and inadequate coordination between different actors in the food supply chain. Food gets wasted due to quality standards such as shape and appearance (ibid). Martinez (2014) also argues that depending on the type of food, wastage by consumers takes place in two different ways namely consumption habits and/or misuse. For example, some consumers dehull maize prior to milling while others buy excessive food which they fail to consume before it becomes unfit for human consumption. Other than losses during transportation and consumption, industrial processing is also a contributing factor (Bucher, 2012) as quoted by Martinez (2014). Some consumers have a careless attitude as they do not consider waste of food as a big issue because they can afford to buy more food (WRAP, 2007 and FAO, 2011). Figure 2.2 provides a summary of food waste along the food supply chain.

Tyler (1982) reported that postharvest losses may be caused by a number of factors which varies from commodity to commodity, across seasons, and a variation in the circumstances under which crops are grown, harvested, stored, processed and marketed. The causes of postharvest losses can be categorized as governance associated and technical. The governance - linked include poor procurement, storage, marketing and distribution policies; inadequate access to credit, lack of mechanisms for dealing with cash needs, mismanagement of stocks, challenges in managing ownership and control of grain storage facilities and price stabilization (FAO-World Bank, 2011). The technical causes of losses are mainly production related and they include: harvesting methods, handling techniques, moisture, damage by pests, and infestations by pathogens (Kiaya, 2014 and FAO - World Bank, 2011).

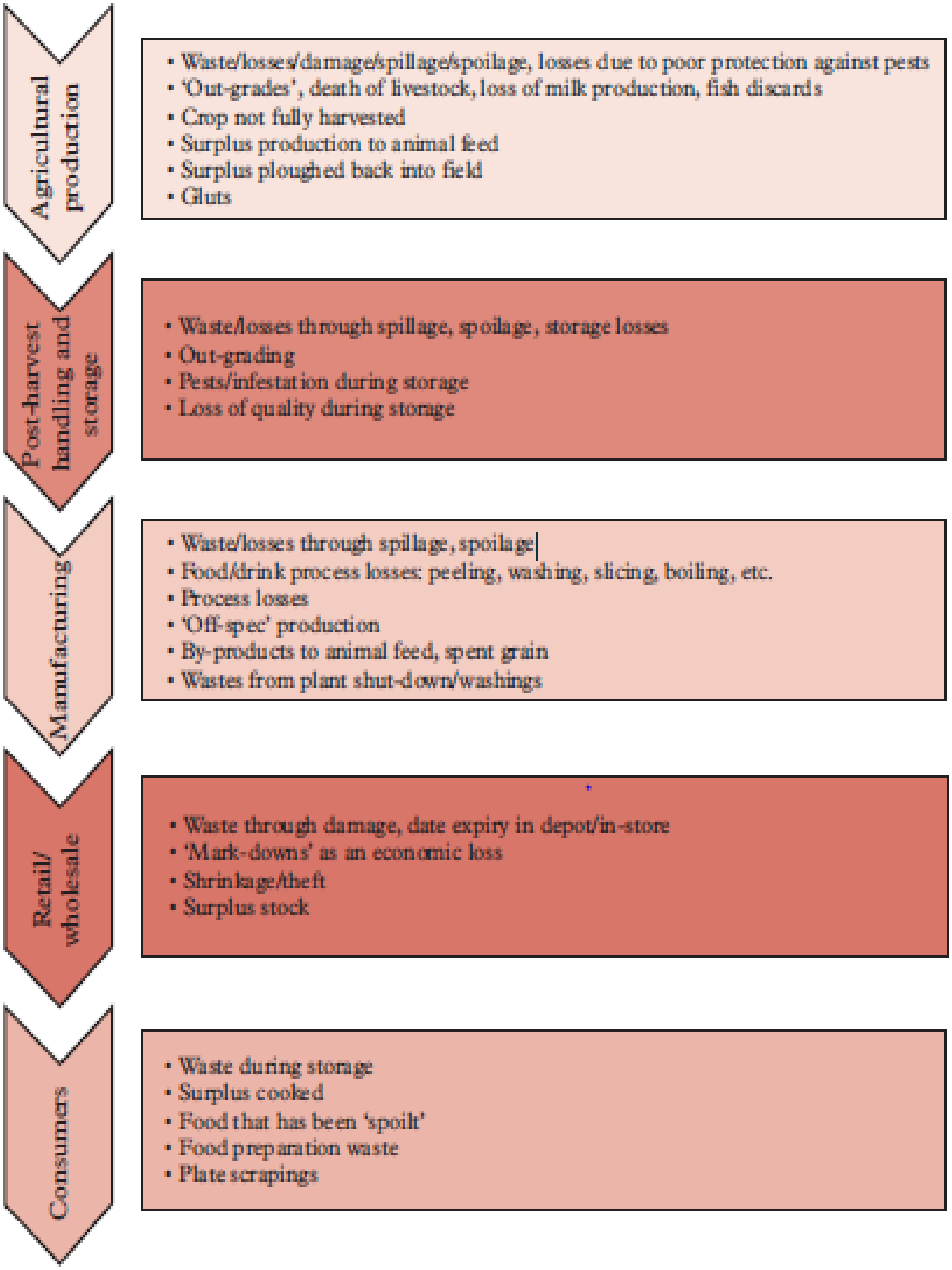

Figure 2. 2: Summary of food waste along the food supply chain. Source: Parliament Publications (2011)

Inadequate information on the precise causes of losses and inconsistent data on PHLs restricts the adoption of practical technologies required to reduce losses in maize and food supply chains in general (Morris and Kamarulzaman, 2014). Kikulwe et al., (2018) contend that many countries have not developed and /or implemented strategies for reducing postharvest losses due to lack of empirical information on the extent of losses. One critical aspect in the PHL discourse relates to the realistic amount of reduction achievable and the cost associated with the attainment of the desired results (Rosegrant, 2015). Furthermore, de Gorter (2014) argues that the postharvest loss reduction targets are idealistic and not practically attainable although with regard to cost effectiveness, it might be more prudent to use the funds in other ways of eradicating hunger than investing resources into trying to achieve the desired PHL reduction levels. Kader (2005) calls for cost-benefit analysis in order to appraise the return to investment as this will assist in establishing realistic loss levels for various products and locations than targeting zero percent loss.

2.3 Estimation of Postharvest Losses

Postharvest losses can either be quantitative or qualitative. Whereas the former refers to the physical loss of food from the supply chain, qualitative losses arise from either superficial regular value, deterioration in taste, consistency and or nutritive value (Morris & Kamarulzaman, 2014; Hodges *et al.,* 2010 and Kader, 2005). An additional feature of postharvest losses relates to monetary losses which occur when the market value of a product gets reduced due to loss of quality (ibid).

Much as it's a lot easier to determine quantitative losses, it's rather difficult and complex to evaluate qualitative losses (Morris & Kamarulzaman, 2014; and Kader, 2005). Since deterioration in quality is determined by several factors including official criterions, quality loss may not necessarily be actual loss of food (Morris & Kamarulzaman, 2014; and Hodges, 2012). No wonder the Africa Postharvest Loss Information System (APHILS) only measures the quantitative losses (ibid).

In a standard supply chain, the quantity and quality changes as products move along the value chain (Cai *et al.,* 2013). Severely deteriorated products end up being rejected as food waste whereas moderately spoiled products may end up in the market but sold at reduced prices. The discarded produce and the products sold at reduced market value due to perceived loss of quality represent quantitative and qualitative losses respectively (Hodges, 2012). The summation of quantitative and qualitative losses gives the total amount of food losses in the supply chain (Figure 2.3). This total loss which is the postharvest loss for that specific supply chain and can be presented as: Total postharvest losses (PHLs) = Σ Quantitative losses + Σ Qualitative losses.

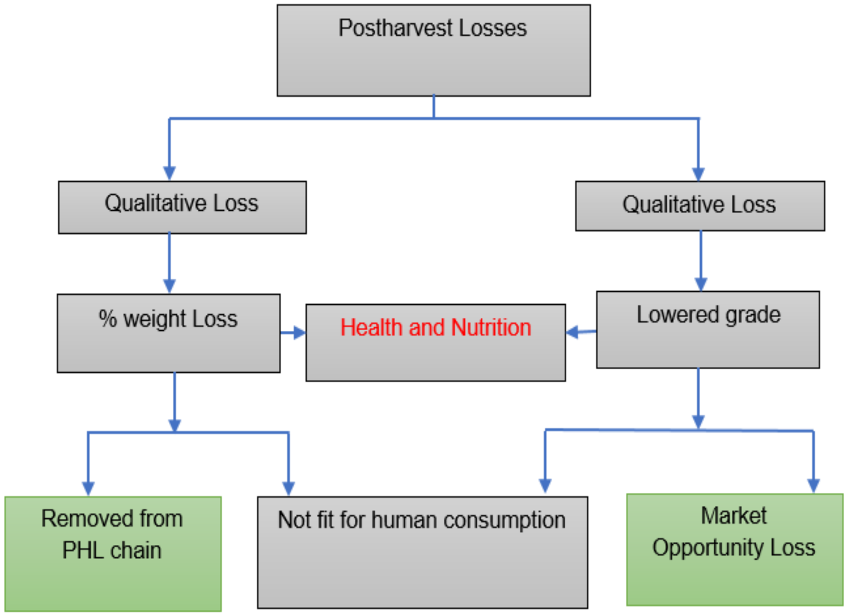

Figure 2.3: The relationship between quantity and quality losses. Source: Adapted from Hodges (2012)

2.3.1 Framework for estimation of postharvest losses

The theoretical framework for estimation of postharvest losses enables impartial documentation of exact losses and causative factors (Labaree, 2009). It helps to predict and control situations and establishes orderly connections between examination and facts (ibid).Furthermore this framework provides the road map for plotting interventions and policies on PHL solutions. Postharvest losses are estimated by either direct measurement or indirect estimation by interviewing farmers and traders as they are the ones affected by food losses (Morris and Kamarulzaman 2014; and Hodges *et al*., 2010). However, each one of these methods has its own pros and cons. While the focus on direct measurement by tracking might only provide discarded or quantitative losses, estimate by survey method may not give representative values due to underestimation or overestimation of definite losses (ibid). Whereas large population samples can be handled by the estimate survey method, this is not possible when using the direct measurement by tracking. Mass flow of food flowing through the food supply chain, developed by the Swedish Institute for Food and Biotechnology (SIK), is another method of quantifying food losses. The Mass flow method is only ideal in settings with updated records and data.

2.3.2 Commodity systems assessment method

The Commodity Systems Assessment Method (CSAM) is a postharvest loss assessment technique whose purpose is to identify weak spots along the agricultural value chain that contribute to food losses and identify solutions as well as to develop plans for enhancing their proficiency (La Gra, 1990 and La Gra *et al.*, 2016). This method has changed over time because of the apparent need for a logical approach to characterise, prioritise and address postharvest challenges from planning to commodity supply for the purpose of ensuring that all elements affecting a specified product are taken into account along the value chain (ibid). The CSAM deals with two main features of the value chain which are pre-harvest (pre-production and production) and postharvest (harvesting and marketing). The different steps which happen between production and marketing of an agricultural commodity are identified through commodity system analysis. The postharvest component of the commodity systems gives a broad illustration of a commodity's supply chain and can be a useful method for assessing PHLs (Morris & Kamarulzaman, 2014; La Gra, 1990 and La Gra *et al.,* 2016).

One principal aspect of this methodology is that it covers 26 components as indicated in Figure 2.4, which allows an investigation of the entire commodity system, therefore facilitating the identification and ranking of challenges along the entire system (La Gra, 1990). A logical initial step towards the identification of sources of PHLs and the remedial solutions is through the systematic analysis of the production and postharvest handling of each product (Morris and Kamarulzaman, 2014 and Kader, 2005). The CSAM was used to evaluate postharvest losses of nearly 16 crops in South Asia (India) and sub Saharan Africa (Benin, Ghana and Rwanda). This was an initial phase towards the reduction of food losses and enhancement of the productivity and efficiency of the value chains of these products (La Gra, 1990).

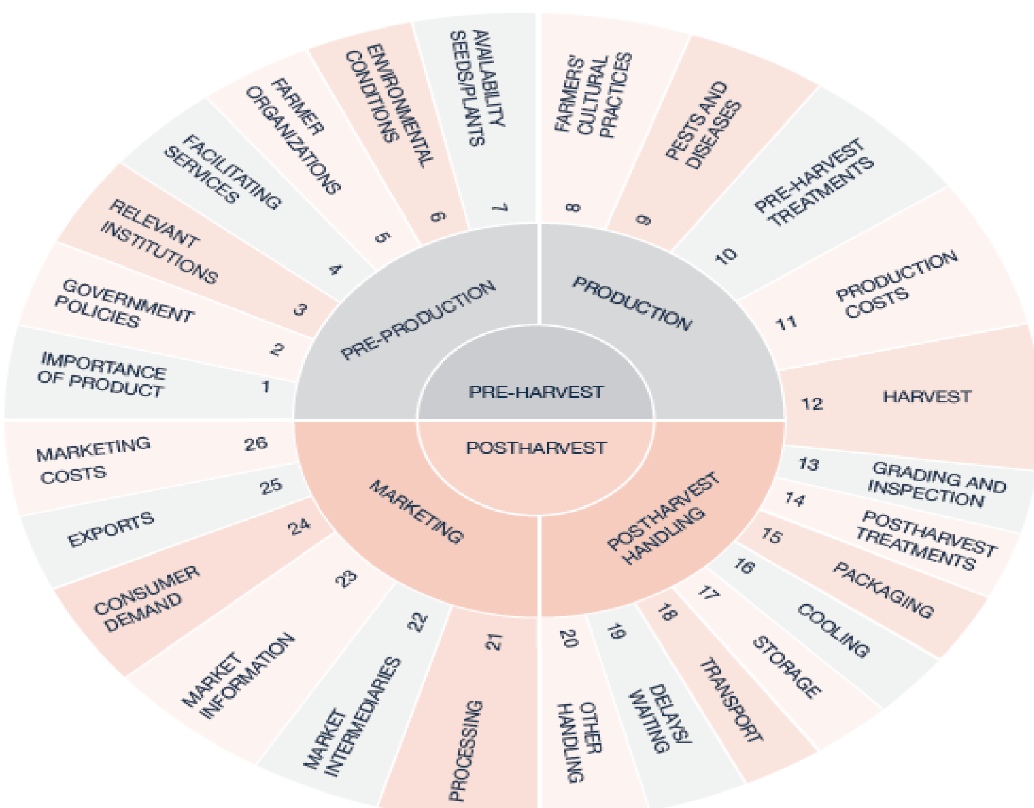

Figure 2.4: Principal components of the commodity systems assessment method from the food losses perspective. Source: La Gra (1990)

The assumption is that shelf life of an agricultural product is at peak during harvest and reduces as the product moves down the value chain (Morris and Kamarulzaman, 2014). The conceptual framework in Figure 2.5 indicates that shelf life of a product is influenced by three variables which are; quality at harvest, postharvest handling and market systems. The function of quality at harvest, postharvest handling and market systems is in turn influenced by several activities termed as X, Y. Z for each of the variables. Depending on the degree, a decrease in the shelf life of an agricultural product leads to either qualitative or quantitative losses. The addition of quantitative and qualitative losses as the product moves down the supply chain gives total post-harvest losses (Baruwa *et al.,* 2011 and Cai *et al*., 2013 and Morris & Kamarulzaman, 2014). In this study the terms value chain, supply chain and commodity system are used interchangeably to include activities such as production, harvesting, processing, wholesaling, and retailing including support functions such as advertising, input supply, packaging, transport and financial services.

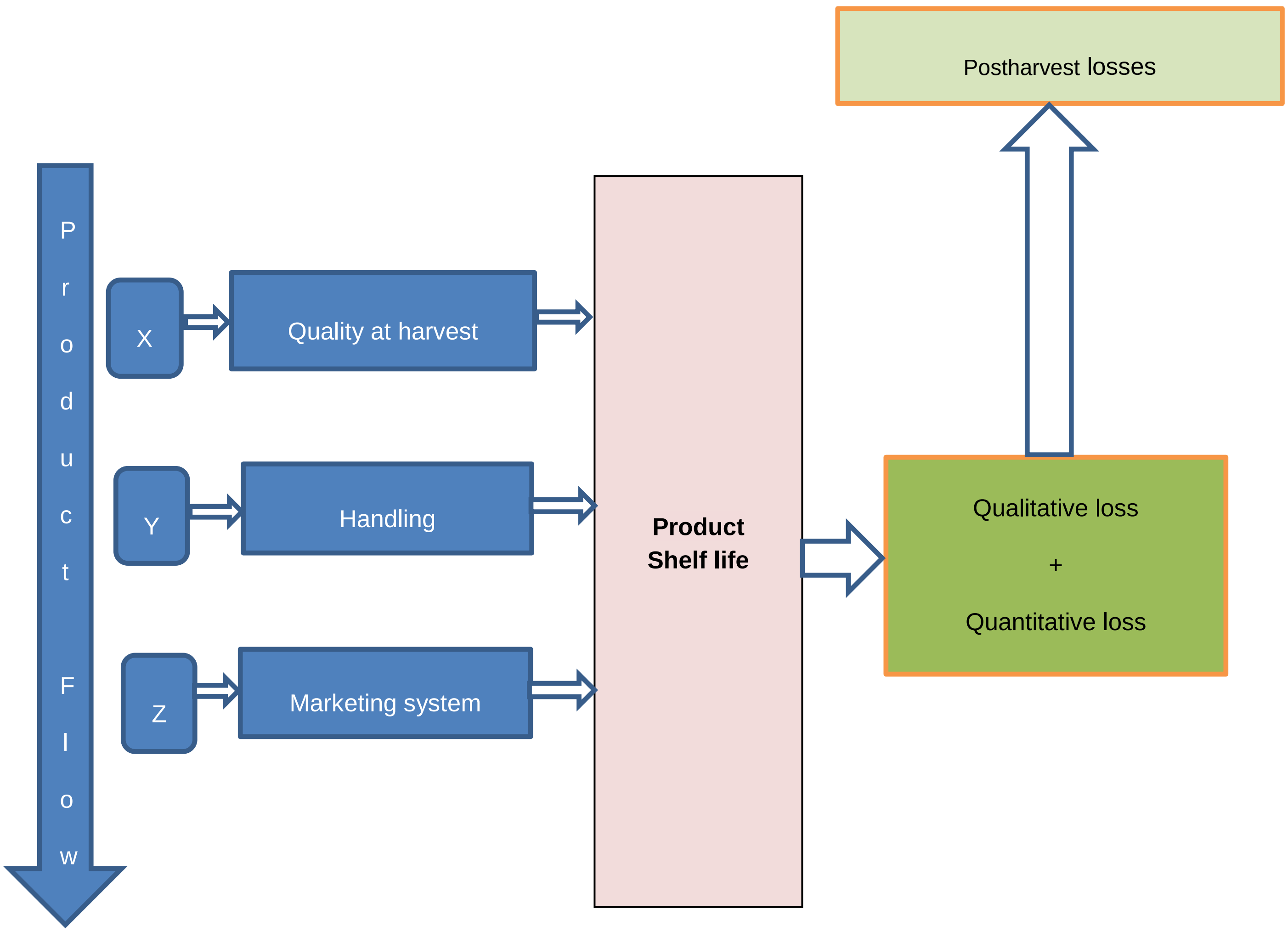

Figure 2.5: Conceptual framework for estimating postharvest losses. Source: Source: Morris and Kumarulzaman (2014)

2.4 Financial Perspectives of Food Loss and Waste

From an economic point of view, food loss and waste represents a wasted investment that can reduce farmers' incomes and increase consumer expenses. Food losses reduce the income of approximately 470 million farmers and other value chain actors by as much as 15% (The Rockefeller Foundation, 2013). In 2011, World Bank reported annual postharvest food losses in sub-Saharan Africa (SSA) exceeding 30% of total crop production and representing more than US$ 4 billion dollars of the estimated cereal value of US$ 27.4 billion. At this production and loss levels, a one percent reduction in cereal PHLs can save approximately US$ 40 million per annum (Hodges, *et al.,* 2010 and World Bank, 2011). The food lost exceeds the value of food aid received by sub-Sahara African countries during the decade 1998 - 2008 and equates to the value of cereals imported into the region during the period 2000 - 2007. The lost food could meet the minimum annual food requirements of at least 48 million of the 220 million undernourished people in Africa (ibid). Approximately 23% of available food in sub-Saharan Africa is lost or wasted. This equates to a loss of 545 kilocalories per person, per day across a sub-continent where 24.8% of the population is undernourished (FAO) 2013.

Based on the estimates provided by the African Postharvest Losses Information System (APHLIS) for Eastern and Southern Africa, the region losses approximately US$1.6 billion worth of grain per year, or about 13.5 percent of the total value of grain production. The estimates provided by APHLIS of grain losses (prior to processing) can range from 10 to 20 percent. Although APHLIS grain loss estimates are below the 40-50 percent frequently cited in the development community, this information should be fairly reliable as it is collected by national researchers (APHLIS, 2011 and Hodges, *et al.,* 2010).

2.5 Environmental Perspectives of Food Loss and Waste

From an environmental point of view, food loss and waste inflict a host of impacts, including unnecessary greenhouse gas emissions and inefficiently used water and land, which in turn can lead to diminished natural ecosystems and the services they provide (GIZ, 2013b; Hodges *et al.,* 2011; Lundqvist *et al.,*2008 and World Bank, 2011).

The scarcity of water is one of the major challenges in increasing food production as nearly 70% of the fresh water on the globe is already used for agricultural production (Kummu *et al.,* 2012 and Rockstrom *et al*., 2009).The food which is harvested and subsequently lost or wasted consumes approximately one - quarter of all water used in agriculture per year (FAO, 2010; and Kummu *et al.,* 2012;). Most studies of food waste have concentrated on the amount of food wasted which mainly gives the environmental cost of the waste. In order to get a more comprehensive picture, the carbon foot print of the food waste should be taken into consideration alongside the weight of the food wanted (FAO, 2013 and Scholz *et al.,* 2013). The carbon foot print of a food product is the total amount of Green House Gases (GHG) emitted throughout its lifecycle expressed in kilograms of carbon dioxide equivalents (FAO, 2011).

The lost or wasted food generates about eight percent of global greenhouses gas emissions annually. When put into perspective, if the food loss and waste were a country it would be the third largest greenhouse gas

(GHG) emitter on earth after China and the United States (FAO, 2013 and WRI, 2014). The total cost of GHG emissions from global food waste is USD 411 billion (FAO 2015; and IFPRI, 2016). On a global basis, developed countries have more than double per capita food waste foot print than low income countries (FAO 2013). China is the leading emitter of greenhouse gases at 10.7 gigatons of carbon dioxide followed by the United States of America at 5.8 gigatons, then food loss and waste at 4.4 gigatons. Figure 2.6 shows carbon dioxide emissions in gigatons by the leading emitters of greenhouse gases. The reduction of postharvest losses (PHLs) is a key component to meeting the current and future food demand (Greeley, 1986; FAO 2011; Hodges *et al*., 2010; Kader, 2005; SDC, 2014 and WFP, 2014). On the basis of available literature, it is proposed that investing in postharvest loss reduction is an avenue of increasing food availability without requiring additional production resources or placing additional burdens on the environment (GIZ, 2013b and Hodges, 2012).

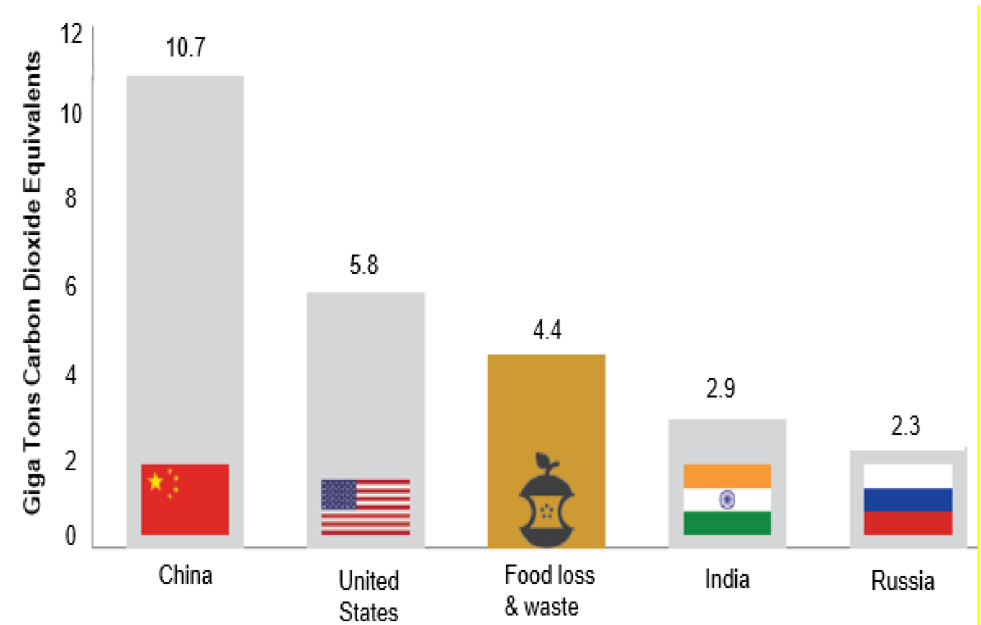

Figure 2. 6: The global leading emitters of greenhouse gas emissions. Source - FAO (2015)

The FAO and World Bank estimate that up to 47% of the USD 940 billion needed to eradicate hunger in SSA by 2050 will have to be invested in the postharvest sector (FAO-World Bank, 2010). However, lack of funding remains a major challenge in the reduction of postharvest losses worldwide. According to Kader (2005), less than 5 per cent of the funding for agricultural research is allocated to postharvest systems. In support of this argument, Goletti and Wolf (1999) declared that “while research on the improvement of agricultural production has received considerable attention and funding, until recently postharvest activities have not attracted much attention from international research organizations” (p.1). They called for increased funding to postharvest research due to benefits such as higher return on investment, effect on poverty, food security and health and on sustainable use of resources. In addition to low funding, one major hindrance to addressing PHLs is the absence of strong knowledge regarding the extent of losses, which renders it difficult to assess the progress made towards mitigation (FAO, 2011). Although the extent of food losses is substantial, measuring them is rather difficult particularly in most developing countries (Vark, 2012 and Martinez *et al.,* 2014). According to Parfitt *et al*., (2010) findings from literature established that data on food waste estimates varied widely, and postharvest losses of grain in developing countries appeared to have been overestimated. They further report difficulties in quantifying current global postharvest food losses because postharvest loss data for developing countries was collected over 30 years ago. The estimates from literature very from 10 to 40 percent of the global food production and in certain cases estimates as high as 50 percent have been quoted. Inadequate knowledge about the segments of the value chains where losses occur and the driving socio-economic factors can contribute to poor policy formulation and selection of irrelevant PHL solutions (FAO-World Bank, 2010; Kader, 2005, Lundqvist *et al.,* 2008 and Prusky, 2011).

The unsubstantiated data for post-harvest losses have to some extent served a valuable purpose. The data has given PHLs world recognition and deserving attention and that reduction of potential losses can make a significant contribution to mitigation of the world food shortage (Tyler 1982). It's worth noting that some of the overstated figures for PHLs may be due to the variability of PHLs across commodities, seasons, countries and the wide variety of conditions under which the crops are produced and the postharvest operations (Hodges *et al*., 2010 and Tyler, 1982). Furthermore, the methodology for computing PHLs is complicated due to necessity of assessing the several constituent causes of losses. Although PHL reduction programmes occasionally over look evidence and quote high figures for losses, maybe in the belief to attract more resources, support should be given to continued use of verified and / or traditional PHL assessment methods that are renowned to have credibility (Aulakh and Regmi, 2013 and Hodges *et al.,* 2010).

The existence of food loss and waste can be explained by low food prices (Bond 2013; FAO, 2011 and Parfitt, 2010). The greater tolerance of food loss and waste in the developed world is attributed to increased food availability and variety, lower prices and lower level of income spent on food (ibid). Under such circumstances, consumers may find it convenient to waste food (BCFN, 2012). In a similar manner, food producers in developing countries might find it rational to incur food losses if they consider the cost of prevention to outweigh the benefits to be realised from increased sales at lower prices (FAO, 2011 and Lipinski *et al.,* 2013). Taking into account the impacts on society, it might be more beneficial to address the underlying causes of food loss and waste. Halloran *et al.,* (2014), propose an integrated agricultural system approach where food utilisation is optimised and loss and waste reduced.

The value chain analysis is cardinal in understanding food loss and waste. According to Porter (1985), the concept of value chain is a process from producers to final consumers of product and services. Porter defined value chain as "the number of buyers willing to pay for what a firm provides" and the conceived value chain "as the combination of nine generic value added activities operating within firm activities that work together to provide value to customers". According to Kaplinsky and Morris (2001), "A value chain describes the full range of activities required to bring a product or service from conception, through different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to the final consumers and final disposal after use". Much as there is temptation to use "value chain" and "supply chain" interchangeably these concepts have significant differences (Reddy, 2013). While the supply chain model concentrates on activities which source raw materials for manufacturing, value chain is the transfer of products from one stakeholder to another in form of a chain (ibid). Porter (1985) reports that the linked up value chains between firms forms what is called a value system. He further states that, the modern times of better outsourcing, collaboration and networking, value creating processes have become what is called value chain.

Value chains are cardinal in converting agricultural products from raw materials to finished products required by clients. The purpose is to convey maximum value to the consumer at the lowest possible cost. That therefore, makes supply chain management a sub category of the value chain analysis (Reddy, 2013).

2.6 Supply Chain and Value Chain

Agricultural product value chains and the apportioning of benefits among the stakeholders is a subject of debate but with little appreciation of the different concepts used in the analysis particularly addressed to developed countries and regarding the participation of smallholder farmers in the value chains. According to (Aksoy, 2005), the major actors in the agricultural value chains are farmers, traders, wholesalers, big retail chains and consumers.

Therefore the primary focus in value chain is on the interdependent processes that generate value and the resultant demand and fund flows that are created (Knorringa and Pegler, 2006). The value chain analysis is cardinal in understanding the postharvest food losses. For example, the demand for maize is anticipated to increase by more 50% between now and 2050 (CIMMYT and IITA 2011; and FAO, 2015). Therefore, this is calls for a need to improve efficiency in the maize value chain. Table 2.3 provides a summary of food loss and waste along the food value chain (FAO, 2011).

Table 2. 3: Summary of food loss and waste along the food value chain. Source: FAO (2011)

Production	Handling and storage	Processing and packaging	Distribution and Market	Consumption
• During or immediately after harvesting on the farm	• After leaving the farm during handling, storage and transportation	• During industrial or domestic processing and/or packaging	• During distribution to markets, including at wholesale and retail stages	• In the home or business of consumer, including restaurants and caterers
• Fruits discarded due to bruising during picking	• Food eaten by pests	• Milk spilled during pasteurisation and processing	• Food sorted out due to quality	• Food sorted out due to quality
• Crops sorted out for not meeting cosmetic standards	• Food degraded by fungus or disease	• Food sorted out not suitable for processing	• Safe food disposed because of going past sell date before being purchased	• Food purchased but not frozen
• Crops left behind in the fields due to poor mechanical harvesting or drop in price	• Livestock death during transportation to slaughter or not accepted for slaughter	• Livestock trimmings during slaughtering and industrial processing	• Food spoiled or damaged in the market	• Food cooked but not eaten
• Fish discarded during fishing operation	• Fish degraded after landing	• Fish damaged during canning or smoking	• Fish damaged in the market	• Fish cooked but not eaten

2.7 Strategies for Reducing Postharvest Losses

Maize is an important staple food in Africa which provides food and income to many smallholder farmers (Tefera, 2012). One of the challenges faced by the smallholder farmers to achieving enhanced food and nutritional security is poor postharvest management which results in losses of 14% to 36% of the maize grain (ibid). In order to reduce postharvest losses of maize, smallholder farmers have devised a number of strategies during operations such as harvesting, drying, shelling and on-farm storage (Kiaya, 2014). It's important that the postharvest strategy gets integrated into agricultural programmes to ensure the provision of technical and affordable solutions to smallholder farmers (ibid). With regard to smallholder farmers that lack resources for investing in modern postharvest practices and technologies, their alternative lies in upgrading storage hygiene and good storage management. Table 2.4 provides abridged information on strategies used by smallholder farmers in reducing postharvest food losses in cereal grains.

Table 2. 4: Strategies for reducing postharvest food losses in cereal grains. Source: Technical paper on postharvest losses (ACF 2014)

#	Stage in the food system	Description and strategy
1	Harvesting	In tropical countries in general, most grains have a single annual harvesting season, although in bimodal rainfall areas there may be two harvests (e.g., Ghana and Uganda). African producers harvest grain crops once the grain reaches physiological maturity (moisture content is 20-30%) (FAO, World Bank, 2011). At this stage the grain is very susceptible to pest attack. Poor farmers sometimes harvest crops too early due to food deficiency or the desperate need for cash. In this way, the food incurs a loss in nutritional and economic value, and may get wasted if it is not suitable for consumption. Quality cannot be improved after harvest, only maintained; therefore, it is important to harvest at the proper maturity stage and at peak quality.
2	Drying	Most farmers in Africa, both small and large, rely almost exclusively on natural drying of crops by combining sunshine and movement of atmospheric air through the product; consequently, damp weather at harvest time can be a serious cause of postharvest losses. Grains should be dried in such a manner that damage to the grain is minimised and moisture levels are lower than those required to support mould growth during storage (usually below 13 -15%). This is necessary to prevent further growth of fungal species that may be present on fresh grains. The harvested crop may be dried in the yard or in a crib.
3	Threshing/Shelling	For some grains, particularly millet and sorghum, threshing may be delayed for several months after harvest and the unthreshed crop stored in open cribs. In the case of maize, the grain may be stored on the cob with or without sheathing leaves for some months, or the cobs may be shelled and grain stored. Some machinery suitable for small-scale operation exist such as maize shellers.
4	Winnowing/cleaning	Usually done prior to storage or marketing if the grain is to be sold directly. For the majority of the smallholders, this process is done manually. It is relatively ineffective from a commercial perspective,

		since grain purchased from smallholders frequently requires screening to remove stones, sand, and extraneous organic matter. There is little incentive for smallholders to provide well-cleaned grain for marketing, as a result profits from sales are limited.
5	On-farm storage	Postharvest losses at storage are associated with both poor storage conditions and lack of storage capacity. It is important that stores be constructed in such a way as to provide: - dry, well-vented conditions allowing further drying in case of limited opportunities for complete drying prior to storage; - protection from rain and ground water; and - protection from entry of rodents and birds and minimum temperature fluctuations.

2.8 Role of Food Prices in Reducing Postharvest Losses

In addressing food loss and waste at a global level, due consideration should be given to the impact of supply and demand of food on food pricing (FAO/LEI, 2015). While food loss and waste basically reduces the net food supply available for humans, it's anticipated that addressing food loss and waste would lead to an increase in the net food supply and a reduction in food prices at local and world levels (FAO, 2011; Lipinski *et al*., 2013 and Lundqvist, de Fraiture & Moulden, 2008). The economic impacts of addressing food loss and waste in the context of changes in prices and their ripple effect on the world economy have not been extensively studied (FAO/REI, 2015 and Rutten *et al.,* 2013). This has been caused by a universal absence of consistent and trustworthy data, including the disparities in and/ or disagreements on data collection methods. For example, the results from a study on healthy and sustainable food showed that reduction of food waste modeled through a 15% supply chain efficiency increase led to a 4 % reduction in prices of agricultural commodities (Westhoek *et al.,* 2011). Other studies on food waste or loss reduction, focusing on the EU (Rutten *et al*., 2013) and Middle East and Africa and North Africa (Rutten and Kavallari, 2013) did not specifically consider price transmission.

The complex interaction between supply and demand shifts caused by food loss and reduction demonstrates the challenges in predicting the potential socio economic impacts of such actions. However they shade some light on what might happen and offer a useful baseline for additional and more detailed analysis of the outlook for 2020 and beyond (Rutten *et al.,* 2013). The global nature of food and agricultural systems and the massive scale and extent of food loss and waste have brought attention to the potential effect on food prices and the processes of price transmission (FAO/LEI, 2015 and Rutten *et al.,* 2016). The other issues worth considering are the impact on sustainability of food systems in light of food security and natural resources management. According to literature there has not been any empirical studies on the impact of food loss and waste on food prices to inform policy and regulatory debate (Rutten, 2013).

The changes in food prices contribute to mediating the impact of food loss and waste on the food system and wider economy. In functioning competitive market, prices ensure that demand equals supply and allocation of scarce resources in an optimal manner. Prices tend to fall in the presence of excess supply and rise when there is excess demand (HLPE, 2011).

Rutten and Kavallari (2016) argue that the existence of food loss and waste can be explained by low food prices. The greater tolerance of food loss and waste in the developed world is attributed to increased food availability and variety, lower prices and lower level of income spent on food (Rutten, 2013). Under such circumstances, consumers may find it convenient to waste food (BCFN, 2012). In a similar manner, food producers in developing countries might find it rational to incur food losses if they consider the cost of preventing food losses to outweigh the benefits to be realised from increased sales at lower prices (FAO, 2011; Lipinski *et al.,* 2013). According to US Department of Agriculture (USDA), Americans spend only 6.4% of their household income on food (WEF, 2019). There are only eight countries in the world that spend less than 10% of their household income on food. Four of these are in Europe: the UK is third at 8.2%, followed by Switzerland at 8.7%; Ireland spends 9.6% and Austria 9.9%. The remaining four countries are spread across the globe. Generally speaking, the more developed a country is, the smaller the percentage of household income it spends on food (ibid).

With regard to developing countries there are nine countries that spend over 40% of their income on food. Four of them are in Africa: Nigeria 56.4%; Kenya 46.7%; Cameroon 45.6%; and Algeria 42.5%. The other countries are in Asia: Kazakhstan 43.0%; Philippines 41.9%; Pakistan 40.9%; and Azerbaijan 40.1%. Guatemala is the only South American country that spends 40.6% of its household income on food (WEF, 2019).

However, there can be wide disparities within a country. Over the past 25 years, the poorest 20% of the households in the USA spent between 28.8% and 42.6 % on food, compared with 6.5% to 9.2% spent by the wealthiest 20% households (WEF, 2019).

When studying the impact of addressing food loss and waste in the short and long terns, Rutten (2013) used basic economic theory of food supply and demand. The study found that impacts were dependent on the extent to which food loss and waste were preventable, contributing factors to their rise and the cost of addressing them. The study further revealed that the relationship between the food supply chain and the macro economy played an important role. On the demand side, addressing food waste would have spin-offs as the readjustment of expenditure on the wasted food makes some producers better off while others worse off (ibid)

For instance, if consumers were to waste less maize, they would buy less of the commodity (assuming their eating habits have not changed). This would result in a reduction in the proceeds of the farmers because of the reduced sales. The money saved by the consumers may be spent on non-food products thereby giving benefits to other producers. If the money saved from buying maize is not immediately spent, there is a likelihood of the impact occurring in the long term (Rutten, 2013). With regard to the supply side, producers tackling food losses may suffer welfare losses in the immediate run due to the costs and / or drop in income arising from the falling food prices due to increased supply of produce (ibid).

The research conducted in the aftermath of the global food crisis of 2007/2008 found significant variability in the domestic and global prices across regions, countries, commodities and time thus justifying further studies (HLPE, 2011 and Minot, 2011).

2.9 Global Historical Trends and Action Towards Reducing Food Loss and Waste

2.9.1 United Nations

The responsibility of reducing food loss and waste and postharvest losses is for all human kind (FAO, 2018). The challenge of food loss and waste has been an issue of global concern since the 1970s (ibid). When the Food and Agriculture Organisation of the United Nations (FAO) was established in 1974, it had a mandate to reduce postharvest food losses. In 1974 the United Nations passed a resolution for a 50% reduction of the estimated 15% postharvest food losses by 1985. Although the main focus was to reduce losses of durable grains, the scope of work was expanded to cover fresh vegetables, roots and tubers. After stabilization of food prices effort went to achievement of food security through economic liberalisation and trade rather than reduction of food loss and waste (FAO, 2018). Grolleaud (2002) argued that a technical approach was not adequate for addressing postharvest food losses. Lundqvist *et al.,* (2008) noted the lack of progress towards achievement of the 1985 postharvest target and called for a 50% reduction in postharvest food losses by 2025.

Since publication of the report on global food losses and food waste (FAO, 2011), which estimated that approximately a third of the food produced for human consumption is lost or wasted globally, there have been renewed concerns about the quantity of these losses in both developing and developed countries. According to Rosegrant (2015), the 2008-2011 food price spikes and worsening global food insecurity and malnutrition reignited the issue of food loss and waste. The subject came to the frontier of policy discussions with many stakeholders once more demanding for a reduction of postharvest losses as an effective weapon to meet the food needs of the growing world population. Table 2.5 gives highlights of some major global milestones in addressing food loss and waste.

Table 2. 5: Global historical trend of interventions for reducing postharvest food losses. Source: Author

#	Year	Major milestones
1	1974	UN resolution to reduce by half postharvest food losses by 1985
2	2006 -08	Global food crisis
3	2008	G8 Food Summit at L'Aquila - Italy
4	2011	FAO Report: Global food losses and food waste - extent, causes and prevention. Rome: FAO
5	2011	World Bank/FAO Report: Missing Food: The case of postharvest grain losses in sub-Saharan Africa
6	2011	Global Initiative on food loss and waste reduction (also called SAVE FOOD)
7	2012	Zero hunger challenge launched as one of the five pillars to the attainment of zero food waste
8	2013	FAO Report: Food wastage footprint: Impacts on natural resources
9	2014	Malabo declaration in which African Leaders made a commitment to half post-harvest food losses by 2025
10	2015	UN General Assembly adoption of Sustainable Development Goals. Target 12.3 calls for a reduction by half the per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains including postharvest losses by 2030.
11	2015	First World Congress on Postharvest Loss Prevention – Rome, Italy
12	2016	Formation of Champions 12.3 – This is an alliance of chief executives of international organizations, governments, research institutions, farmers groups, and civil society organizations providing leadership in the reduction of food loss and waste by generating social, political and business impetus to lower food loss and waste.
13	2017	First African Congress on Postharvest Losses – Nairobi, Kenya
14	2020	Launch of the International Day of Awareness of Food Loss and Waste

In September 2015, the United Nations General Assembly elevated the profile of food loss and waste by adopting 17 Sustainable Development Goals (SDGs) as part of the 2030 Agenda for Sustainable Development (UN 2015). The third target under Sustainable Development Goal 12 calls for " halving per capita global food waste at the retail and consumer levels and reducing food losses along production and supply chains (including post-harvest losses) by 2030" (ibid).

This global target has the potential to get the participation of public and private sector in food loss and waste reduction activities. This target will contribute to the attainment of other objectives such as the Zero Hunger Challenge. Since the adoption of SDGs in 2015, some governments and private companies have set food loss and waste targets which are consistent with target 12.3 (Foodtank, 2016).

2.9.2 African Union

In 2014, the 54 Member States of the African Union (AU) issued the Malabo Declaration, which is a set of agriculture goals aimed at achieving shared prosperity and improved livelihoods (AUC, 2014). The declaration includes a commitment "to halve the current levels of post-harvest losses by the year 2025." Unlike Target 12.3 passed by the UN, the focus is on food loss because this is a bigger issue during production and storage in Africa than food waste at the retail and consumption levels (ibid).

In order to address the identified challenges on the continent the African Union Commission (AUC) developed the Postharvest Loss Management Strategy (PHLMS) (AUC, 2018). The purpose of the strategy was to contribute to enhance food and nutrition security at the member states level through reduced postharvest losses in food including horticultural crops, livestock and fisheries products (ibid).

The strategy has four pillars which include;

a. Policy awareness and institutional capacity,
b. Knowledge and management, data, skills and human development,
c. Technology, markets and infrastructure, and
d. Finance and investment.

The strategy is to be operalionalised in five-year cycles and will have a PHL Management Monitoring and Evaluation System to monitor outcomes of policies, strategies, plans, and interventions (AUC, 2018).

The concept of postharvest management is an integrated method for dealing with postharvest losses. It involves bringing together all possible forms of approaches across the entire value chain that together contribute to reduced levels of losses occurring during and post harvesting of grains, fruits, vegetables, oilseeds and all food crops, livestock and fisheries products.

The reduction of the prevailing levels of postharvest losses by 50% requires having a greater appreciation of the current levels of postharvest losses in food crops. Therefore delivery on the Malabo Declaration will require conducting of studies and analysis of PHL estimates to use as a bench mark for reducing losses. The first logical step in the identifying appropriate strategies for reducing postharvest losses requires carrying out a logical analysis of agricultural product, production and handling method (Kitinoja and Gorny, 1999) as quoted by Kiaya (2014). As such, the achievement of the Malabo Declaration will depend on political will, policy awareness, financial support and investment in PHL reduction. However, (Irani *et al.,* 2018) contend that policy makers lack resources for performing an ex-post assessment of the social, structural and consequences of their interventions to lessen food waste within the context of food security arena.

The performance target set for reporting on the Malabo Declaration was to reduce by 50% the prevailing levels of postharvest losses, from 2015 to 2025. The performance indicators were computed on the reduction of postharvest losses for at least the 5 main national agricultural products and probably for the 11 Africa Union agricultural commodities. This rate was defined as "a percentage of total production that is lost (quantitative and qualitative) phases during all of the postharvest system (harvesting, storage, transport, processing, packaging and sales) for priority products" (AUC, 2018).

One milestone achieved since the launch of the programme was implementation of the Continental Post harvest Management Strategy in 2018. This document was to support realisation of the Malabo Declaration, which calls for halving food losses in Africa by 2025. In order to have a clear road map towards the attainment of the Malabo Declaration commitments of reducing postharvest losses by 50% by 2025 there was a need to have a sound policy and strategy (AUC, 2018). According to Centre for Disease Control and Prevention (CDC) (2015, p. 1) a policy can be defined as "law, regulation, procedure, administrative action, incentive, or voluntary practice of governments and other institutions". A policy can be defined as "general statements about priorities, written regulations or guidelines, procedures and/or standards to be achieved. At its simplest, a policy refers to a distinct path of action which is suitable for the pursuit of desired goals with a particular context, directing the decision making of an organization or individual" Mackay and Shaxton (2007). Policies are normally executed using one or more strategies. The strategies explain how the set out goals in a policy can be achieved and the required resources.

To this end, five countries participated in the development of the continental postharvest loss management strategy. These countries included Ethiopia, Kenya, Tanzania, Zambia and Zimbabwe. It was envisaged that the lessons learned from these five countries can be scaled up in the later phases of this programme.

The Biennial Review Report of 2017 revealed that only five countries (Malawi, Mauritania, Rwanda, Togo and Uganda) were on track in implementing the Malabo Declaration. These five countries (9% of the continent) were on track regarding the attainment of the postharvest loss targets by 2025. There were no reports presented by the other 42 countries (76%) on this indicator (AUC, 2018). While the Inaugural Biennial Review Report of 2017 showed that 20 out of 47 countries reported being on-track towards achieving the goals and targets in the Malabo Declaration by 2025, the Second Biennial Review Report of 2019 showed that only four countries achieved the required milestone to be on-track (AUC, 2020) (Refer to table 2.6). The four Member States, which obtained or surpassed the benchmark of 6.66 to be on-track towards achieving the commitments of the Malabo Declaration by 2025 were: Rwanda (7.24), Morocco (6.96), Mali (6.82) and Ghana (6.67). However the Biennial Review Report 2019 noted the considerable efforts made in improving the quality of the data presented and the increased number of countries submitting reports (ibid).

Table 2. 6: Summary of the Second Biennial Report to the AU Assembly on implementing the June 2014 Malabo Declaration. Source: AU Biennial Report (2019)

Against the 2019 Benchmark of 6.66 out of 10 which is the minimum score for a country to be on track for implementing the CAADP Malabo Declaration, countries whose score appears in "green" are ON TRACK while countries whose score appears in "red" are NOT ON TRACK for the 2019 report to the February 2020 AU Assembly. The arrows with percentages indicate the progress made by the country between the first (2017) and second (2019) biennial review cycles.

Algeria	n.a	
Angola	4.77	↑ 127 %
Benin	5.76	↑ 34 %
Botswana	3.35	↓ -34 %
Burkina Faso	5.31	↑ 26 %
Burundi	5.82	↑ 24 %
Cabo Verde	4.82	↑ 5 %
Cameroon	4.21	↑ 100 %
Central African Rep.	4.41	↑ 84 %
Chad	3.89	↑ 77 %
Comoros	n.a	
Congo	3.46	↑ 24 %
Côte d'Ivoire	4.79	↑ 37 %
Djibouti	2.82	↓ -12 %
DR Congo	3.33	↑ 138 %
Egypt	n.a	
Equatorial Guinea	2.46	↓ -32 %
Eritrea	3.89	
Eswatini	4.19	↑ 5 %
Ethiopia	5.31	↑ 0 %
Gabon	4.00	↑ 38 %
Gambia	4.95	↑ 60 %
Ghana	6.67	↑ 71 %
Guinea	4.43	↑ 34 %
Guinea-Bissau	2.49	
Kenya	4.88	↑ 2 %
Lesotho	3.26	↓ -12 %
Liberia	3.05	↑ 239 %
Libya	n.a	
Madagascar	4.92	↑ 59 %
Malawi	4.81	↓ -2 %
Mali	6.82	↑ 22 %
Mauritania	5.37	↑ 12 %
Mauritius	5.95	↑ 19 %
Morocco	6.96	↑ 27 %
Mozambique	4.06	↓ -1 %
Namibia	3.38	↓ -18 %
Niger	4.11	↑ 17 %
Nigeria	5.18	↑ 52 %
Rep. A. Saharawi	n.a	
Rwanda	7.24	↑ 19 %
São Tome & Principe	n.a	
Senegal	5.18	↑ 36 %
Seychelles	4.53	↑ 13 %
Sierra Leone	5.34	↑ 256 %
Somalia	0.55	
South Africa	2.88	↓ -30 %
South Sudan	2.89	
Sudan	3.33	↑ 75 %
Tanzania	5.08	↑ 64 %
Togo	5.14	↑ 5 %
Tunisia	6.20	↑ 265 %
Uganda	5.68	↑ 29 %
Zambia	5.11	↑ 42 %
Zimbabwe	4.58	↑ 43 %
2019 Benchmark	6.66	

2.9.3 European Union

The European Union (EU) and member states reaffirmed their commitment to support the Sustainable Development Goals (SDGs) and Target 12.3 on food loss and waste (EU, 2016). To this end, the EU Platform on Food Losses and Food Waste was established. The platform supports all actors in defining measures needed to prevent food losses, sharing best practices and monitoring progress made overtime (ibid).

2.9.4 United States of America

In September 2015, the US Department of Agriculture and the US Environmental Protection Agency (EPA) announced the "US 2030 Food Loss and Waste Reduction Goal." In line with Target 12.3, it calls for a reduction of food loss and waste by half by the year 2030 (EPA, 2015).

2.9.5 Private Sector

Since September 2015, private sector at a global level has become actively engaged in supporting SDG Target 12.3. The Consumer Goods Forum (CGF) passed the "Food Waste Resolution" which is a commitment to halving food waste within their individual retail and manufacturing operations by 2015 (CGF, 2017). Courtauld 2025, made a voluntary commitment among more than 100 business and government agencies to reduce food and drink waste in UK by a further 20 percent per capital between 2015 and 2025 (WRAP, 2016).

2.9.6 Champions 12.3

Champions 12.3 which is an alliance of chief executives of international organizations, governments, research institutions, farmers groups, and civil society organizations was formed in 2016 (Champions, 2016; WRI, 2016). The members dedicated themselves to accelerate progress, mobilize action and inspire ambition towards attainment of Sustainable Development Goal Target 12.3 (ibid).

The Champions are working to generate social, political and business impetus to lower food loss and waste globally by:

- Communicating the significance of food loss and waste;
- Demonstrating successful food loss and waste reduction methods;
- Lobbying for additional innovation, greater financing, improved information, and enhanced capacity to decrease food loss and waste;
- Providing leadership in the reduction of food loss and waste; and
- Stimulating others to meet the SDG 12.3

The 2018 SDG Annual Report showed that almost 66% of the world's 50 largest food companies were involved in activities dealing with food loss and waste reduction targets. There was evidence that nations and business entities working in the food industry were measuring food loss and waste.

2.10 Food Loss and Waste and Postharvest Loss Reduction Targets

Although all nations agreed to SDG Target 12.3, it's not automatic that food loss and waste will receive government attention it deserves. The indicator of attention and focus will only be confirmed after governments have set food loss and waste targets in line with Target 12.3 (WRI, 2018). The year 2018 saw a steady progress in the number of countries or regional blocks and companies in support of SDG target 12.3. These included African Union, European Union, Australia, Japan, and United States of America. Once the G20 members reaffirm their commitment to supporting SDG Target 12.3 then more than two thirds of the global population would be covered (WRI, 2018).

Quantification of food loss and waste and postharvest losses within a country, processes or supply chains can give decision makers a better appreciation of the quantities, locality, and reasons for food loss and waste (WRI, 2018). Information of this nature would form a strong basis for prioritisation of food loss and waste reduction strategies and monitoring of progress. One major achievement in 2018 was than more than 100 companies started measuring food loss and waste. In accordance with the harmonized methodology due for adoption in 2019, the amended EU legislation requiring member states to monitor food waste annually effective 2020. There was also the surfacing of country - level public private partnerships on food loss and waste reduction, with the new cooperation establishment in Indonesia and Netherlands (ibid). Furthermore, there was the launch of the online Food Waste Atlas, which is a global repository of food loss and waste data. This database enables governments, private sector and other stakeholders to have access to data which they can use when performing food loss and waste inventories and a place to deposit their food loss and waste inventories (WRI, 2018).

2.11 Food Wastage Reduction Levels Achievable by 2030

According to FAO (2015) the food wastage reduction levels achievable by 2030 for agricultural production and processing are 5% and 15% of the 2011 figures in developed and developing countries respectively. The same report estimates that during the postharvest handling and storage phases, developed and developing countries will need to reduce food wastage by 5% and 54% respectively. During distribution and consumption, there will be a need of a 50% reduction of the 2011 food wastage figures in all regions. Table 2.7 depicts assumptions for food wastage reduction ratios achievable by 2030 (FAO, 2015).

Table 2. 7: Assumptions for food wastage reduction ratios achievable by 2030. Source: FAO (2015)

Agricultural production and processing phases	Postharvest handling and storage phases	Distribution and consumption phases
● 5% reduction of 2011 food wastage in developed countries. ● 15% reduction of 2011 food wastage in developing countries (large progress margin assumed).	● 5% reduction of 2011 food wastage in developed countries. ● 54 % reduction of 2011 food wastage in developing countries.	● 50% reduction of 2011 food wastage in all regions.

2.12 Importance of Maize in sub - Saharan Africa

Although there are many agricultural commodities in sub-Saharan Africa (SSA) which experience postharvest losses, this study is focusing on Maize. This crop has been selected because it is the most important cereal and staple food for about 1.2 billion people in Africa (IITA, 2009; CIMMYT and IITA, 2016; and FEWS NET, 2017; VIB, 2017) and occupies one third of cultivated area (Blackie, 1990) as reported by Suleiman and Rosentrater (2015).

Maize (*Zea mays* L.) is the third most important cereal grain worldwide after wheat and rice (Golob *et al.,* 2004). According to Kumar and Kalita (2017) many households in sub-Saharan Africa (SSA) depend on maize for 36% of their calorie intake. Maize grain is one of the major diets of millions of people in the world (Nuss and Tanumihardjo, 2010; Nwosu, 2016). Approximately 50 percent of the population in sub-Saharan Africa depends on maize (CIMMYT and IITA, 2016) and the crop is an important food and feed source for smallholder farmers in Africa (Mwololo *et al.,* 2012). Furthermore, Muzemu *et al.,* (2013) and OECD-FAO (2016) report that maize is also the most important crop in Africa that makes a significant contribution to national food security.

According to the United States Department of Agriculture (USDA) as reported by World Agricultural Production.Com (2020) the annual global maize production is estimated to be 1.1 billion tons with the United States being the largest producer followed by China and Brazil. Africa produces 6.5% of the world maize production and the largest African producer being Nigeria with nearly 33 million tons, followed by South Africa at 11 million tons (IITA, 2020).

The maize grain has four distinct parts which include; the endosperm (80 – 85 %), the germ (9 - 10%), the pericarp (5 - 6 %) and the tip carp (Choudhary *et al.,* 2014). Most of the nutrients of the grain are in the germ, which contains high concentrations of fat (33%), protein (18-19%), minerals and vitamins (vitamin B complex and E) (Nuss and Tanumihardjo, 2010). Furthermore, the germ is a rich source of unsaturated fatty acids mostly oleic and linoleic acids (Choudhary *et al.*, 2014).

According to literature maize is thought to have originated from Central America, where maize Teosinte and Zea Mexicana were the dominant species (van Heerwaarden *at el.,* 2011; Maag *et al.,* 2015; Smith *et al.,* 2017) Archaeological studies conducted on the Bat Caves of New Mexico revealed corncobs which were 5,600 years old. Much as the exact date and circumstances of the first cultivation of Zea mays remains a subject of debate, by 1500 A.D, the Aztec and Mayan civilizations had long referred to offspring of that plant as maize (McCann, 2007). Maize varies considerably in appearance, kernel colour, composition and texture. Botanically, maize is an annual plant which belongs to the grass family gramineae (Poaceace) and has diploid species with 2n=2x=20 chromosomes (Cai, 2006) as reported by Suleiman *et al*., (2013).

2.12.1 Maize production in Zambia

Although mining is the major driver of the Zambian economy, agriculture is an important sector for employment and sustains more than 66% of the population (Tembo and Sitko, 2013) as reported by ReliefWeb, 2017). In 2018, the contribution of agriculture to Gross Domestic Product (GDP) was 5% and supported about 60% of the population (IFAD, 2019). Maize production in Zambia is expected to increase from 3 million tons to 4 million tons by 2025 (Zambiainvest, 2016). With regard to domestic food availability, Zambia is a food surplus country. In Zambia, white maize is the most dominant type of maize produced with Central, Eastern and Southern provinces as the key production areas. It's worthwhile noting that genetically modified maize is banned for importation or production in Zambia (Fig, 2003; Broadbent, 2012).The availability of maize in the country is usually equated to food security. The maize value chain in Zambia is rather complex with the key players being formal and informal, large and small-scale producers, private and public sectors (ReliefWeb, 2017).

Zambia's 2019 maize production was about 2 million tons due to a 16% reduction caused by drought (Shinobi, 2019; USDA, 2019). Although the annual maize consumption was estimated at 2.1 million tons, the country had sufficient supplies for domestic consumption due to the large carry over stock of about 500, 000 tons (USDA, 2019).

After South Africa, Zambia is main exporter of maize and source of food supply and trade in the Southern African region (ReliefWeb, 2017). Maize is usually exported to neighboring countries such as Democratic Republic of Congo (DRC), Malawi and Zimbabwe. The unclear trade policies, government interference in the local public markets generates encumbrances, instability and impartialities in the food markets (ReliefWeb, 2016). For example, government at times bans the exports of maize and gets involved in setting of price ceilings of purchases and sales of maize on the market (ibid).

Zambia experiences substantial maize postharvest losses due to weak capacity to store large quantities of the staple food (Ballad, 2013). Much as there was lack of strong empirical data to back this statement, the Ministry of responsible for agriculture had stated that postharvest losses were in the region of 32% due to inadequate storage (ibid). The estimates of grain losses quoted by APHLIS for Zambia are between 15-20%, which is less than what is found in most publications (APHLIS, 2011). The report by Zambia Parliamentary Committee on Agriculture revealed that during the 2006/2007 agricultural season, the Food Reserve Agency (FRA) lost 5,776 tons of maize from main depots and 2,800 tons from sheds (National Assembly of Zambia, 2011).

The weak spots in the food value chains in Zambia, similar to other African countries, are caused by farmers and processers using outdated machinery and technologies, while the food production systems remain unorganized and fragmented. Similar to other developing countries the lack of access to specialized equipment for transportation, processing, and storage only adds to the extensive food loss at the harvest, postharvest and storage stages of the food supply chain in Zambia (Aulakh, *et al.*, 2013).

In spite the availability of a variety of practices, innovations and technologies for reducing postharvest maize losses worldwide (Rosegrant, 2015), research has shown that their adoption rate remains low in Africa (Ambuko, 2017; Kitinoja *et al.,* 2011). Therefore, there is a need to identify and eliminate the constraints to the application of exiting technology for reducing postharvest food losses. The major constraints may be lack of finances, knowledge and trained personnel, political and cultural issues. Irrespective of global region, there is a need for successful introduction of culture-specific innovations and technologies across the food supply chain to reduce losses (Nellemann *et al*., 2009). Therefore, it's important to assess the effect technology would have on the roles of men, women and the youth in reducing postharvest losses (ibid).

Literature review revealed several initiatives which had attempted to provide solutions for postharvest losses since the early 1980s in Zambia. The first major intervention started in 1983 when the Food and Agriculture Organisation (FAO) supported regional programme introduced the cement and mud plastered storage structures. The other programmes were supported by United Nations Development Programme (UNDP), Southern Africa Development Community (SADC), Southern Africa Trade Hub (SATH) and Non-Governmental Organisations (NGOs) such as World Vision (SDC, 2015). During the early to mid-2000s, the Southern Africa Development Community Regional Food Security Training Programme SADC-RFSTP implemented a distance learning programme in grain management which targeted small and medium scale grain traders in Lesotho, Mozambique, Tanzania and Zambia (Chikoye and Chisala, 2006). Table 2.8 provides summarised information about efforts on postharvest management and on farm storage in Zambia.

Table 2. 8: Efforts on postharvest management and on-farm storage in Zambia. Source: (Author)

Year	Organization	Project Title	Geographical Coverage	Programme Focus and Achievement
1983	FAO	Improved Farm Storage	Eastern and Southern Provinces, Zambia	Solid walled grain storage bins (ferrumbu, cement plastered and mud plastered baskets) introduced in 80 agricultural camps
1986 -1992	FAO and UNDP	Postharvest Loss. Control Pilot Project	Choma and Monze districts, Zambia	Improved storage structures introduced
1991-1993	CIDA-PASU	Food Security Project	Zambia	Construction of commodity storage shades
1991-1993	CIDA-PASU/ ISTC/NRDC	Fertilizer and Maize Handling Project	Zambia	Trained depot managers and supervisors from cooperative unions in grain handling
1995 - 2000	IFAD	On-farm storage component of Southern Province Household Food Security Programme	Southern Province, Zambia	Improved storage structures (Ferrumbu, cement plastered baskets and brick-bins).
1997	UNDP/MAFF	National Larger Grain Borer Control Programme	Zambia	Created public awareness campaigns, trained agricultural staff and other stakeholders. Introduced insecticides for control of LGB and promoted improved storage structures

1999 - 2003	SADC/ISTT	Distance Learning Programme in Grain Management	Eastern Province, Zambia	Small and medium scale grain traders trained in grain handling and business management
2000 - 2007	FAO, MAFF, FCSU	Small- Scale Farmer Maize Marketing and Storage	Sinazongwe and Siavonga Districts, Zambia	Training in improved storage management
2012 - 2013	Southern Africa Trade Hub /ISTT	Grain Traders	Zambia	Trained 100 traders in grain management
2012 - 2016	SDC/CIMMYT	Effective Grain Storage Project (EGSP II)	Katete district, Zambia	Promoted hermetic storage technologies
2013	WFP	Grain Quality Control and Mobile Data Collection Pilot Project	Katete district, Zambia	Review of the quality assurance, fumigation procedures, and management process at both satellite and the main depots
2014 - 15	AGCO	Bag to bulk training programme	Kabwe, Mkushi, Petauke and Katete districts, Zambia	120 traders and farmers trained in grain handling
2015	WFP/FAO	Conservation Agriculture Scaling Up (CASU) Project	Eastern and Southern provinces, Zambia	Post-harvest grain handling

In spite the several projects conducted by UN Agencies, NGOs, Regional Organisations, these efforts have not been sustained after project life because they were not mainstreamed in the agricultural extension systems of countries in sub-Saharan Africa (Kitinoja *et al.,* 2011; and World Bank, 2011). In Zambia, the ministry responsible for agriculture has not mainstreamed postharvest in the extension system, although the

2005-2015 Agriculture Policy clearly stated that in order to increase food security, attention would be given to reduce postharvest losses (MACO, 2011 and MACO, 2004).

If Zambia and other sub-Saharan African countries wish to succeed in reducing postharvest food losses, its cardinal that they integrate postharvest management in the agricultural extension service. Additionally, postharvest management should be integrated in the agricultural curriculum in developing countries because of the critical need for capacity building in postharvest policy formulation at government, research, extension services and design of appropriate technology levels (Kitinoja *et al.,* (2011; World Bank and FAO (2011)). Prior to integration, the problem of inadequately trained human resource will need to be addressed. Most of the agricultural universities and technical colleges which train individuals that get employed in the extension service do not offer postharvest management in their curriculum. Consequently, when these graduates get employed in the agricultural sector, they cannot provide adequate knowledge and skills in postharvest management.

Notwithstanding the availability of a variety of practices, innovations and technologies for reducing postharvest maize losses worldwide, research has shown that their adoption rate remains low in Africa. Van Vark (2012) reports that sub - Saharan Africa experiences maize losses which are two times more than Central America, where farmers have adopted new technologies. Therefore, there is a need to identify and eliminate the constraints to the application of exiting technology for reducing post-harvest food losses. According to Loevinsohn *et al*., (2012) technology is the means and method of producing goods and services, inclusive of methods of organization and physical technique. Technology is the knowledge /information that allows certain tasks to be completed more easily, enhanced service delivery or the creation of a product (Lavision 2013). The use of technology leads to an improved condition or converting the existing situation to a more desirable level. Technology saves time and labour because it assists the user to work much better (Ramey, 2012). Agricultural technologies include all the different types of improved methods and practices which influence the growth of agricultural production (Jain *et al.,* 2009). The common areas for technology development and promotion for crops comprise new varieties and management systems. Challa and Tilahun (2014) report that due to input/output interaction, new technology contributes to an increase in output and a reduction in average cost of production which subsequently results in considerable increase in farm revenue.

Adoption is defined as the integration of a new technology into exiting practice and is normally preceded by a trial period and some kind of adaptation (Loevinsohn *et al.,* 2012). Technology adoption is in five phases namely; awareness; assessment of appropriateness; acceptance; learning the process and usage of the technology (Bridges to Technology Corp, 2006). The major constraints to the adoption of technology may be lack of finances, knowledge and trained personnel, political and cultural issues. Irrespective of global region, there is a need for successful introduction of culture-specific innovations and technologies across the food supply chain to reduce losses (Nellemann *et al*., 2009).

Although several approaches and technologies for reducing postharvest losses in developing countries have been developed there are challenges in adopting these technologies in the rural areas (Rosegrant *et al.,* 2015). The major constraints to postharvest loss reduction in developing countries is the reluctance of smallholder farmers to change unless losses are substantially higher than average (Greely, 1982). Shiferaw *et al.*, (2012) report that technologies face adoption challenges because of their inappropriateness for smallholder farmers, unavailability at the right place, right time and right price. They further observe that there is inadequate knowledge among smallholder farmers of the biological and environmental factors which cause crop deterioration and that farmers are more willing to adopt technology when it's for free (ibid).

There is a link between the adoption of improved technologies and increased income and reduced poverty levels (Kassie *et al*., 2011; Minten *et al.,* 2007), enhanced national food security (Kumar and Quisumbing, 2010), a drop in prices of staple food (de Janvry *et al,.* 2011), and in increased on farm employment prospects and incomes for landless workers (Binswanger and van Braun, 1991). Ravallion, and Chen, 2004; Kasirye, 2010) report that the adoption of improved technology may have been a major factor behind the success of the green revolution in Asia.

Agricultural technologies are of great relevance to smallholder farmers in developing countries due to many pre-and post-production challenges they face hence making them a primary target for development solutions (Loevinsohn *et al.,* 2013). Although literature reports of several studies conducted on innovation and uptake of agricultural technology and its impact on smallholder farmers in developing countries, its adoption is slow and certain features of adoption are not yet properly understood although they are a critical creation of prosperity in developing countries (Bandiera and Rasul, 2006).

With regard to the determinants of agricultural technology adoption, Levinsohn *et al*., (2012) found that the farmers' resolution regarding the adoption of a new technology was influenced by dynamic relationship between the features of the technology and the range of conditions and operating environment. An appreciation of factors determining the choice of technology was important for economic studies on factors of growth and for the producers and promoters of such technologies (ibid).

The economic analysis of technology adoption behavior is explained in terms of personal characteristics and endowments; imperfect information, risk, uncertainty, institutional challenges, input availability, and infrastructure (Foster and Rosenzweig 2010; Rogers 2003 and Uaiene 2009) as reported by Mwangi and Kariuki (2015). The determinants of agricultural technology can be grouped into three categories namely; economic, social and institutional factors (Akudugu *et al.,* 2012).

2.12.2 Maize varieties

Globally there are six principal varieties commercially grown particularly for human consumption and these include; Zea mays var. dent (indurate Sturt), flint (indurate Sturt), popcorn (everta Sturt), waxy and sweet (saccharata Sturt) (Nuss and Tanumihardjo, 2010). McCann (2007) reports that there are five phenotypes of maize; dent, flint, floury, pop and sweet.

Dent corn (indurate Sturt) which is also called field corn is the most commonly grown type around the globe for silage, grain and biofuel. At drying stage, the endosperm collapses to form an indentation, and this crown is unique to the dent types and originated the name 'dent' maize (PE/AI, 2012). Because of its soft endosperm dents, this type of maize is more susceptible to insect pests and moulds, both in the field and in storage (Paliwal *et al*., 2000) as reported by Suleiman *et al.,* (2013). The two common types of dent maize are identified as yellow and white, with the latter normally preferred in the food processing industry (ibid).

Flint maize is the type of maize with short, rounded kernels surrounded by a hard outer layer (hull), starchy and soft endosperm in the middle. Other distinguishing features are long, slender ears with few rows, fairly high protein and lipids content and the ability to produce high quality flour (Ruiz de Galarreta and Alvarez, 2010). Arising from the hardness of the maize out layer, flint maize is less susceptible to damage by insect pests and mould (Paliwal *et al*., 2000). The grain color ranges from pale-orange to dark red. Flint maize is commonly grown in Africa, Asia, Central and Southern America and Southern Europe (ibid).

According to Miracle (1965), the original mention of maize in Africa applies to West Africa. In the description of West African coast in 1502 by writer, Valentim Fernandes, there is a mention of milho zaburro (ibid). Maize is thought to have arrived in Africa after 1,500 A.D., although there is little documentation of the process used in introducing the crop to the continent (McCann, 2007). According to Miracle (1965) verbal evidence indicates that maize spread to the interior of tropical Africa from the coastal regions. However, the mode and timing of its introduction cannot be ascertained. Although the frequently repeated contention that maize was introduced by the Portuguese explorers cannot be confirmed, they seem to have had the economic reasons for doing so. It's believed that the introduction of maize to tropical Africa was done at different times and at several points. During the sixteenth century maize was grown around the mouth of the Congo River, along the coast from Gambia River to Sao Tome. In the seventeenth century, there is mention of maize in Zanzibar and around the mouth of Ruvuma River. Maize was termed as important food stuff and a major provision for slave ships between Niger Delta and Liberia (Miracle, 1965).

The penetration of trade in the hinterland followed by colonialism contributed to the spread of maize cultivation in Eastern Africa. The introduction of maize in Southern Africa was similar to other parts of the continent as it followed population movement and international trade. McCann (2007) further reports that Portuguese traders appear to have introduced the crop as suggested by use of names such as zaburro in Mozambique from Portuguese milho zaburro and mealie (Afrikaans from Portuguese milho) (ibid).

2.12.3 Chemical composition and nutritional value of maize

Cereal grains are important in human nutrition because they provide significant quantities of energy and protein to many people, particularly in developing countries (FAO, 2011). It's estimated that cereals provide 10% and 15% of the global calories and protein, respectively (Nuss and Tanumihardjo, 2010). According to Kulp and Ponte (2000), dried maize kernel contains about 72% to 74% carbohydrates, 6.8% to 12% protein, 4 % lipids, 1.2 % ash, 2.0 % fiber and 10.4 % moisture. Additionally, it further contains macro and micronutrients such as calcium (7mg/100 g), phosphorus (210 mg/100 g), iron (2.7 mg//100 g), sodium (35mg/100 g), potassium (287 mg//100 g), zinc (2.2 mg//100 g), copper (0.3 mg//100 g), magnesium (127 mg//100 g), and manganese (0.45 mg//100 g) on dry matter basis (db) (Nuss and Tanumihardjo, 2010). The composition varies according to variety, growing season, soil type and conditions and geographic location.

2.12.4 Insect pests of stored maize

According to Boxall (2002; and Paliwal (2000) insect infestation is responsible for the largest losses of grain in the world and that the most ideal environment for them to multiply, damage the grains as well as contaminate it with fecal matter and body parts in grain storage. Likewise, White and Sinha (1980) established that grain storage systems were not ecologically stable and that they harboured different types of prolific insect species with capacity to damage grain within a short period of time. Ileleji *et al.,* (2007) and Nukenine (2010) estimated that 20% to 50% and 1% to 5% of the stored grain in developing and developed countries respectively are lost due to insect destruction. In a related matter, Jian and Jays (2012) stated that of the more than 500 insect species reported to be linked to grain, 250 are connected to field and stored maize. Insects of stored grain are classified into internal and external feeders. Whereas the former are insects developed within the kernels the latter are those whose eggs hatch and larvae live on the surface of the maize grains (Montross *et al*., 1999).

The maize weevil (*Sitophilus zeamais*) is one of the pests of maize with economic importance (Kanyamasoro *et al*., 2012). Arising from its ability to damage the entire grain kernel it's classified as a major primary pest (ibid). Maier *et al.,* (1996) as reported by ul-Hasan *et al.,* (2017) found that storage of maize grain exposes it to a wide range of complicated environmental factors with temperature and moisture being responsible for grain quality deterioration and insect pest development. They further established that temperature and moisture content in storage and environmental factors such as temperature and relative humidity were critical to the rate of insect pest development and threat to quality and quantity of stored grain (ibid).

In related research, Montross *et al*., (1999) report that moisture content, temperature of the grain, level of destruction, foreign matter of the grain and the temperature around the grain were the factors necessary for the multiplication and development of insects. The temperature range between 25 °C to 30 °C and relative humidity of 70% and 80% are ideal for the development of most grain insect pests (Hayma, 2003). However, the results from a study conducted by Yakubu *et al.,* (2011), indicated that under hermetic storage conditions at moisture and temperature ranges of 6% and 16% and 10°C and 27°C respectively, insect pest infestation can be controlled. In related work, Los *et al*., (2018), established that the maximum moisture content figure for short term storage of cereal grains including maize was 13% while oxygen and temperature played a critical role.

2.12.5 Mould and fungi of stored maize

On-farm storage of staple foods like maize exposes the grains to infestation by fungi and insect pests (De Groote and Masinde, 2018). These pests can contribute to the infection of mycotoxins, especially aflatoxins which are poisonous food toxins produced by *Aspergillus flavus* (ibid). According to Kaaya and Kyamuhangire (2006) one of the most serious food safety problems in the world was the contamination of maize with fungi and mould. Both species can develop in the field and storage.

There are two groups of toxigenic fungi invading maize, and these are field fungi and storage fungi (Barney *et al.,* 1995) as reported by Suleiman *et al.,* (2013). With regard to field fungi, it attacks maize and produces toxins prior to either harvest or threshing of grains. Relative humidity of over 80% and moisture content of 22% to 33% and a varied range temperature (10 ± 35°C) promote the development of field fungi (Williams and Macdonald, 1983; Montross *et al.,* 1999). Although field fungi usually die in storage, some can survive under storage conditions (Suleiman *et al.,* 2013). In warm humid conditions, field fungi cause considerable damage leading to a loss in yield and quality (Moturi, 2008). Likewise, Reed *et al.,* (2007) report that storage fungi infect grain mainly in storage and depend on moisture content to be in equilibrium with relative humidity of 70% to 90%. They further argue that field moulds which infest grain before harvest get replaced by storage moulds.

The main fungal species which damages grain in storage include; *Aspergillus* spp, *Fusarium* spp*, Penicillium* spp *and Rhizopus* spp (Williams and MacDonald, 1983). According to Chuck-Hernandez *et al.,* (2012) maize infested by storage fungus results in chemical and nutritional changes, dry matter loss, discoloration and reduction in grain quality. In related research, Fandoham *et al.,* (2003), found that 50% of the maize grain loss in the tropics was caused by storage fungus, which ranks second after insects in causing maize deterioration and loss. It was affirmed by Williams and MacDonald (1983) that kernel discoloration, viability loss, rotting, mycotoxin contamination and successive seedling blight was caused by storage moulds. Dharmaputra *et al*., (1994), found that mechanical damage to maize grain during or after harvest can provide entry points to fungal spores. Similarly, Fandohan *et al.,* (2003) and Sone (2001) revealed that development of storage moulds was accelerated by broken grain and foreign materials.

The two key environmental factors which determine the growth of moulds and fungi are moisture and temperature (Alborch *et al*., 2011). At harvest maize usually has a moisture content of about 18% to 20%. If maize is not properly dried, moulds and fungi can easily grow resulting in a reduction in quality and quantity (Marin *et al*., 1998). Further review of literature established that the growth of fungi in stored grain in the tropics was influenced by fluctuation in temperature and increase in grain moisture content, resulting in unsafe storage of grain with high moisture content and condensation (Rees, 2004). According to Reed *et al*., (2007) while studying the effect of moisture content and temperature on storage moulds found that the maize kernels were greatly infected if the initial moisture content was higher. Miller (1995) acknowledged that crop (nutrients), physical (temperature and moisture) and biotic (insects, interference competition) factors were responsible for the growth and development of storage fungi in grain.

2.12.6 Mycotoxins in stored maize

According to Weinberg *et al.,* (2008), mould growth on maize grains poses a huge risk, especially through production of mycotoxins. Kaaya and Kyamuhangire (2006) report that for maize grown in the warm, humid, tropical and sub-tropical regions, mycotoxins are a chronic problem. The infection of grain by moulds and fungi can produce mycotoxin contamination during growth, harvesting, storage and processing (Chulze, 2010). In related work, Pitt (2000) found that aflatoxins, fumonisins, ochratoxins, trichothesenees and zearalenone were the most important toxins which commonly occur in cereal grains. Additionally (Krska *et al*., 2008) established that in the tropical and sub-tropical countries, aflatoxins and fumonisins were the most common toxic mycotoxin compounds found in maize. Aflatoxin which is produced by three major species of fungi namely; Aspergillus *flavus, Aspergillus parasiticus*, and *Aspergillus nomius* were primarily a problem in cereals especially in maize (Miller, 1995). These fungi can withstand an array of conditions and are found in different places such as in milk, plant and animal remains, in grains and seed of maize and groundnuts (Pitt, 2000). Widstrom *et al*., (2003) explains that the fungi produce four important aflatoxins called B1, B 2, G 1 and G 2 and that the toxins can be produced during processing, storage and transportation of grain. Aflatoxin B1 is believed to be among the most powerful natural known carcinogens (ibid). It's considered a quadruple threat, that's as a mutagen, teratogen, carcinogen and potent toxin (Waliyar *et al.,* 2007; Norlia *et al.,* 2019). According to World Health Organisation (WHO) classification, aflatoxins are in class number one carcinogens due to their extreme poisonous and toxic nature (Martinez *et al.,* 2011).

The higher incidence of cancer in East Asia, China and sub-Saharan Africa, and stunting in children, micronutrient deficiencies, and immune suppression have been attributed to aflatoxin (Smith *et al.,* 2012; Moturi, 2008). According to Orsi *et al.,* (2000), there is research which supports the suggestion of a relationship between the consumption of maize infected with *Fusarium moniliforme* and a high incidence of human esophageal carcinoma.

According to De Groote and Masinde (2018), long term exposure to aflatoxins can hinder child growth due to suppressing of immune systems and can cause cancer of the liver. There is a strong correlation between liver cirrhosis and aflatoxin exposure (Hell, 2010). It's further reported that long term storage under poorly ventilated and unsanitary conditions promotes aflatoxin contamination (Egal *et al.,* 2005). Arising from the carcinogenic nature of aflatoxin, most countries are regulating the allowable aflatoxin levels in foods (Liu *et al.,* 2006).

Kaaya and Kyamuhangire, (2006); Tubajika and Damann (2001) found that one of the main factors influencing aflatoxin contamination was temperature. Mycotoxin production and the rate of fungal spoilage are influenced by temperature and water activity (Alborch *et al.,* 2011). A study conducted in Uganda revealed high levels of aflatoxins in the moist than dry regions (Kaaya and Kyamuhangire, 2006). Pitt (2000) reports that mycotoxins produced by *Fusarium moniliforme*, which are associated with growth on maize and other cereals are problematic all over the world. They are commonly found in tropical and sub-tropical regions (Afolabi *et al,* 2006).

The presence of fusarium is usually ignored because there are no clinical signs of infection on the maize plant and grains (Fandohan *et al.,* 2003). Research estimates that mycotoxin contamination with fusarium is responsible for 25% crop loss in the world (ibid). They further reported that fusarium which is considered a field pest attacks 50% of the maize grain prior to harvest (Fandohan *et al.,* 2003). Furthermore, Scott (1993) found that fusarium was the most common fungi linked to maize and that the crop does not show any symptoms of infection.

In review of literature Miller *et al.,* (1983) and Berthiller *et al*., (2015) found several reports that confirmed that fusarium toxins (Fumonisins) could affect humans and livestock. Likewise, Pitt (2000) found that fumonisins were a significant cause of leukoencephalomalacia, a deadly brain disease of rabbits, donkeys, mules and horses. A study conducted in rural Tanzania revealed that exposure of infants to fumonisins had an adverse effect on their growth (Kimanya *et al*., 2010). Fumonisins B1, B2, and B3 which occur in maize fungal cultures and naturally contaminated maize generate the largest quantity of toxins (up to 17900 µg/g) (Fandohan *et al*., 2003). Research by Afolabi *et al.,* (2006) established that warm and dry conditions promoted fusarium contamination and development. However, according to Robertson-Hoyt *et al*., (2007) the optimum conditions for production of fumonisins remain unknown. In connection to this, Kamle *et al.,* (2019) reported that drought stress and climatic conditions were associated with the existence of *Fusarium moniliforme.*

The characteristic symptoms of maize grains attacked by fusarium are pinkish – white or white color on the maize kernels. Marin *et al.,* (2003) demonstrated that water activity and temperature were critical to the development rates of fusarium and other fungal species. In related research, Perincherry *et al., (*2019) found that the major factors for growth and mycotoxinogenesis of fusarium species were temperature and water content. It was reported that in maize, the ideal temperature for production of fumonisin B1 was 30°C and 0.98 aw (Marin *et al.,* 1998).

Unlike aflatoxin, fumonisins are found in the pericarp and germ of the maize grain. Therefore removal of the pericarp and germ can greatly reduce toxin levels in maize (Charmley and Prelusky, 1994) as reported by Fandohan *et al.,* (2003). Furthermore research results have shown that after dehulling of maize grain, there was a significant reduction in fumonisins (Fandohan *et al.,* 2003). There is close correlation between storage fungi and insect infestation. In a study conducted by Jian and Jays (2012), they report that while some storage fungi inhibit secretion of toxic metabolites, others attract insects and stimulate their growth. Similarly Smith (2015) established that mycotoxins are a major food safety issue connected to climate change in Africa. The degree to which occurrence of mycotoxins will present a climate change threat will be contingent on the weather and climate. The mycotoxin episodes may be inhibited by extreme weather occurrences (ibid).

2.12.7 Maize storage

According to Nukenine (2010), “storage is a way or process by which agricultural products or produce are kept for future use”. Other researchers describe storage as a method by which grain is incorporated with other elements like relative humidity and temperature to safeguard grain and surroundings in order to maintain good quality grain up to the end of the storage period (Jian and Jays, 2012). They further state that the quality of grain is directly affected by the grain storage management (ibid). Furthermore, Montross *et al.,* (1999), found that the key elements which influence insect pest and mould attack in maize storage environments were air, temperature and water activity. Yakubu (2009) and Montross, (1999) classified maize and grain storage systems into three key types; bag, bulk and crib storage. Hellevang (2005) reports that the time when 0.5% dry matter decay is achieved, was the allowable storage time for maize. The production of carbon dioxide (CO_2) is directly related to dry matter loss in maize. In support of this, Bern *et al.,* (2002) report that in order to lose 0.5% of the dry matter, 7.33g of CO_2 per kg of dry was required. According to Hellvang (2005) and Bern *et al.,* (2013) as reported by Suleiman *et al.,* (2013), allowable storage time is collective term and a function of temperature and moisture content of maize grain. Twenty nine days is the allowable storage time of maize with 20% moisture content and relative humidity of 15.5°C.

Arising from the increase in market competition and more rigorous food safety demands, grain quality is essential in modern grain trade. Consequently, in order to maintain grain quality during storage, it's essential to establish the safe grain storage time. According to Kaleta and Górnicki (2013) "safe grain storage time is the period of exposure of a commodity at particular moisture content to a particular relative humidity and temperature below which crop deterioration may occur and beyond which the crop may be impaired". The time in which the development of detrimental processes does not cause any changes in grain quality, is called time for safe grain storage (ibid). Ekechukwu (1999) found that that in an effort to maintain grain losses low, it's important to dry crops to the safe storage moisture content within the safe storage time. The length of time that grains of a specific temperature and moisture content can be stored without the threat of quality loss is determined by the safe grain storage time Kaleta and Górnicki (2013). The determinants of the length of time of safe grain storage are appearance of visible moulds, germination capacity, CO_2 production and loss of dry matter of grain (ibid).

2.13 Project Interventions in Postharvest Management in Eastern and Southern Africa

Over the years there have been several postharvest management projects and/ or programmes implemented in the Eastern and Southern Africa regions. These projects have used a number of mediation approaches ranging from mainly technological to socio economic approaches, knowledge management and interventions at policy levels (SDC, 2015). Table 2.9 illustrates project interventions in reducing postharvest food losses implemented in Eastern and Southern Africa since the 1980s.

Table 2. 9: Project interventions in postharvest management in Eastern and Southern Africa. Source: (Author).

Year	Organization	Project Title	Coverage	Programme Focus and Achievement
1983 - 88	FAO	Improved Storage	Malawi, Mozambique, Tanzania, Kenya, Uganda, Zambia, Zimbabwe	Solid walled grain storage bins (Ferrumbu, cement plastered and mud plastered baskets) introduced in the 1980s
1999 -2003	SADC/ISTT	Distance Learning Programme in Grain Management	Lesotho, Mozambique, Tanzania and Zambia	120 small and medium scale grain traders trained in grain handling and business management
2008-2011	SDC/CIMMYT	Effective Grain Storage Project (EGSP I)	Kenya and Malawi	Promoted hermetic storage technologies

2012 -2016	SDC/CIMMYT	Effective Grain Storage Project (EGSP II)	Kenya, Malawi, Zambia and Zimbabwe	Promoted hermetic storage technologies
2012 -2013	Southern Africa Trade Hub/ISTT	Grain handling training programme	Malawi, Mozambique, Zambia,	Trained 300 traders in grain management
2014 -15	AGCO	Bag to bulk training programme	Zambia	100 grain traders and farmers trained in grain handling and storage
2015 -2016	FAO, UNICEF & WFP	Agriculture and Market Support	Uganda	Support to 60,000 smallholder farmers
2014 -2019	MoA/ZARI	APPSA	Malawi, Mozambique, Zambia	Reducing pre and postharvest losses and food safety/value addition, marketing and agriculture mechanization.

2.14 Factors Which Affect Adoption of Postharvest Technologies

When addressing PHLs it's important to understand the technical, economic, and social factors which contribute to the adoption of postharvest technologies and practices (Bokusheva *et al*., 2012). Additionally, it's also cardinal to appreciate the reasons behind the tolerance of postharvest losses by farmers. One factor which is normally attributed to tolerance is the lack of economic incentives for reducing PHLs (WFP, 2014, Kaminski *et al*., 2014). They further report that technology is expensive, inadequate connectivity and access to electricity, poor access to finance and inadequate access to market opportunities mean that the benefits in the short term are less than the cost of the technology (ibid).

Reducing postharvest losses to considerably low levels is technically achievable through the application of technology and use of appropriate management techniques (SDC, 2014). However, the report further states that the use of these interventions has cost implications and therefore their use should be based on cost benefit analysis (CBA). Farmers are more likely to adopt a technology if the benefit justifies the associated costs (Affognon *et al*., 2015). It's worth noting that cost benefit analysis is just one of the factors for consideration as the final decision for adoption will depend on other considerations (ibid).

The earlier attempts to reduce postharvest losses concentrated on farm level interventions (Sheahana *et al.*, 2016). The market-oriented approaches and linking farmers to markets contributes to the understanding of constraints and the inadequate incentives towards improving postharvest management (GKI, 2014; Deloitte, 2015). This information is helpful in the identification of the entry critical points for reducing PHLs along the value chains and how various actors interact as well as how they are affected by the external context (ibid).

Arising from the lessons learnt from previous attempts, the value chain approach is increasingly being used in addressing postharvest losses (Parfitt *et al*., 2010). Although the markets have not previously rewarded efforts made by farmers towards improving the quality of grains, the situation is slowly improving. The market entry of quality conscious buyers such as World Food Programme, the changing consumer preferences, and growing middle class in developing countries have provided market opportunity for farmers who meet the required standards of quality, quantity and consistence (Food Trade ESA, 2015). In view of the foregoing, stakeholders are now more systematic through making the entire value chain more efficient than single point interventions previously used.

In Africa, when considering the reasons for low technology uptake, it should go beyond the issue of knowledge, information, cost, tradition and consider the role of gender (Sheahana *et al*., 2015; SDC, 2014). Due consideration should be given to comprehending the effect which introduction of technology would have on the roles of men, women and the youth in agriculture (Rugumamu 2009). It would further be important to bring on board private sector as it plays a significant role in technology transfer (SDC, 2014).

The identification and elimination of the constraints to the application of exiting technology for reducing post-harvest food losses should be given due attention (Kitinoja *et al.,* 2010). The major constraint may be lack of finances, knowledge and trained personnel, political and cultural issues (Kiaya, 2014).

In view of the fact that food loss and waste reduces net food supply available for human consumption, it's envisaged that the reduction of food losses and waste would contribute to increasing net food supply, which could subsequently lower food prices locally and globally (FAO, 2011; Lipinski *et al.,* 2013; Lundqvist, de Fraiture and Moulden, 2008). The impact of lower prices would be felt differently by the various actors along the food value chain (FVC).

There is very little empirical data on the economic impacts of addressing food loss and waste using price fluctuations and their effect on the world market. There is limited, consistent and reliable data due to disagreements on the definitions and methods used in data collection (Bellemare *et al*., 2017; UN, 2017). For example, the results from a study on healthy and sustainable food showed that reduction of food waste modeled through a 15% supply chain efficiency increase, reduced prices of agricultural commodities by nearly 4% (Westhoek *et al.,* 2011).

Few studies have been conducted on the economic impacts of addressing food loss and waste by using fluctuations in price changes and their ripple effect on the global economy. This may be caused by limited consistent and reliable data caused by differences in and /or disagreements on definitions and methods of data collection (Westhoek *et al.,* 2011). In addition, the empirical studies conducted in the aftermath of the global food price hikes of 2007/2008 propose significant variability in the global and domestic prices across regions, countries, commodities and time warranting further research (HLPE, 2011; Minot, 2011).

The complex interaction between supply and demand shifts caused by food loss and reduction demonstrates the challenges in predicting the potential socio economic impacts of such actions (Rutten *et al*., 2013). However they shade some light on what might happen and offer a useful baseline for additional and more detailed analysis of the outlook for 2020 and beyond (ibid).

2.14.1 Technological factors

A study by Mignouna *et al*., (2011) found that one of the preconditions for adopting a technology was its characteristic. The extent to which a new technology can be tried on a small scale would be a major determinant for its adoption (Dos, 2003). Adesina and Zinnah (1993) found that the way in which farmers perceived a characteristic of new rice variety greatly influenced its adoption. The involvement of farmers in the evaluation of a technology for appropriateness to the local context is a prerequisite to its adoption (Karugia *et al.,* 2004).

2.14.2 Economic factors

According to Foster and Rosenzweig (2010), the net gain from adoption, including the operational costs of using a new technology is a major determinant in its adoption. It has been found that cost is a major hindrance to adoption of technology. As a result of the removal of subsidies on agricultural inputs since the 1990s arising from the World Bank supported Structural Adjustment Programme (SAP) in sub-Saharan Africa, farmers could no longer afford the cost of seed and fertilizers (Muzari *et al.,* 2013). Other studies conducted on factors which determine technology adoption found that the high cost of technology was a major constraint to its adoption (Makokha *et al.,* 2001; Ouama *et al.,* 2002; Wekesa, 2003).

2.14.3 Institutional factors

According to (Mignouna *et al.,* 2011) social capital allowing trust and an exchange of ideas and information can be strengthened through membership to social groups. The decisions made by individual farmers are greatly influenced by social networks especially when considering the adoption of agricultural technologies (Uaiene *et al.,* 2009). A study by Katungi and Akankwasa (2010) found that enhanced social learning about a new technology increased the chances of technology adoption among farmers who were members of community based organizations (CBOs). While many studies reported that social groups had a positive influence on technology transfer, the existence of free riding behavior in social groups may negatively impact technology adoption. While studying the adoption of the Green Revolution technologies in India, Foster and Rosenzweig (1995) found enhanced profitability of adoption due to learning externalities in the social groups. They further found that some farmers seemed to be free-riding on their neighbor's expensive trials with the new technology. Bandiera and Rasul (2002) and Hogset (2005) proposed opposite effects generated by learning externalities, in the sense that an increase in the number of people engaged in trials with a new technology, attracts additional members to join, and the more beneficial it is to the free-riders. Arising from these different results, (Bandiera and Rasul, 2002; Mwangi and Kariuki, 2015) suggested a U-shaped individual adoption curve, proposing that while network effects were positive at low adoption rates, they were negative at high rates of technology adoption.

Access to information regarding the availability of a new technology is another determinant to adoption of technology (Mwangi and Kariuki, 2015). Information helps farmers become aware of the existence and the effective use of the technology and farmers will only adopt technology they are aware of or have heard about (ibid). Ambiguity about the performance of a technology can be lessened through information acquisition by an individual whose evaluation may change from subjectivity to objectivity over time (Caswell *et al.,* 2001). The acquisition of information about a technology does not necessarily translate into adoption by farmers. The farmers' ability to access technology might actually lead to dis-adoption of a technology. In instances where there is limited information about a particular technology, additional information might trigger negative views regarding its adoption, maybe due to the additional information revealing more information gaps thereby increasing the risk associated with the technology (Bonabana-Wabbi, 2002). It's paramount that there is accuracy, reliability and consistency in the information provided to farmers about a particular technology. Therefore, farmers should be informed about availability of a technology; its benefits and usage to enable them make a decision regarding its adoption (Bonabana-Wabbi, 2002).

The availability of extension services is another important determinant of technology adoption (Genius *et al.,* 2010). Extension workers usually provide farmers with information regarding the existence, effective usage and benefits of a new technology. The linkage between the innovators and users of a technology provided by extension agents helps to reduce the transaction costs when promoting the new technology to many farmers (Genius *et al.,* 2010). Farmers that are regarded as peers of extension agents are usually targets for introduction of technology because of their perceived influence on other farmers in the community (Genius *et al.,* 2010). The negative impact of lack of education and indecision in technology adoption can be counteracted by extension service (Yaron, Dinar, and Voet, (1992).

Mohamed and Temu (2008) found credit to be an important stimulus to technology adoption. According to Simtowe and Zeller (2006) the risk bearing ability of households can be enhanced through access to credit and the easing of cash flow can stimulate the adoption of risky technologies. This is so because the opportunity to borrow empowers households to focus on more risky but cost effective investments (ibid). According to literature there is gender bias in accessing credit in countries where credit institutions discriminate against female-headed households leading to low rates of technology adoption (Muzari *et al.,* 2013). Therefore, policy makers need to put in place measures that reduce gender discrimination in the access of credit, more particularly to female - headed households (Simtowe and Zeller, 2006).

2.14.4 Household factors

The assumption is that the farmers' decision to adopt a new technology is influenced by their educational level or human capital (Ghimire *et al*., 2015). According to Mignouna *et al*., (2011); Lavison (2013); Namara *et al*., (2003) the sourcing, processing and utilization of information is enhanced by their level of education. Studies by Okunlola *et al.,* (2011) on adoption of technology by fish farmers and organic fertilizers by crop farmers found that adoption of technology was positively influenced by educational levels of respondents. This arises from the fact that educated prospective users of technology are more rational and have the ability to analyse the benefits of the new technology (Waller *et al.,* 1998). It's a lot easier to introduce a new technology when working with more educated farmers and this subsequently affects the adoption process (Adebiyi and Okunlola, 2010). The results of a study conducted by Riddle and Song (2012) were consistent with the views that usage of technology that entails or supports workers to perform non routine tasks is enhanced by formal education. However, although many studies have reported a positive influence of education on technology adoption, a study on the adoption of genetically modified crops revealed a negative influence (Uematsu and Mishra, 2010).

Age is considered to have influence on the adoption of new technology as elderly farmers are assumed to be more knowledgeable and experienced at evaluation of technology information than younger farmers (Mignouna *et al*., 2011; Kariyasa and Dewi, 2011). Some studies report of negative influence of age on technology adoption (Ghimire *et al.,* 2015). This is supported by Mauceri *et al*., (2005) who report increased risk aversion and reduced long term farm investments for aged farmers. On the contrary, since young farmers are more daring they are keen to try new technologies. Alexander and Van Mellor (2009) found that due to age, inadequate experience and human capital of young farmers there was a corresponding increase in the adoption of genetically modified crops than among more elderly farmers.

The analysis of the impact of gender on adoption of improved varieties of maize in Ghana conducted by Morris and Doss (1999) found no significant relationship. They concluded that access to resources rather than gender was a determinant of technology adoption. For example, if the adoption of an improved crop depended on access to resources such as land, labor, machinery, and if men have better access to these resources it subsequently follows that men and women will not equally benefit from the technology (ibid).

By and large, technology adoption may significantly be influenced by gender. For example, since the head of the household is the major decision maker, then men have more significant and positive influence on adoption of technology (Mishra at el., 2015; Namonje-Kapembwa and Chapoto, 2016; Melesse, 2018). Obisesan (2014) found that gender had a significant influence on adoption of improved cassava production in Nigeria. A study by Lavison (2013) established that the adoption of organic fertilizers is more likely among male than female farmers. Household size plays an important role in the adoption process as a larger household has the capacity to meet the labour required to implement a new technology (Mignouna *et al*., 2011).

Appreciation of determinants or constraints to agricultural technology adoption is necessary for planning and implementation of technology correlated programmes designed to address challenges of food production in developing countries (Mwangi and Kariuki, 2015). Consequently, in order to increase technology adoption by smallholders, policy makers, creators and promoters of new technology should appreciate the circumstances of the farmers as this will lead to the development and introduction of appropriate technology (Masere, 2015; Mwangi and Kariuki, 2015; Namonje-Kapembwa and Chapoto., 2016).

Meena *et al*., (2009) further assert that one of the major setbacks to reduction of postharvest losses in developing countries is the big gap between agricultural technology development in research institutions and their subsequent adoption by smallholder farmers. The low adoption rate of technologies in rural areas is due to inadequate information, and development of technologies that are not suitable to farmers' conditions and hence are considered irrelevant by smallholder farmers (Affognon *et al*., 2015; Sheahan and Barrett, 2014).

Atibioke *et al.,* (2012) reported that factors such as socio economic status, economic motivation, educational level and training received have a positive effect on technology adoption.

Therefore, when making decisions on the nature of interventions or whether not to intervene at all, there is a need to apply an integrated and multidisciplinary approach (FAO, 2018). Furthermore, some of the factors worth considering would include value of the grain in economic terms; national balance of payments, the social changes that will be brought about, stability of process and conflict factors which affect players along the value chain (Bokusheva *et al*., 2012).

2.14.5 Public sector related factors

Public sector has an important role in the promotion of adoption of postharvest loss reducing technologies (Goldsmith *et al.,* 2015). The contribution made by private sector in improving postharvest systems needs to be supported and there should be creation of an enabling environment which facilitates private sector investment (ibid). The provision of accessible roads, improved access to rural finance, lower transport costs and electricity can assist in spreading postharvest loss reducing efforts to value chain players beyond the farmers (Goldsmith, *et al*., 2015; Rosegrant, 2015; Tefera *et al.,* 2012; Parfit *et al*., 2010). Increased market opportunities can accelerate trade and this could reduce the period of on- farm grain storage and subsequently reduce the losses (Rosegrant, 2015). A predictable policy on the price and export of grain can bring private sector investment in providing drying, processing and storage services to smallholder farmers as well as provision of other postharvest solutions (Rosegrant, 2015; Rutten, 2013).

There is a need for better integration of PHL issues into the agricultural research and extension services for the provision of technical advice to all the value chain actors (Kitinoja *et al.,* 2011). A well-coordinated research cycle creates improved opportunities for the uptake of technologies and postharvest improvement (Kikuwe *et al.,* 2018; Beretta *et al.,* 2013). For the farmers to be effective players in the value chain they need to be better organized, equipped in business and entrepreneurial skills. Poor representation of postharvest management in the curricula for agricultural education and in agricultural policy needs to be addressed including increased awareness of the benefits of postharvest solutions (Kitinoja *et al*., 2011). Since inadequate access to markets and poor education can contribute to postharvest losses, agriculture requires policy support from other sectors.

2.15 Theoretical Framework for Adoption of Postharvest Reducing Technologies

In order to situate this study in a broader perspective regarding the topic of PHLs, this section provides a theoretical framework for the significance of adoption of PHL reducing technologies. A theoretical framework in a study is based on an existing theory or theories (Kothari, 2006; Kumur; 2011, Labaree, 2009; Saunders *et al.,* 2019).

This study was anchored on the Unified Theory of Acceptance and Use of Technology (UTAUT) theory advanced by Venkatesh *et al.*, (2003). Technology Acceptance Model (TAM) has been used extensively in research that looks at the acceptance of new technology (Davis, 1989). Technology Acceptance Model

(Davis, 1989; Davis, Bagozzi, and Warshaw, 1989) which is derived from the Theory of Reasoned Action (TRA) (Fishbein & Ajzen, 1975) offers a formidable explanation for user acceptance and usage behavior of information technology. The Theory of Reasoned Action postulates that individual behavior is determined by behavioral intention where behavioral intention is a function of an individual's attitude towards the behavior and subjective norms surrounding the performance of the behavior. This implies that one's behavior and the intent to behave is a function of one's attitude towards the behavior and their perceptions about the behavior. Therefore, behavior is a function of both attitudes and beliefs (ibid).

The Technology Acceptance Model (TAM) hypothesizes that an individual's behavioural intention to adopt a system is determined by two theories, perceived usefulness (PU) and perceived ease of use (PEU) (Davis *et al*., 1989). Davis (1989) further found that there is a relationship between users' beliefs about a technology's usefulness and the attitude and the intention to use the technology. However, perceived usefulness shows a stronger and more reliable relationship with usage than other variables reported in literature. Furthermore, an individual may adopt a technology if it is perceived appropriate, useful and socially desirable even if they do not enjoy using the technology (Li *et al*., 2013; Moghavvemi, 2011., Isaac *et al.,* 2006; and Saga and Zmud, 1996). Figure 2.7 depicts the Technology Acceptance Model.

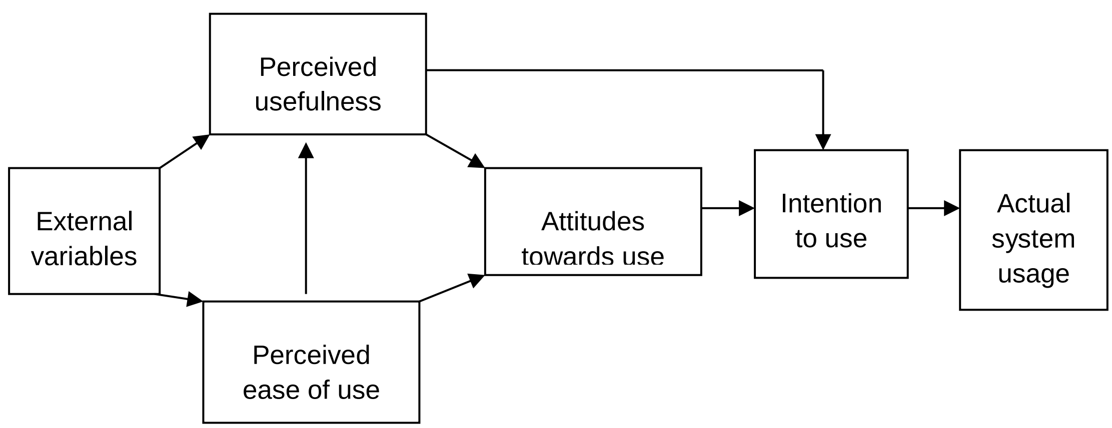

Figure 2.7: Original technology acceptance model. Source: Davis *et al*., (1989)

There are several methods used to analyse product, system or technology acceptance. Davis (1989) proposed that what motivates the user of a system or technology could be supported by three factors, perceived ease of use (PEU), perceived usefulness (PU) and attitude towards using a system or technology. According to Davis (1989), Davis *et al.,* (1989), Venkatesh and Davis (2000), and Venkatesh and Bala (2008), perceived ease of use (PEU) is defined as "the degree to which a person believes that using a particular system would be free of effort" and perceived usefulness (PU) as "the degree to which a person believes that using a particular system would enhance his or her job performance". The attitude of the user towards a system or technology was a major determinant of whether the user actually uses or rejects the system or technology (Davis 1985). The attitude of the user in turn was considered to be influenced by two major beliefs, perceived usefulness (PU) and Perceived Ease of Use (PEU) with the latter having a direct influence on PU. Between the two theories, perceived ease of use has a direct effect on both perceived usefulness and technology usage (Adams *et al*., 1992; Davis, 1989).

The Technology Acceptance Model (TAM) (Davis *et al.,* 1989) is the most commonly known and used in research focusing on users (Venkatesh and Davis, (2000). The consumers' acceptance of new technologies and their intention to use has been explained by several theories (Venkatesh and Bala, 2008) including, but not limited to: Theory of Diffusion Innovation (DIT) (Rogers, 2003), which began in 1960; Theory of Reasonable Action (TRA) (Fishbein and Ajzen, 1975); the Theory of Task-technology Fit (TTF) (Goodhue, and Thompson, 1995);Theory of Planned Behaviour (TPB) (Ajzen, 1985, 1991); Decomposed Theory of Planned Behaviour (DTPB) (Taylor and Todd, 1995); Final version of Technology Acceptance Model (Venkatesh and Davis, 2000); and Unified Theory of Acceptance and Usage of Technology (UTAUT) (Venkatesh *et al*., 2003) and TAM 3 (Venkatesh and Bala, 2008).

The most prominent of these is the Unified Theory of Acceptance and Use of Technology (UTAUT) (Lescevica *et al.,* 2013). See figure 2.8. This model was created from studies done on eight major models in adoption research. Empirical studies conducted have demonstrated that the UTAUT model outperformed the other eight models inclusive of the popular TAM (ibid). While UTAUT is a versatile model, it has raised some issues among researchers (Mohavvemi *et al.,* 2012). When prospective users are deciding on technology adoption, intentions are formed before behavior although the link between them is rather complicated and might require more inquiry (Krueger, 2007) as reported by Mohavvemi *et al*., 2013. Venkatesh *et al.,* (2007) found that performance of behavior is not affected by behavioral intention because the latter lacks the necessary external factors. They further found that behavioral intention does not have a strong predictive and explanatory ability between the time of formation of intention and when behavior is put into action (Ibid). Finally, behavioral intention lacks strength in its capacity to foretell behaviors which are not fully within an individual's power to choose (Mohavvemi *et al.,* 2013). Sheeran *et al.,* (2003), describes the gap between intention and behavior as the "intention-behavior gap".

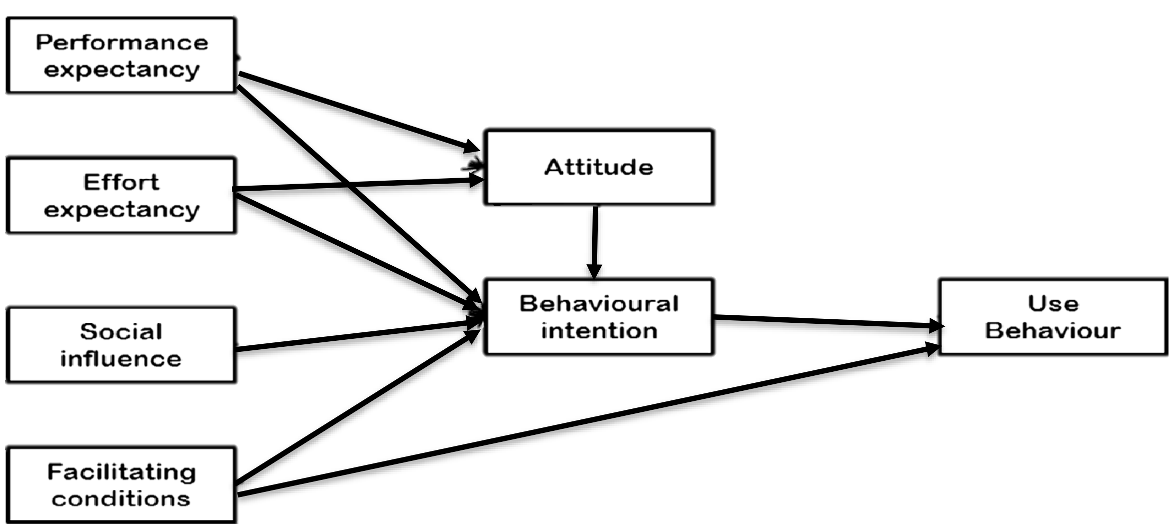

Figure 2. 8: UTAUT Model. Source: Adapted from Venkatesh *et al.,* (2003)

The central constructs or endogenous variables of the Unified Theory of Acceptance and Use of Technology Model are; Knowledge Expectancy (KE), Performance Expectancy (PE), Effort Expectancy (EE), Attitude Towards Using the Technology (ATUT). Social Influence (SI), Facilitating Conditions (FC) towards adoption of postharvest loss technology. Gender, age and education are categorized as key moderators or important moderating influences on behavioral intention and user behavior (exogenous variables) (Venkatesh *et al.,* 2003, Niehaves and Plattfaut, 2014).

Warshaw & Davis (1985, p. 214) define behavioral intention (BI) as “the degree to which a person has formulated conscious plans to perform or not perform some specialized future behavior”. According to Fishbein and Ajzen (1975, p.288) behavioral intention refers to “a person’s subjective probability that he will perform some behavior”. Furthermore, behavioral intention is a function of three self-regulating precursors which are subjective norms, consumer attitude and perceived behavioral control (Mamman *et al.,* 2016).

Subjective Norm refers to an individual’s “perception of social pressure to perform or not to perform the behavior” (Ajzen, 1988, p. 132). He further reports that attitude refers to “an individual’s positive or negative evaluation of the behavior”. Furthermore, its “an individual’s action suggested by their close friends that will affect their particular behavior” (Mamman *et al.,* 2016, p. 52). Attitude is defined as “individual’s behaviour towards negative or positive feelings about carrying out target behaviour” (Mamman *et al.,* 2016, p. 52).

Other scholars have reported that behavioral intentions are motivational elements that capture how much effort an individual is prepared to make in order to execute a behavior (Ajzen, 2012). It’s argued by Bagozzi (1992) that once the intention is triggered it will operate as part of a self - fulfilling system and push people into a position of “must do” or “will do”.

Intention is simply how hard persons are willing to try and how much they are planning to move towards performing a behavior (Mamman *et al.,* 2016.).Table 2.10 provides additional information on constructs or endogenous variables used in the UTAUT model.

Table 2. 10: Definition for constructs used in the UTAUT model. Source: Adapted from Venkatesh *et al.,* (2003)

#	Construct	Definition
1	Knowledge Expectancy (KE)	The degree to which an individual perceives that they have understood how a particular technology works (Venkatesh *et, al*., 2003).
2	Effort Expectancy (EE)	The degree to which an individual believes that using a particular system would be free of physical and mental effort (Venkatesh *et, al.,* 2003).
3	Performance Expectancy (PE)	The degree to which an individual believes that using a particular system would enhance his or her productivity (Venkatesh *et, al.,* 2003).

4	Attitude towards using the technology (ATUT)	Technology characteristics could directly influence the attitude of the person toward using the technology, without the need by the person to form a belief about the technology (Davis et., 1989; Fishbein and Ajzen, 1975; Taylor and Todd 1995 a, b).
5	Facilitating Conditions (FC)	Given a system which was perceived useful, a person may form a strong behavioral intention to use the system without forming any attitude (Venkatesh *et, al.,* 2003).
6	Social Influence (SI)	Person's perception that people who are important to him think he should or should not perform (Venkatesh *et, al.,* 2003).

According to Lescevica *et al.,* (2013), Unified Theory of Acceptance and Use of Technology has been applied, integrated and extended by researchers when studying distinct technology acceptance and use across an array of scenarios such as different types of technologies, different periods and places. They further proposed that technology users can be grouped into consumers, citizens, workers. For instance, (Hong *et al.,* 2011) used a sample of workers at organizational level while (Zhou *et al.,* 2010) used a sample of service users such as consumers. The Unified Theory of Acceptance and Use of Technology Model has further been used in studies investigating technology acceptance in settings which are not in western countries, such as Korea (Im; Hong and Kang, 2011), India (Gupta *et al.,* 2008), China (Venkatesh and Zhang, 2010). Furthermore, the Unified Theory of Acceptance and Use of Technology Model can be used to study different types of tasks such as those which focus on technology supports which include idea initiation, and decision formulation in technology design (Brown *et al.,* 2010). Additional research has concentrated on particular economic factors like food services (Yoo, Han and Huang, 2012), public sector (Dasgupta and Gupta, 2011) and education (Chiu and Wang, 2008).

To all intents and purposes, research has established beyond any reasonable doubt that the Unified Theory of Acceptance and Use of Technology Model is a versatile model (Lescevica *et al.,* 2013). Nevertheless studies have not thoroughly investigated the moderating influences of factors such as experience, age and gender. Most investigations have merely tested the key effects (Chang *et al.,* 2007), while other researchers have studied the subclass of the moderation effects (Gupta *et al.,* 2008). Generally numerous research findings back the generalizability of the Unified Theory of Acceptance and Use of Technology Model, although only in terms of its principal effects (Lescevica *et al.,* 2013).

2.16 Conceptual Framework Adopted for This Study

This study attempted to establish the factors that cause the low adoption of technologies for reducing PHLs of maize among smallholder farmers in Zambia. The research was guided by the conceptual framework in figure 2.9. A conceptual framework is model that a researcher can develop from a theoretical framework (Kitson *et al.,* 1998).

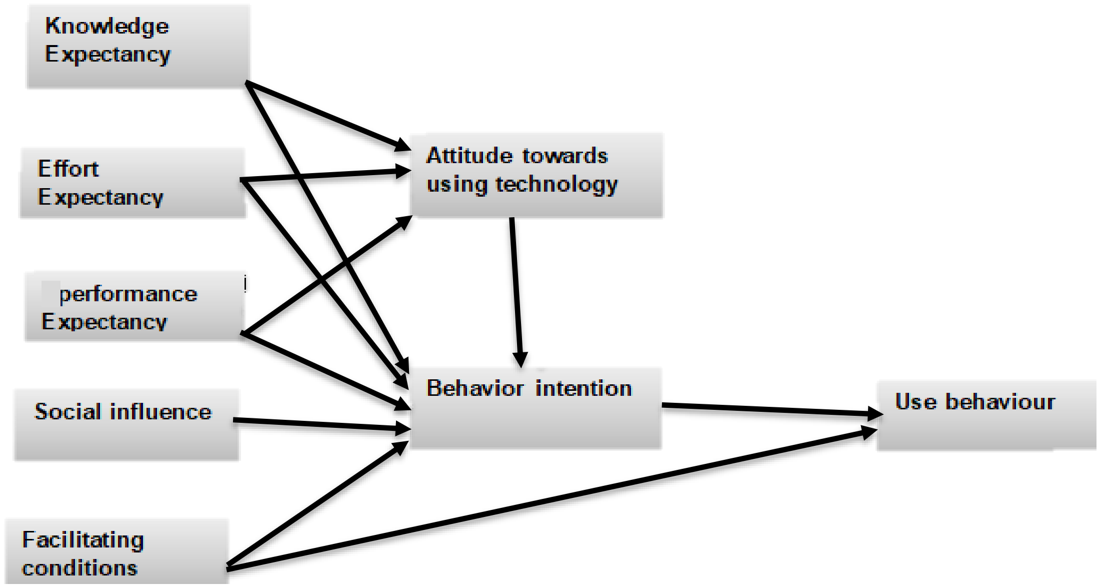

Figure 2. 9: Conceptual Framework. Source: Adapted from UTAUT Model

The study was restricted to following factors: Knowledge Expectancy (KE); Performance Expectancy (PE), Effort Expectancy (EE), and Attitude towards using the technology (ATUT), Social Influence (SI), Facilitating Conditions (FC) towards adoption of postharvest loss technology. Gender, age and education were categorized as key moderators or important moderating influences on behavioral intention and user behavior. The direction of arrows in figure 2.9 indicates the interrelationships between the key variables of the study. The study further took into consideration the Diffusion of Innovation Theory (DOI) advanced by Rogers (2003). Diffusion is defined as the process by which an innovation is adopted and gains acceptance by members of a given community. This theory has been used in agriculture to increase adoption of innovative technologies and practices. The diffusion of an innovation is influenced by an interaction of several factors. These elements include the nature of social system into which the system is introduced, innovation itself, how information about the innovation is communicated, and the amount of time it takes (Bennett and Bennett, 2003; Kaminski, 2011; Rogers, 2003; Sahin, 2006). Instructional technologists would be in a better position to explain, predict, and account for factors that hinder or facilitate the diffusion of their commodities if they understood the several factors which are responsible for the adoption of innovations (Rogers, 2003; Sahin, 2006).

Diffusion of an innovation is considered to happen over time and has five different stages which are knowledge, persuasion, decision, implementation and confirmation. The potential adopters of innovations need to learn about it, be persuaded about the advantages of the innovation, decide on the adoption, implement the innovation and confirm (reaffirm or reject) the decision to adopt the innovation (Kaminski, 2011; Rogers, 2003). Diffusion of an innovation becomes possible when a person perceives the idea, behavior or product as new or innovative. It was found out that in the adoption of an innovation some people were quick to adopt innovation than others. Research has shown that early adopters of innovation have different traits from people who adopt innovations later. Understanding of the characteristics of the target population assists in the adoption or rejection of an innovation. As indicated if Figure 2.10, there are five recognised adopter categories namely; Innovators (2.5%), Early Adopters (13.5%), Early Majority (34%), Late Majority (34 %) and Laggards (16%).

Innovators - these people are risk takers and are usually the first to develop new ideas. They are enterprising and interested in new ideas. Very little persuasion is needed to convince these to adopt an innovation.

Early Adopters - these are opinion leaders in the community. Since they play a leadership role, they embrace change opportunities. They are comfortable at adopting new ideas because they are already aware of the need for change. There is no need to provide them with information to convince them to change. They simply need literature such as fact sheets and manuals to assist with innovation implementation.

Early Majority - these people will adopt new ideas before the average person and are not necessarily leaders. One characteristic feature they possess is that they will only adopt an innovation based on the evidence that the innovation works. Strategies used to convince these people include proof of innovation effectiveness and success stories.

Late majority - These are doubters of change and will only adopt an innovation after it has been tried by the Early Majority. Strategies used to convince this group include information on successful adoption of innovation by many other people after conducting trials.

Laggards - these people are usually very conservative and traditional in nature. It's very difficult to convince this group to adopt an innovation. Strategies which can be used include pressure from people in adopter groups, use of statistics on the number of people using the new innovation and fear appeals.

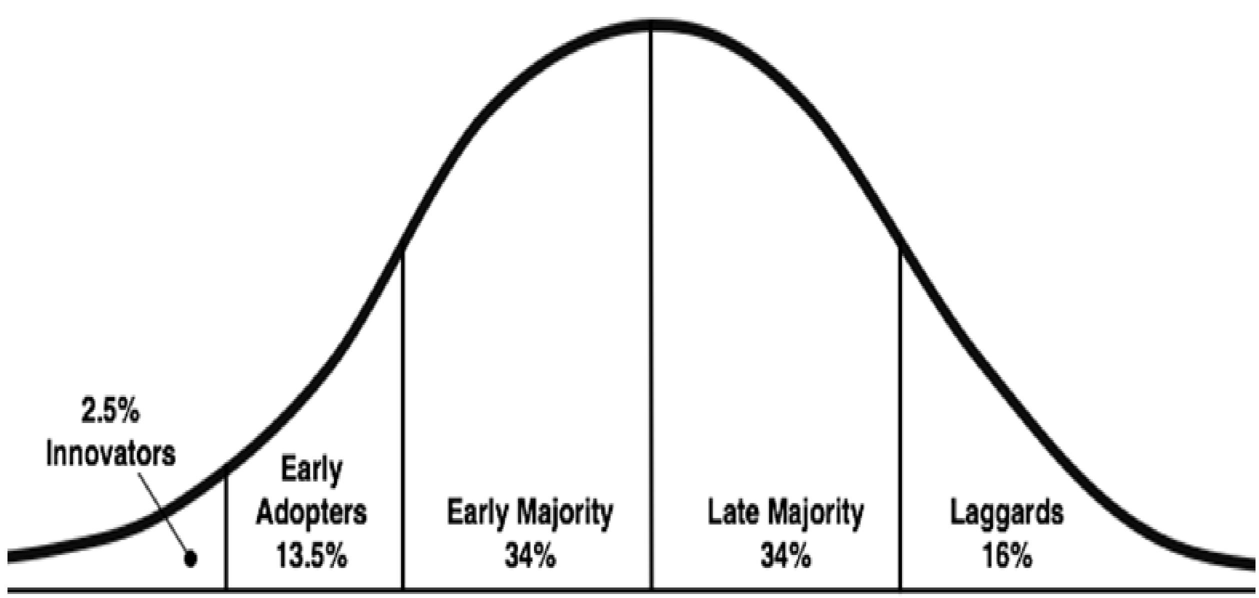

Figure 2. 10: Innovation adopter categories. Source: http://blog.leanmonitor.com/early-adopters-allies-launching-product/

There are five major factors which influence adoption of an innovation and each of these elements has a role in the five adopter categories (Rogers, 2003; Sahin, 2006). These factors include:

i) Relative advantage - the extent to which an innovation is considered superior to the product, programme or idea it substitutes;
ii) Compatibility- the consistency of the innovation with the norms, experiences and requirements of the prospective adopters;
iii) Complexity - the degree to which the innovation is difficult to understand and /or use;
iv) Triability - the degree to which the innovation can be tried or trialed prior to making a commitment to its adoption; and
v) Observability - the degree to which the innovation produces substantial results.

Summary

This chapter provided a literature review of research conducted on postharvest food losses. It gave a synopsis of the global food loss and waste situation, challenges encountered in estimation of food losses, and the available technologies for reducing food loss and waste. Furthermore, it brought to the fore, work being done by several actors such as researchers, international organisations, NGOs, governments and private sector in addressing food loss and waste including postharvest losses.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

"If we knew what we were doing it would not be called research, would it"? - Albert Einstein

In this study the interpretive paradigm has been selected because it helps to "gain full access to the knowledge and meaning of the phenomenon" (Collis and Hussey, 2009, p. 65). The other reason for selecting the interpretive paradigm is its relation to "an inductive process where patterns and /or theories are developed in order to understand phenomena" (Collis and Hussey, 2009, p. 74). "A research paradigm is a philosophical framework which guides how scientific research should be conducted" (Collis and Hussey, 2009, p.55).

The inductive research approach was selected because the data collected allowed for the generation of theories and explanations to the phenomena discovered through the research findings. This approach is usually associated with the social constructivist paradigm which emphasises the socially constructed nature of reality. It is about recording, analysing and attempting to uncover the deeper meaning and significance of human behavior and experience, including contradictory beliefs, behaviours and emotions.

The case study strategy was used because of its advantage of enabling a systematic investigation into the issues, the collection of large amounts of data, and the easy analysis of information. Robson (2002, p. 178) defines case study as 'a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence'. Yin (2003 and 2009) also highlights the importance of context, adding that, within a case study, the boundaries between the phenomenon being studied and the context within which it is being studied are not clearly evident. Case studies help to answer the how and why questions and providing in-depth understanding of phenomena as widely described by Yin (2003 and 2009).

Quantitative data was analysed using the Statistical Package for Social Scientists (SPSS) while the grounded theory approach was used in qualitative data analysis. Grounded theory is commonly used in the analysis of qualitative data (Creswell, 1998; Charmaz, 2000; Hussey and Hussey, 1997; Strauss and Corbin, 1998).

3.2 Research Design and Methodology

In this descriptive research the target population consisted of smallholder farmers who were members of the dairy cooperatives in Choma and Kalomo districts and households in Songwe and Kaluzi Villages in Katete District. (See figure 3.1 for the map of Zambia indicating location of the targeted districts).

Figure 3. 1*:* Map of Zambia showing target districts. Source: Google maps

A total of 100 farmers were selected for this study based on the Krejcie and Morgan (1970) sampling table via a random sampling method. The research instrument was a questionnaire completed through face to face interviews by the researcher and four trained enumerators.

Structured interviews were used as they were considered to be an appropriate method for gathering empirical data as endorsed by Kothari (2006). The research focused on 3 districts as case studies to provide comprehensive outlooks regarding the adoption of technologies for the reduction of postharvest losses of maize. The rationale behind focusing on 3 districts from different parts of Zambia was to obtain different perspectives behind investment choices in the adoption of technology. Saunders et al., (2009) contend that this type of approach helps in verifying whether the results from one case can happen in another case. The restriction to 3 districts was to assist in reducing the common criticisms of case studies in terms of control, access, time and travel and the cost of the analysis as affirmed by (Gable, 1994; Darke et al., 1998).

Research methodology is where the research problem is addressed by answering the research questions. According to Collis and Hussey (2009), one strategy which a researcher can use in the selection of a research methodology is to identify one with the highest quality in terms of credibility, transferability, dependability and conformity. Therefore, in selecting the research methodology, an attempt was made to choose one with highest quality.

According to Yin (2003), there are five key components in the design of a case study and these include:

i) Its study questions;
ii) Its proposition, where applicable;
iii) Its units of analysis;

iv) The logic connecting data to the proposition; and

v) The criteria for explaining the results.

In this study the research questions were developed after clearly identifying the research problem. The second part demanded for the development of a hypothesis for the study. Since this study takes an interpretive approach, there was no need to develop a hypothesis. However, Yin (2003) argues that even a case study of explorative nature should have a purpose. In a counter argument Hussey and Hussey (1997, p.118) propose that interpretive research study does not require development of a hypothesis in the sense that "a theoretical framework is a collection of theories and models from the literature which underpins a positivistic study". Data collection illustrates the methods adopted for gathering of the empirical data. Data analysis provides a logical connection of the data to the research questions. Therefore, this study was guided by the research problem, goal, objectives and research questions.

3.3 Unit of Analysis

The definition of the unit of analysis (the case) is connected to the manner in which the initial research questions have been defined (Yin, 2003). The units of analysis are associated with fundamental challenge of describing the case under consideration. Therefore, case selection is a critical aspect of research design which determines the quality and significance of the empirical data to be collected and has a bearing on the conclusions. According to Yin (2003) correct design of the primary research questions contributes to the selection of suitable units of analysis.

Three districts were selected for this study using the purposive sampling method. In Kalomo, and Choma districts, three dairy cooperatives were selected for data collection, while in Katete District two villages (treated as one case) were targeted. Purposive sampling or known as judgmental or selective was used in this study in order to obtain a wide variety of responses which helped to strengthen the collected empirical data. According to Patton (2002) purposive sampling is a method commonly used in qualitative studies for the identification and selection of knowledge-rich cases for the utmost practical utilization of scarce resources. This entails the identifying and choosing entities or groups of entities that are particularly well informed or experts knowledgeable about the event being investigated (Creswell and Plano Clark, 2011). Yin (2003) and Patton (2002) propose that researchers using purposive sampling should choose the components or units of the study grounded on the features critical to the research. In order to address the research problem, goal and research objectives, the following standard was used in the selection of the institutions and interviewees under this study.

i). the interviewees or participating institutions had to be actively involved in the maize postharvest value chain;

ii). the participating institutions or villages had to be located in a high maize production area;

iii). the interviewees located in different geographical areas (3 districts).

Case 1a: Kalomo Dairy Cooperative Society

The Kalomo District Dairy Cooperative Society (KDDCS) is a well-established member-based institution with a total membership of one hundred and six (106) distributed as sixty eight (68) male and thirty eight (38) female farmers. The Cooperative Society is made up of members from 6 Primary Cooperative Societies. Besides dairy production the members are also engaged in rearing of beef cattle, production of field crops such as maize, sunflower and groundnuts. The dominant crop grown is maize which is mostly produced for business, household food security and animal feed. The members of the cooperative were a mixture of individuals that had lived in the villages throughout their lives and those that had retired after formal employment.

The interviewees were selected among society board members, primary cooperative leaders and ordinary cooperative members of Kalomo Dairy Cooperatives.

Case 1b: Choma Dairy Cooperative Union

Choma District Dairy Cooperative Society (CDDCU) Ltd was registered in 2005 under the Cooperative Act of the laws of Zambia and at the time of the study had seven (7) primary cooperative societies. As of 2018 the Union had a membership of 600 smallholder farmers with a gender distribution of five hundred and sixty eight (568) males and thirty two (32) females. The Union is located in an area where farmers use traditional knowledge of cattle rearing and are also engaged in field crop production with maize, sunflower, and cotton being the predominant crops.

The Cooperative Union members were a mixture of retirees and individuals that had grown and lived in the villages. The Union has experience in brokering products such as stock feed, milking churns, drugs for its members that make payment from milk sales through the stop order system. The interviewees were randomly selected among society board members, primary cooperative leaders and ordinary cooperative members.

Case 1c: Batoka Dairy Cooperative Society

Batoka Dairy Cooperative Society which is located in Batoka along the Lusaka-Livingstone road was formed in 2012 and registered in 2013 under the Cooperative Act of the laws of Zambia. As of 2018 the Batoka Dairy Cooperative Society had seventy four (74) members distributed as fifty five (55) male and nineteen (19) females. The cooperative society is made up of members from one primary cooperative. Previously Batoka Cooperative Society was affiliated to Choma Dairy Cooperative Union. Besides milk production, the cooperative members are involved in maize, cotton, sunflower, and sweet potatoes production.

Most of the cooperative members are farmers that have grown up in the surrounding villages. Similar to the other dairy cooperatives, the interviewees were randomly selected from society board members, primary cooperative leaders and ordinary cooperative members.

Case 2: Songwe and Kaluzi Villages

Songwe and Kaluzi villages were located about 7 Kilometers from Katete town in Eastern province. Since the two villages were connected to each other they were treated as one case. The villages had a population of 550 households under two headmen who maintained registers of the number of households in the villages. The villages were under Chief Mbangombe. The number of females was about 51% of the population. The people in this area were predominantly smallholder farmers that produced crops such as maize, sunflower, cotton, groundnuts, sweet potatoes and vegetables.

The households involved in the study were randomly selected from the registers kept by the village headmen. During the interviews the households were represented by either male or female spouses. It was in very rare cases that the interviewees were either children or dependents. Table 3.1 gives a synopsis of the case organisations.

Table 3. 1: Synopsis of the case organisations. Source: (Author)

#	**Organisation**	**Location of district**	**Chiefdom**	**Target population**	**Major activity**
1	Choma Dairy Cooperative Union	Choma	Singani	600	Crop and dairy production
2	Batoka Dairy Cooperative Society	Choma	Moyo	74	Crop and dairy production
3	Kalomo Dairy Cooperative Society	Kalomo	Sipatunyana	106	Crop and dairy production
4	Songwe and Kaluzi Villages	Katete	Mbangombe	550	Crop and livestock production
5	**Total**	**3**	**4**	**1,330**	

3.4 Research Philosophy

The constructivist epistemology was considered appropriate because it is a theory of knowledge that argues that humans generate knowledge and meaning from an interaction between their experiences and ideas (Bruner, 1966). According to Kuhn (1970) constructivism is an epistemological premise grounded on the assertion that, in the act of knowing, it is the human mind that actively gives meaning and order to reality to which it is responding. Constructivism urges researchers to reflect upon the paradigms that may be underpinning their research, and it’s in the light of this that they become more open to consider other ways of interpreting any results of the research. In addition, the focus should be on presenting results as negotiable constructs rather than as models that aim to represent social entities more or less accurately.

3.5 Research Paradigm

In this research the interpretive paradigm was been selected because it helps to "gain full access to the knowledge and meaning of the phenomenon" (Collis and Hussey, 2009, p. 65). In addition, the Interpretive paradigm was selected because it is related to "an inductive process where patterns and /or theories are developed in order to understand phenomena" (Collis and Hussey, 2009, p.74). "A research paradigm is a philosophical framework which guides how scientific research should be conducted" (Collis and Hussey, 2009, p 55).

3.6 Research Approach

There are different descriptions of the main research approaches. For example, inductive is also known as qualitative approach (Saunders *et al*., 2019; Engel and Schutt, 2013). The inductive research approach was chosen because the data collected allowed for the generation of theories and explanations to the phenomena discovered through the research findings. This approach is usually associated with the social constructivist paradigm which emphasises the socially constructed nature of reality. It is about recording, analysing and attempting to uncover the deeper meaning and significance of human behavior and experience, including contradictory beliefs, behaviours and emotions.

3.7 Research Strategy

3.7.1 Case study

The case study strategy was selected for this study because it's associated with different philosophies such as positivism, intepretivism and pragmatism (Sahay, 2016). There are several definitions of case study research. According to Creswell (2013, p. 97), the case study method "explores a real-life; contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information ……..and reports a case description and case themes". According to Starman (1997, p.61), "a case study is a general term for the exploration of an individual, group or phenomenon". In a case study the focus is based on a special unit (Jacobsen, 2002). A similar description is that a case study is an analysis of systems that are studied with a comprehensive view by either one or several methods (Thomas, 2011). Other scholars have described a case study as an intensive, systematic investigation of a single individual, group, community or some other unit in which the researcher examines in-depth data relating to several variables (Woods and Calanzaro, 1980; Heale and Twycross, 2017). Robson (2006, p. 178) defines case study as "a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence". Yin (2008) also highlights the importance of context, adding that, within a case study, the boundaries between the phenomenon being studied and the context within which it is being studied are not clearly evident. Case studies help to answer the how and why questions and providing in-depth understanding of phenomena as widely described by Yin (2008).

The case study method is not aimed to analyse cases, but it is a good way to define cases and to explore a setting in order to understand it (Cousin, 2005). Case study methodology serves to provide a framework for evaluation and analysis of complex issues (Heale and Twycross, 2018). Researchers describe how case studies examine complex phenomena in the natural setting to increase understanding of them (Hamel, 1993; Yin, 2003). Undeniably, Sandelowski (1996) suggests that using case studies in research means that the holistic nature of nursing care can be addressed. Furthermore, when describing the steps undertaken while using a case study approach, this method of research allows the researcher to take a complex and broad topic, or phenomenon, and narrow it down into a manageable research question(s). By collecting qualitative or quantitative datasets about the phenomenon, the researcher gains a more in-depth insight into the phenomenon than would be obtained using only one type of data Sandelowski (1996).

Although widely used, the qualitative case study method is not completely understood (Starman, 2013). Due to conflicting epistemological assumptions and the complex features in qualitative case studies, scientific diligence can be difficult to prove, and any resulting findings can be difficult to validate (Baškarada, 2014).

Case studies usually have a double function, in that they can be individual units as well as case studies of a larger group of units. The conclusion that is aimed by a case study can either be illustrative or verifiable (Gerring, 2004). The qualitative case study method requires tools which assist scientists to study the comprehensive view within their settings. If the method is applied correctly, it can be advantageous when studying science, evaluating programmes and developing theories (Baxter & Jack, 2008).

3.7.1.1 Format of a case study

This study used multiple cases to understand the variations and similarities between the cases and to analyse the data both within each circumstance and across circumstances. In identifying the specific type of a case study to use, researchers have to decide whether to conduct a single or multiple case studies, for better understanding of the phenomenon. When a research includes more than one single case, a multiple case study is needed. This is frequently associated with several experiments. The difference between a single case study and a multiple case study is that in the latter, the researcher is studying multiple cases to understand the differences and the similarities between the cases (Baxter & Jack, 2008; Stake, 1995). Another difference is that the researcher is able to analyse the data both within each situation and across situations (Yin, 2003). Multiple case studies can be used to either augur contrasting results for expected reasons or either augur similar results in the studies (Yin, 2003). In this way the author can clarify whether the findings are valuable or not (Eisenhardt, 1991). When a comparison is made of case studies the researcher also can provide the literature with an important influence from contrasts and similarities (Vannoni, 2014; 2015). A generally acceptable fact is that the evidence generated from a multiple case study is more reliable (Baxter & Jack, 2008). They further state that other advantages with multiple case studies are that they generate a more credible theory when the propositions are more deeply grounded in empirical evidence from several sources. Therefore, multiple cases allow wider exploring of research questions and theoretical evolution (Eisenhardt and Graebner, 2007). Multiple case studies can be time consuming and very costly to implement (Baxter & Jack, 2008). In a contrasting view Siggelkow (2007), argues that the occurrence of phenomenon can be explained by a single case study. Dyer and Wilkins (1991) debated that for creating high-grade theories, single case studies are better than multiple cases since a single case study produces extra and better theory. When a single case study is used, the researcher can interrogate long standing theoretical relationships and discover contemporary ones since a more careful study is made. Therefore, this makes the researcher to get a deeper understanding of the subject (Dyer & Wilkins, 1991).The researcher can decide to make a single case study with embedded units. That way the researcher is able to explore the case with the competence to analyse the data within the case analysis, between the case analysis and make a cross-case analysis. This approach provides the researcher the power to examine subunits that are found within a larger case (Yin, 2003).

3.7.1.2 Presentation of a case study

It's not easy for a researcher to report a case study because it's a complex type of the approach. The difficult part is to present the case study findings for easier apprehension by the reader. The wish of the researcher is that the reader understands the findings so well that they can implement the results in their own setting (Stake, 1995). Some approaches to present case study findings are through the delivery of a linear report, informing the readers a story. The case study focuses and deals with the research questions. In this case, the researcher needs to pay attention to the propositions or the issues in order to get around the information that is redundant to the research question. Furthermore, the researcher should relate the results to facts in published literature and existing data. This approach helps to fully understand whether the findings and the results are more reliable (Baxter & Jack, 2008; Eisenhardt 1989). The literature links together those similarities that are not usually associated with each other (Eisenhibidardt 1989). According to Yin (2009) the researcher has to identify the specific audience of the study and therefore also understand their specific needs (Yin, 2009).

In summary, a case study should be easy to understand so that it achieves its objective. It's cardinal that the researcher is clear about the audience of the study and should compare the results to published evidence for increased reliability. The research context will assist the researcher to decide whether to make a single case study or a multiple case study. There are different opinions regarding whether a single case study or a multiple case study is the best choice. Benefits with a multiple case study are that the writer is able to analyse the data within each context and across different contexts. Other benefits are that the evidence generated from a multiple case study is strong and reliable and the researcher can clarify if the findings from the results are valuable or not. Furthermore, it also allows a wider discovering of theoretical evolution and research questions. Benefits with a single case study are that they are not as expensive and time consuming as multiple case studies. Single case studies are better when the writer wants to create a high-quality theory because this type produces extra and better theory. According to Dyer and Wilkins (1991) the number of cases or the page length is not the big issue. Instead what's important is the researcher's ability to understand and explain context of the scene being interrogated for easier understanding of the context by the reader as well as to generate theory in relationship to the context.

This study used multiple case studies for comparative purposes of the three settings where the research was conducted. This approach provided the researcher the power to examine subunits that were found within a larger case as reported by (Yin, 2003). Furthermore, it enabled the researcher to analyse the data within the case analysis, between the case analyses and make a cross-case analysis.

3.7.2 The grounded theory

In this study the grounded theory strategy was selected for data analysis because it's a robust approach to qualitative data analysis (Glaser and Strauss, 1967, Creswell, 1998; Hussey and Hussey, 1997 & Strauss and Corbin, 1998, Charmaz, 2006; Engward, 2013; and Cho & Lee; 2014) and suitable across a spectrum of research paradigms (Locke, 2003). Nonetheless, grounded theory is more suitable in interpretivist paradigm (Strauss and Corbin, 1998) which has been used in this research. The term grounded theory was introduced in The Discovery of Grounded Theory (1967) by Glaser and Strauss as "the discovery of theory from data-systematically obtained and analyzed in social research" (p. 1). According to Strauss and Corbin (1994) it is "a general methodology, a way of thinking about and conceptualizing data" (p. 275). They argue that most of the contemporary research mainly involves the verification or development of theory through logical deduction rather than from the experimental data itself. This use of grounded theory was partly influenced by Hussey and Hussey (1997) that posited that the grounded theory is popularly used in qualitative data analysis in business oriented research.

According to Glaser & Strauss (1967) many studies over the past 40 years have been analyzed using grounded theory (or one of its variants), which remains one of the most commonly used approaches nowadays. Some researchers argue that content analysis is more appropriate in positivist paradigms due to emphasis on the a priori concept construction and hypothesis testing (Flick, 1998; Locke, 2001) as cited by Kandadi (2008). Cho & Lee (2014) posit that several scholars that reported having used grounded theory had in fact applied the qualitative content analysis as it combines certain approaches of grounded theory, like open coding and memoing. However, Crawford *et al.,* (2004) report that content analysis and the grounded theory methods as the main methods for analyzing qualitative data.

The grounded theory has a number of strengths and weakness. The "Grounded theory provides a methodology to develop an understanding of social phenomena that is not pre-formed or pre-theoretically developed with existing theories and paradigms" (Engward, 2013, p.38). Grounded Theory avoids making assumptions and instead adopts a more neutral view of human action in a social context (Simmons, 2006). Grounded theory is principally well suited for investigating social processes that have attracted little prior research attention, where the previous research is lacking in breadth and/or depth, or where a new point of view on familiar topics appears promising (Milliken, 2010). According to Saunders *et al.,* (2012) other advantages of grounded theory include:

- Grounded theory is better at determining what actually happens;
- As a general theory, grounded theory adapts readily to studies of diverse phenomena;
- Grounded theory can identify the situated nature of knowledge, as well as the contingent nature of practice;
- Grounded theory can respond and change as conditions that affect behavior change; and

- Grounded theory produces a 'thick description that acknowledges areas of conflict and contradiction

According to Bryant and Charmaz (Eds) (2007) grounded theory fails to recognise the embeddedness of the researcher and thus obscures the researcher's action in data construction and interpretation. The subjectivity of the data leads to difficulties in establishing reliability and validity of approaches and information. Other weaknesses of grounded theory from literature (Saunders *et al.,* (2012) include:

- It is difficult to detect or prevent researcher bias;
- It tends to produce large amounts of data often difficult to manage;
- There are no standard rules to follow for the identification of categories; and.
- The highly qualitative nature of the results can make them difficult to present in a manner usable to practitioners.

In their introduction of using grounded theory in qualitative data analysis, Glaser and Strauss (1967) found that comparative analysis of data comprised "explicit coding and analytic procedures" (p.102) and proposed the following four methods of analyzing data:

i. comparison of events appropriate to each grouping;
ii. integrating groupings and their properties;
iii. delineating the theory; and
iv. writing the concept (p.105).

According to Corbin and Strauss (1990); Cho & Lee (2014) coding is defined as "the process and concept of labeling and categorising" (p.7). They considered the theory as a "basic unit of analysis". Charmaz (2006) described coding as "categorising segments of data with a short name that simultaneously summarises and accounts for each piece of data" (p.43) and as "the pivotal link between collecting data and developing an emergent theory to explain the data" (p. 46). It's through coding that a scholar grasps the implication of the data. Austin and Sutton (2015) refer to coding as the "identification of topics, issues, similarities and differences that are revealed through the participants' narratives and interpreted by the researcher. This method allows the researcher to begin to appreciate the environment from the respondent's viewpoint (ibid).

Diverse versions of the coding processes were suggested during the evolution of grounded theory (Cho & Lee, 2014). Two phases of coding proposed by Glaser (1978, 1992) were theoretical coding and substantive coding (open coding and selective coding). Corbin and Strauss (2008) proposed four analytical coding stages: open coding, axial coding, selective coding and coding for process as reported by Cho and Lee (2014). Charmaz (2006) suggested three theoretical techniques of coding: initial coding, focused coding and theoretical coding.

Open coding is "the initial step of theoretical analysis that pertains to the initial discovery of categories and their properties" (Glaser, 1992, p. 39). It is "the interpretive process by which data are broken down analytically" (Corbin and Strauss, 1990, p. 12). Open coding involves contrasting of event with other events regarding disparities and relationships, providing theoretical tags to events and categorising those theories together (Corbin and Strauss, 1990) as cited in Cho and Lee (2014, p. 8). Axial coding involves the procedure of discovering the connections among categories (Strauss, 1987). According to Corbin and Strauss, (2008) axial coding involves researchers linking categories with their subcategories, examine the connections against data and test the hypothesis. Selective coding relates to the procedure used by researchers to choose single or more main groupings meant to create a story that links the groupings or categories. Glaser (1978) describes theoretical coding as a procedure of theorising the connections amongst considerable codes. Corbin & Strauss (2008) posit that a concept or set of theoretical intentions are generated at the end of the analysis. Furthermore, Charmaz (2006) postulates that theoretical coding which is a procedure for establishing correlations between codes and groupings has the prospect of developing a concept. Figure 3.2 shows the procedure for analysis of data in grounded theory.

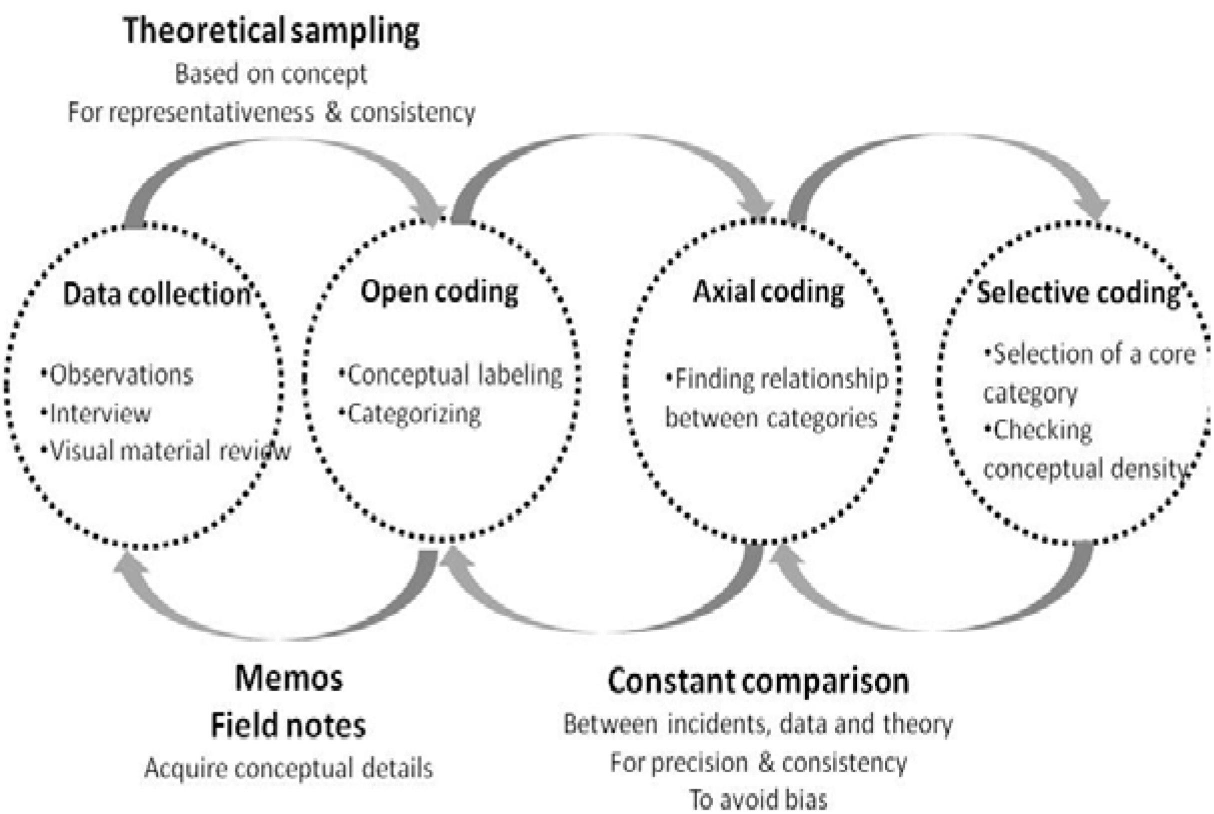

Figure 3. 2: Data analysis procedure of grounded theory. Source: Clef.T. (2013)

The grounded theory and content analysis are used in analysing and interpreting qualitative data (Priest, Roberts & Woods, 2002) as cited in Cho & Lee (2014). However, there is lack of clarity in literature regarding the variations and similarities in qualitative content analysis and grounded theory (ibid). Priest *et al*., (2002) argue that grounded theory and qualitative content analysis are considered identical approaches for interpreting qualitative data. Grounded theory was considered as a research methodology while content analysis as a method (Crotty, 2003). Additionally content analysis was treated as a research method for literal data analysis whereas grounded theory was considered as a theoretical framework (Patton, 2002).

3.7.2.1 Content analysis

The goal of content analysis is "to provide knowledge and understanding of the phenomenon under study" (Downe-Wamboldt, 1992, p.314). Initially, researchers used content analysis as either a qualitative or quantitative method in their studies (Berelson, 1952) as cited in Berelson (2018). Content analysis was initially defined as "a method to classify written or oral materials into categories of similar meanings." (Moretti *et al.,* 2011, P. 420) Content analysis is a widely used qualitative research technique (Hsieh and Shannon, 2014). According to Hsieh and Shannon (2014) qualitative content analysis can be defined as a ‘‘research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns: (p.1278).

There are three approaches used in content analysis and these include conventional, directed and summative approaches. These approaches are used to decode meaning from the content of text data and, as such, follow the naturalistic paradigm. The key variations among the approaches are origins of codes, coding schemes, and risks to trustworthiness. The conventional approach of content analysis derives the coding categories directly from the text data. The advantage of the conventional approach to content analysis is that it gains direct information from study participants without imposing preconceived theoretical perspectives. Knowledge generated from content analysis is based on participants' unique perspectives and grounded in the actual data. However, conventional content analysis has weaknesses in its failure to develop a comprehensive understanding of the background, hence failing to pinpoint the major categories. Consequently, this can produce results that do not correctly exemplify the data. According to Lincoln and Guba (1985) this can be called credibility within the natural concept of trustworthiness or internal validity within a concept of reliability and validity. Lincoln & Guba (1985) and Manning (1997) argued that credibility can be created through activities like protracted engagement, peer debriefing, triangulation, tenacious observation, and referential adequacy affiliate trials. The second weakness of conventional approach to content analysis is that is can be mistaken for qualitative techniques like grounded theory. Although these methods share similar initial analytical approaches, grounded theory goes beyond content analysis by developing theory. The conventional approach to content analysis is considered restricted in both theory development and narrative of the lived experience, as both sampling and analysis processes make the theoretical connection between concepts difficult to deduce from the results.

The directed approach begins with a theory or pertinent research findings as a guide for the original codes. There are times when prevailing model or previous research results exist about a phenomenon that is partial or would benefit from additional narration. The goal of a directed approach to content analysis is to endorse or broaden a theoretical concept or framework. The prevailing research can assist clarify the research question. It can be used to predict the variables of interest or about the connections amongst variables. This can assist to establish the initial coding scheme or connections between codes. According to Mayring (2000) this has been called a deductive category application. Content analysis using a directed approach is guided by a more structured process than in a conventional approach (Hickey & Kipping, 1996). In utilising existing research results, researchers begin by identifying key concepts or variables as initial coding categories (Potter & Levine-Donnerstein, 1999). What follows is using the theory in determining the operational definitions for each category. An open-ended question might be used if data are collected primarily through interviews, and then followed by targeted questions about the predetermined categories. Depending on the research question coding can start with one of two strategies. What follows in the analysis is to use the preset codes in coding all the underlined segments. New codes can be assigned to any text that could not classified with the first coding scheme.

Summative approach in content analysis encompasses tallying and contrasting content, then explanation of the fundamental setting (Hsieh and Shannon, 2014). The Identification and quantifying of certain words or content in text with the purpose of understanding their contextual use is the initial step when using summative approach to qualitative content analysis. This computation is an endeavor to investigate usage. According to Potter and Levine-Donnerstein (1999) analysis for the presence of a certain word or subject in written material is called manifest content analysis. Kondracki *et al*., (2002) reported that the analysis would be quantitative if it ended at this stage, where the focus is on counting the occurrence of certain words or content. Holsti (1969) and Gavora (2015) put forward that the process of clarification of content is referred to as latent content analysis. Babbie (1992), Catanzaro (1988), Morse and Field (1995) as cited by Hsieh and Shannon (2014) suggested that in this analysis the spotlight is on finding core meaning of words or the content. Content analysis from the summative approach is used by researchers in studies that analyse scripts in a specific journal or particular content in text books. Babbie 1992 stated that one of the advantages of the summative approach to qualitative content analysis is that it's an unobtrusive and nonreactive method to investigate the phenomenon of interest. It can give elementary perceptions on the actual usage of words (ibid). The weakness of this approach though is that the findings are incomplete due to lack of attention to the wider meaning present in the data (Babbie, 1992).

3.8 The Study Context

Zambia's population in 2015 was estimated at 16. 5 million people with a sex distribution of 51 percent females and 49 percent males (CSO, 2015). Of the 16.5 million Zambians, 60 percent live in rural areas and are dependent on small scale farming for their livelihoods. Nearly 45 percent of Zambia's population is below the age of 15 years and is still under parental care and support (CSO, 2015). Many of the rural households depend on agriculture for food security, income generation and improved livelihoods (ibid).

3.9 Selection of Study Sites

3.9.1 Choma district

Choma is one of the thirteen districts of Southern Province of Zambia with a total area of 7,296 square kilometers. Choma district has a human population of about 269,963 people of which 49 percent are males and 51 percent females (CSO, 2015). Choma District has 47,714 smallholder farmer households and according to Southern Provincial Administration (GRZ, 2019) smallholder farmers are those managing less than 20 hectares of land (ibid). Choma district has five (5) Agricultural Blocks and thirty two (32) Agricultural Camps which are coordinated by a Block supervisor and Camp Officer respectively with support from the Community Agricultural Committee (GRZ, 2019). Agricultural camps are divided into 8 zones which are drawn on the basis of local level factors such as villages, traditional governance structures and layout. Smallholder farmers express their farming requirements and receive technical assistance and information on farming subsidies through the Camp Officer.

The average size of the farms is approximately five (5) hectares per household. Although the land is suitable for growing of different types of crops about 46% is allocated to maize while the remainder is under cotton, groundnuts, sunflower, sweet potatoes and pastures (GRZ, 2019).

3.9.2 Kalomo district

Kalomo is one of the thirteen districts of Southern Province of Zambia with a total area of 15,000 square kilometers. Kalomo district has a human population of about 258,570, of which 48 percent are males and 52 percent females (GRZ, 2019). In Kalomo district, agricultural farming is divided into six (6) Blocks and twelve (12) Agricultural Camps. The average size of the farms is approximately 5 hectares per household. Although the land is suitable for growing of different types of crops about 46% is allocated to maize while the remainder is under cotton, groundnuts, sunflower, sweet potatoes and pastures (GRZ, 2019).

3.9.3 Katete district

Katete is one of the eight districts of Eastern Province of Zambia with a total area of 3,989 square kilometers (GRZ, 2019). This district was selected for its intensive maize production in Zambia and to represent the marginal maize growing environments, with 800-1000 mm of precipitation per year. Katete District has a human population of about 243,849, of which 48 percent are males and 52 percent females (GRZ, 2019). In Katete district agricultural farming is divided into five (5) Blocks and twenty (20) Agricultural Camps. The average size of the farms is approximately four (4) hectares per household. Although the land is suitable for growing of different types of crops about 48% is allocated to maize while the reaming is under cotton, groundnuts, sunflower, sweet potatoes and beans (GRZ, 2019).

The three districts were considered to be a fair representative of maize farmers in other parts of the country although PHLs differ with geographic location and climatic conditions. It is envisaged that insights from this study will be useful in other milieus.

3.10 Data Collection Methods

This research adopted a mixed parallel followed by convergent design. This method was preferred because it allowed for collecting, analyzing and mixing both qualitative and quantitative research methods in a single study to understand a research problem (Creswell 2011).Tashakkori and Teddlie (2003) argue that multiple methods are useful if they provide better opportunities for a researcher to answer research questions and where they allow for better evaluation of the extent to which the research findings can be trusted and inferences made from them. Creswell and Clark (2008) define the mixed method as “a research design with philosophical assumptions as well as quantitative and qualitative methods”. Tashakkori & Teddlie (2003) define mixed methods as “a type of research design in which QUAL and QUAN approaches are used in types of questions, research methods and data collection and analysis procedures and inferences”. It’s based on the conviction that merging the two viewpoints gives a richer appreciation of the research question or problem. The mixed method uses both qualitative and quantitative methods in a given study to gather and analyse empirical data.

There are six (6) types of mixed methods design (Creswell, 2013). These are the convergent followed by parallel design, the explanatory sequential design, the exploratory design, the embedded design, the transformative design and the multiple designs. The convergent parallel design, explanatory sequential design, and the exploratory sequential design are known as the basic mixed methods designs (Creswell, 2013). Figure 3.3 shows the three basic mixed methods designs.

In the convergent parallel design (parallel followed by convergent), the researcher collects both qualitative and quantitative data, the datasets are analysed independently, results from datasets are compared and interpretation is made regarding whether the results are contradictory or supportive of the study (ibid). The convergence of data is from the direct comparison of the two datasets by the researcher. In the explanatory sequential design, a researcher initially gathers data and analyses the quantitative data. After that the qualitative data are gathered and analysed and the results assist explain the quantitative results obtained earlier. The qualitative stage builds on the quantitative phase and the two stages are linked in the intermediary phase of the research.

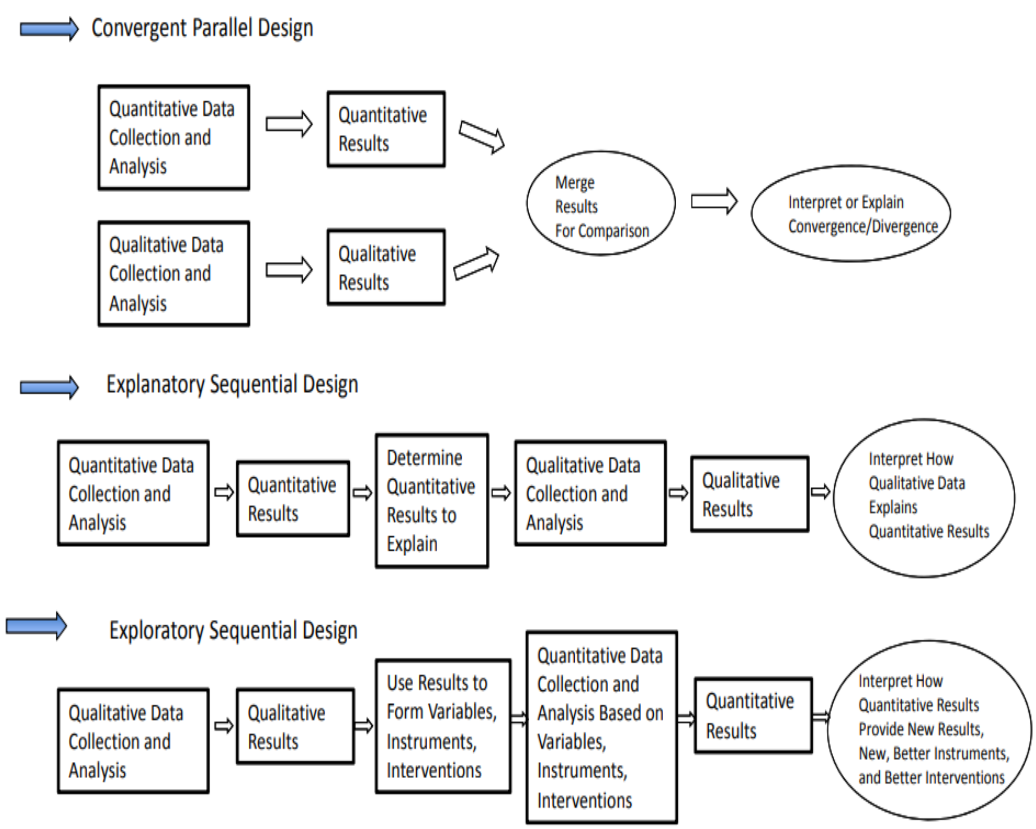

Figure 3. 3: Shows the three basic mixed methods designs. Source: Creswell (2013)

According to Creswell and Plano Clark (2011) and Subedi (2016), in exploratory sequential design the researcher collects qualitative data which is followed by gathering of quantitative data. The goal of this method is to first gather qualitative data in order to discover a phenomenon and subsequently collecting quantitative data to clarify relations located in the qualitative data (ibid). Of the six mixed method designs explained above, the explanatory sequential design is the most popularly used by researchers. This design involves gathering of quantitative data followed by collection of qualitative data to assist in explaining the quantitative results (Creswell & Plano Clark, 2011).

This research adopted the parallel followed by convergent design because it was considered most suitable. This is a natural approach which is efficient, especially if a researcher interacts with respondents. However, it requires careful planning of parallel data collection procedures for easier comparison of the two sets of results (Creswell & Plano Clark, 2011) phase of the research. The reasoning behind this method is that quantitative and qualitative data and their analysis enhance and clarify those statistical results through a deeper investigation of the respondents' position (Creswell, 2013; Subedi, 2016).

3.10.1 Methodology and data collection

In this study primary data was collected from different sources such as field interviews with smallholder farmers, focus group discussions, field observations and key informant interviews. In order to improve the data collection procedure and the results, the collected raw data was coded and reviewed several times. After the first day of conducting interviews the research instrument was adjusted slightly in order to enrich the data being collected. The gaps which were identified during review of the collected data were addressed during subsequent interviews and focus group discussions. This approach is supported by Cho and Lee (2014), Crawford (2008) and Mayring (2000, 2014) who underscored the importance of combining data collection and analysis. Furthermore, Merriam (2009) and Charmaz (2008) advocate the scrutinising of data as it is collected. According to Creswell (2014) and Yin (2003), one of the features of a good qualitative study is obtained utilising arduous data collection techniques. Snider (2010) observes that although numbers impress, regrettably they also hide far more that they divulge. On the other hand, Davis (2010) argues that "good qualitative research has equaled, if not exceeded, quantitative research in status, relevance and methodological rigor". There are several principles which guide the planning and reasoning of most qualitative researchers. The philosophical assumptions of qualitative inquiry guide the qualitative research in all of its complex designs and methods of data analysis. In order to comprehend a complex phenomenon, one needs to consider the different "realities" experienced by the interviewees that are the "insider" perceptions.

Creswell (2014) and Yin (2003) suggest that the use of meticulous data collection methods is critical in a reliable qualitative study. This research used multiple sources of data in order to triangulate the imperial material and thereby lessen the possibility of misinterpretation. Yazan (2015) reports that in order to minimize the chances of misinterpretation, qualitative researchers employ different techniques of data collection using a procedure called triangulation. Saunders *et al.,* (2019) emphasize that validity of research is assured through triangulation of data. Olsen (2004) argues that triangulation goes beyond validation as it assists in intensifying and broadening one's understating. The application of existing data analysis and review is the major strength of triangulation and that it uses several sources to interrogate a given setting (Saunders et al., 2019). Furthermore, triangulation is something done to generate a dialectic of learning, combining methods two or three notions about what is being (ibid). Denzin (1978) defines triangulation as "the combination of methodologies in the study of the same phenomenon". In this study several sources were used to gather first hand data. Saunders *et al.,* (2019) and Yin (2003) propose six main sources of data when case study methodology is used. These sources of data include participant observation, direct observation, archival records, interviews, physical artifacts and documentation. These sources of data were used during the study.

The interviews were the main data collection method used in this study. Babbie (2010) identified three major categories of interviews which included standardized interview, semi-standardized interview and unstandardized interview. Standardised (structured) interviews use an interview schedule which contains structured or unambiguous questions. Interviewees are asked same questions by the interviewers. Berg (2009) proposes that this form of interviewing is based on the premise that responses to the questions will be comparable. Standardized interviews predominantly generate quantitative data (ibid).

Semi-standardized interviews offer more flexible approach to the interview process. According to Tod (2006, although predetermined questions have a schedule, semi-structured interviews allow for unanticipated issues and responses to emerge. The wording of questions is flexible and allows for different level of language to be used and clarifications to be made by the interviewers (Berg, 2009). This method allows the interviewer to get the interviewees' experiences about the topic at hand (Bridges *et al.,* 2008). This facilitates the collection of richer, more textured data from the interviewee than that obtained through formally structured scheduled questions (ibid).

Unstandardized interviews do not a specific framework for questioning (Ryan *et al.,* 2009). There is no set answers to the questions as the interview follows the direction of responses given by the participant (Moley, 2002) as reported by Ryan *et al,* (2009). This type of interviews can be conducted to supplement field observations.

In qualitative research, the interview seeks to explain the meaning of main premises in lifespan of the domain of the subject. The major undertaking in interviewing is to comprehend the meaning of the answers given by the respondents (Kvale, 1996) as reported by Valenzuela and Shrivastava (2008). Interview data presents actualities which are neither partial nor perfect but are just valid (Silverman, 2005) as reported by Kandadi (2008). Interviews are mainly beneficial for obtaining the tale behind the experiences of the respondents (McNamara, 1999). The researcher can follow more far-reaching evidence around the subject matter (ibid). Quite often interviews are combined with other methods of data gathering with a view to give the investigator a comprehensive compilation of material for analyses (Turner III, 2010). Interviews may be beneficial as they provide an opportunity for probing responses from the interviewees (McNamara, 1999). According to McNamara (2009) as reported by Turner III (2010), the strength of the common interview guide method is the skill of the investigator, "to ensure that the same general areas of information are collected from each interviewee, and this provides more focus than the conversational approach, but still allows a degree of freedom and adaptability in getting information from the interviewee".

The study used a mixed methods approach to data collection and analysis. Quantitative data was collected through household interviews while qualitative data through semi-structured key informant interviews and focus group discussions. In this research, the quantitative part helped to answer the “what” questions, while the qualitative approach responded to the “why questions”. Data collection was done from June to August 2017 in Choma and Kalomo districts and October 2017 in Katete district. The timing of the data collection was after crop harvest. The interview respondents permitted the researcher to use their responses in this study and the key informants and participants of group discussions agreed to being mentioned by name.

The data collection tools included questionnaires for structured interviews directed at smallholder farmers and a checklist for focus group discussions (FGDs). A copy of the questionnaire is attached in Appendix A. The information from focus group discussions assisted to triangulate and qualify data collected from interviews and in making the recommendations on remedial measures to be undertaken. Other techniques used in data collection included observations and case studies. Key informants comprised government agencies and policy makers, board members of cooperatives, members of grain traders association, village headmen, maize processors and manufacturers of agro storage equipment.

The statements in the section of questionnaire assessing technology acceptance, were based on previous studies relating to adoption and use of technology. The variables were measured on a 5 point scale as in the original UTAUT, where 1 was equivalent to the negative end (fully disagree) and 5 for the positive end of the scale (fully agree).

From the outset it was made clear to the respondents that the purpose of the visit was to learn from them about their knowledge and experience in maize handling along the value chain. At the end of the interviews the respondents were eager to find out from the research team about the technologies for the prevention and control of mostly maize weevils (*Sitophilus zeamais*) and the larger grain borer (*Prostephanus truncatus*).

In Zambia, similar to most countries in sub-Saharan Africa tradition dictates that men are the ones who are supposed to be interviewed although most postharvest operations are done by women. In instances where both spouses were at home, the household members decided upon the individual to be interviewed.

3.10.2 Sampling techniques

Purposive sampling was used because it helps to answer the research questions (Kothari, 2006, Kumar, 2011; Saunders *et al.,* 2019). Purposive sampling is a deliberate selection of particular units of the population for establishing a representative sample of the universe (Kothari, 2006, Kumar 2011; Saunders *et al.,* 2019). Purposive sampling is virtually synonymous with qualitative research (Palys, 2008), also known as judgmental, selective or subjective sampling, is a type of a non-probability sampling technique. The main goal of purposive sampling is to focus on particular characteristics of a population that are of interest, which best provide answers to research questions. Although the sample studied was not representative of the population, for researchers pursuing qualitative or mixed methods research designs, this was not considered to be a weakness.

Compared to probability sampling techniques such as simple random sampling and stratified sampling, the sample being investigated was quite small. Simple random sampling is where each and every item in the population has an equal chance of inclusion in the sample (Kothari, 2006, Kumar, 2011; Saunders *et al.,* 2019). Stratified sampling is a probability sampling technique in which the researcher divides the whole population into different sub-groups or strata, and then randomly selects the final subjects proportionally from the different strata (Kothari, 2006; Kumar, 2011; Saunders *et al.,* 2019). The sample size comprised 100 respondents from Choma, Katete and Kalomo districts in Zambia.

One hundred smallholder farmers were randomly selected using RANDBETWEEN Excel function. The 100 sampled respondents were at the standard error of the mean ≥ 0.05 (i.e. N= 0.05). Therefore this sample size was within the 95% confidence interval and 5% margin of error.

3.10.3 Primary data collection

Primary data is the information which is collected anew or for the first time thereby being in its original character (Kothari, 2006; Kumar 2011; Saunders *et al*., 2019). The researcher uses primary data collection methods through obtaining information directly from the respondents (ibid). Survey questionnaires were used to gather quantitative data directly from the farmers while key informant interviews were used to collect qualitative data from staff of support institutions. The questionnaires comprised both open and close ended questions.

3.10.4 Secondary data collection

Secondary data collection is the gathering of information from already existing sources which would have been collected by someone and already passed through the statistical process (Saunders *et al*., 2019). This information supplemented what was collected using the primary methods and provided an opportunity to the researcher to have additional information about the subject matter under consideration. The review of documents provided the researcher an opportunity to validate information collected from other data collection methods.

3.10.5 Survey questionnaire

A questionnaire was used to facilitate quantitative data collection. A questionnaire is a form comprising interconnected questions developed by a researcher regarding a research problem under investigation based on the study objectives. A questionnaire is used to collect facts, opinions perception, attitudes abd beliefs from a large number of respondents at a given time. A questionnaire is used to gather data because of its efficiency in data collection particularly when the researcher knows what is required and how to measure the variables of interest (Creswell, 2014). Furthermore, it allows a researcher to collect information within a short period of time at a low cost and free from bias (Kothari, 2006). A questionnaire should be prepared very carefully in order for it to be effective in the collection of relevant data (Kothari, 2006). Therefore the research instrument was carefully designed in such a way to facilitate the capture of data relating to the adoption of postharvest technology by small scale farmers.

3.10.6 Key informant interview guide

A key informant interview guide was used to get information from key informants. A key informant interview is a qualitative, in-depth interview of people chosen for their first-hand knowledge about a topic of being interrogated (Kumar, 2011). The key informant guide provides information which guides the interview process. The key informant guide had a check- list of questions which were asked regarding the adoption of postharvest technologies by smallholder farmers.

3.11 Validity and Reliability of Research Instruments

Much as the terms 'reliability' and 'validity' are controversial among qualitative scientists, (Lincoln and Guba, 1985), with certain researchers having a preference for 'verification', truthfulness and rigorousness are equally important in qualitative research. Cohen and Crabtree (2008) argue that there is a general consensus among researchers regarding the need for qualitative research to be vital, upright and sensibly defined as well as the application of suitable and robust methods. Quality of findings and conclusions of a study are ensured by testing goodness of data. Validity and reliability are the two criteria used for testing goodness of measures (Sekaran, 2003).

3.11.1 Validity of results

Validity refers to the accuracy and meaningfulness of inferences made on the basis of the results obtained (Saunders *et al.,* 2019). Validity is the agreement between a researcher's conclusion and the actual reality (Lamont and White 2005). Validity was also checked during the pretesting of the instruments and content validity was done prior to the onset of the study. The pretest area was excluded from the actual research. Validity is the degree to which results obtained from the analysis of data essentially represent the subject being studied. It's the ability of the instrument to gather truthful and justifiable data (Hammarberg *et al.,* (2016). Furthermore, validity refers to the accuracy and relevance that are based on the research findings and measure of the extent to which an instrument measures what it is supposed to measure (Saunders *et al.,* 2009, 2019). Validity explains how well the collected data covers the actual area of investigation (Ghauri and Gronhaug, 2005).

Neuman (2005) proposed that when administering any data collection instrument, a researcher should ensure that the tool being used has face validity, content validity, criterion validity and construct validity. Furthermore, Sekaran (2003) suggested that several types of validity tests for testing the goodness of measures include content validity, criterion-related validity, and construct validity.

Face validity is the extent to which a measure apparently reflects the content of the concept in question. A researcher must establish face validity if an instrument is being developed for the first time. Bryman & Bell (2007) argue that face validity can be ensured by obtaining subjective judgments by the experts of the concerned field.

According to Sekaran, 2003, content validity is closely related to face validity. It ensures that a measure includes an adequate and representative set of items to cover a concept. It can also be ensured by experts‟

agreement. Content validity is defined as "the degree to which items in an instrument reflect the content universe to which the instrument will be generalized" (Straub, *et a*l., 2004).

Criterion validity is the degree of correlation of a measure with other standard measures of the same construct (Zikmund, 2003). Criterion validity has two types namely, concurrent validity and predictive validity. In concurrent validity, the researcher engages a criterion on which cases (individuals and institutions or nations) are known to be different and that is pertinent to the concept in question (Bryman & Bell, 2007).

Predictive validity is the extent to which a new measure is able to predict a future event. Here the researcher uses a future criterion instead of contemporary one. (Bryman & Bell, 2007).

Construct validity measure of validity refers to developing correct and adequate operational measures for the concept being tested (Yin, 1994) as reported by Petter *et al.,* (2007). Construct validity is the degree to which a measure/scale confirms a network of related hypotheses generated from theory based on the concepts (Zikmund, 2003). Construct validity has two types which convergent validity and discriminant validity. Straub *et al.,* (2004) convergent validity results when two variables measuring the same construct highly correlate. A tool is considered to have discriminant validity if by using similar measures for researching different constructs results into relatively low inter correlations (Cooper & Schindler, 2003) The draft questionnaire which was developed for the study was subjected to a validity test prior to administering it to the respondents in line with Harkness *et al.,* (2010).

3.11.2 Reliability of results

Zikmund (2003) defined reliability as "the degree to which measures are free from random error and therefore yield consistent results". According to Hair *et al*., (2006); Sekeran 2003, Cronbach's coefficient alpha by Cronbach (1951) is one of the most common methods in assessing reliability. According to Nunnally, 1978, this method estimates the degree to which the elements in the scale are illustrative of the concept being measured and is recommended as the very the first measure one should use to assess the reliability of a measurement scale. Reliability of an instrument is a measure of the extent to which a research instrument yields consistent results or data after repeated trials of the research (Haradhan, 2017). Reliability measures the relevance and correctness of the instruments (Taherdoost, 2016). De Vaus, (2013); Hair et al., 2006 and Sekeran, (2003) report that generally scholars agree that an alpha value of at least 0.7 is considered acceptable for reliability. However, Hatcher (2003) argues that the reliability estimates of 0.6 and above are considered reasonable for an exploratory study.

The consistency of the tools was confirmed by administering the questionnaire two times to the same respondents. This method helped to identify questions which lacked clarity as they were interpreted differently by the respondents.

3.11.3 Pretesting of research instruments

In questionnaire design, there is usually likelihood that certain questions could be ambiguous and as such questionnaire testing is cardinal for identification and removal of such challenges (Sudman and Blair, 1998) as quoted by Blumberg *et al.,* (2008); and Saunders *et al.,* (2019). The piloting of the questionnaire was done in Chongwe district. This location was selected because of similarities in the crops grown, culture and local language spoken in the area to that used by smallholder farmers in the target districts. The prominent crops grown were maize, groundnuts, cotton and sunflower. Pretesting of data collection instruments is conducted to enable the researcher perform a preliminary analysis prior to embarking of a fully-fledged study (Hurst *et al*., 2015). Pretesting is a measure taken to ensure that the data to be gathered is consistent and representative of the sample. A pretest can reveal deficiencies in the design of a questionnaire or proposed procedure and the necessary adjustments can be made to study instruments or the entire research (Hurst *et al*., 2015). Pretesting is done to ensure validity and reliability Saunders *et al.,* (2019).

During the pretest, the questionnaire was administered to 15 respondents with a gender distribution of 7 men and 8 women. The age of the respondents ranged from 29 to 71 years. Of the 15 respondents that participated in the pretest 5 had secondary school education, while 7 had gone up to primary school and 3 had not been to school. The results from the pretest contributed to a modification of the questionnaire. The parts of the questionnaire which were adjusted included a reduction in the number of questions, use of phrases and words which could easily be understood by the respondents. Furthermore, the pretest gave an indication of the amount of time needed to administer a single questionnaire.

The pretest helped to identify the areas which needed emphasis during the training of enumerators, and helped in the translation of certain scientific words into the local languages spoken by smallholder farmers in the three target districts. Overall the respondents found the topic being researched very interesting and relevant to the postharvest management practices of smallholder farmers.

3.11.4 Procedure of data collection

The researcher used a systematic procedure during data collection. The researcher had a letter of introduction to the cooperative societies and village headmen. Questionnaires were administered to the respondents by the researcher and three trained enumerators. This approach was used because some of the respondents could not read, let alone understand English which was the language used in the questionnaires. The interview started by explaining the objective of the study and seeking their permission to proceed with administering the questionnaire. The researcher also held focus group discussions (FGDs) with the farmers in groups of 15 - 20 people. Focus group discussion is often used as a qualitative method to gain an in-depth understating of social issues. The approach aims at collecting data from a purposely chosen group of individuals rather than from a randomly selected sample.

Furthermore, the researcher held interviews with key informants. The purpose of key informant interviews is to obtain data and insights from knowledgeable people which cannot be obtained from other approaches (Kumar, 2011). Key informants normally offer confidential information that would not be revealed in other situations. Key informant interviews provide flexibility for exploration of issues and new ideas not anticipated during the planning stage of the study but are relevant for its purpose (Kumar, 2011). The questionnaire for key informant interviews which in certain cases was sent prior to the meeting was used to guide the discussion.

3.11.4.1 Household interviews

The questionnaire was administered to 100 respondents who were smallholder farmers. Most of the interviews were held in Tonga and Nyanja which are the local languages spoken in Choma and Kalomo and Katete districts respectively. Five to 10 % of the interviews were partially conducted in English. Each interview on average took 25 to 35 minutes. According to (Oltmann, 2016; DeJonckheere and Vaughn, 2018), the advantage of the interview technique is that it enables the respondents to provide immediate feed-back to the researcher about unfamiliar aspects of setting and situation.

After interviews, the questionnaires were sorted to remove mistakes, and confirm completeness, accuracy and consistency. The data was then entered into the computer and analysed using the Statistical Package for Social Scientists (SPSS).

3.11.4.2 Focus group discussions

Focus group discussions (FDGs) involving 15-20 people were carried in Choma, Kalomo and Katete districts. The sessions started with introductions of the research team and the purpose of the study. This was followed by self-introductions of respondents. Focus group discussions provided an opportunity to obtain information for validation and triangulation of the findings from questionnaire interviews. They provided a forum for respondents to raise pertinent issues to postharvest losses and the available technologies. The focus group discussions were conducted in a semi-structured manner. The discussions covered postharvest activities along the maize value chain, the magnitude and type of losses and the solutions applied to preventing or reducing maize losses at household level.

Prior to conclusion of interviews, farmers were given an opportunity to ask questions. They reported that they found the interview had been an eye opener and very informative about the challenges and opportunities that existed for reducing postharvest losses. The farmers considered the interaction beneficial to them as well because they were reminded that maize losses were a reduction in revenue and household food security. They pledged to reduce maize losses in the coming years particularly that in the preceding years, crop production had been affected by fluctuations in the rainfall pattern due to climate change. The farmers considered it prudent to preserve the already produced grain rather than embarking on more production.

The fact that smallholders wanted more information on postharvest losses and the available technologies was a demonstration of their concern about the need to preserve the maize already produced. The positive attitude shown by smallholders about the need to reduce losses would be a good entry point for the introduction of postharvest solutions.

3.11.4.3 Key informant interviews

The study interviewed 10 key informants from institutions which are stakeholders in the maize value chain. The criteria for their selection included their position, expertise and experience in agricultural policy, crop production and PHLs. The purpose of these interviews was to seek a wider scale views and obtain information on ongoing and planned postharvest loss interventions in the country. Similar to smallholder farmers the respondents consented to be cited in the study.

3.11.5 Challenges in methodology and data collection

The challenge faced during data collection was to get the respondents have a clear understanding of certain questions particularly that they had to be translated into the local language. There is a possibility of loss of meaning during translation. However, since most of the questionnaires were administered by the researcher a lot of care was done to ensure clarity during data collection.

3.11.6 Ethical considerations

Ethical considerations safeguard the rights of respondents by guaranteeing confidentiality. Ethical consideration is obligatory for maintaining the integrity of both the researcher and the study (Creswell, 2007). The respondents were assured of confidentiality of the information they provided and that it was only going to be used for the purpose of the research. Prior to commencement of the interviews or discussions permission was sought from them regarding their willingness to participation in the study.

3.12 Data Analysis: Grounded Theory and Content Method

Data analysis is the process of creating order, structure and meaning to bulk of the collected data in order to obtain utilizable and valuable information (Saunders *et al.,* 2009). In this study the grounded theory and the content method were selected for qualitative data analysis. According to Yin (2009) there are five approaches for analyzing case study based research. For this study, the Grounded Theory was selected because it employs analysis tool such as coding, which facilitated the development of the intended framework. “Grounded theory is a methodology in which a systematic set of procedures is used to develop an inductively derived theory about phenomena” (Collis and Hussey, 2014; Charmaz, 2008,). It aims “to arrive at prescriptions and policy recommendations with the theory which are likely to be intelligible to, and usable by, those in the situation being studied” (Collis and Hussey, 2014). The selection of grounded theory was further influenced by Hussey and Hussey (1997) who posit that the grounded theory is popularly used in qualitative data analysis in business oriented research. The grounded theory and content analysis are used in analysing and interpreting qualitative data (Priest, Roberts & Woods, 2002) as cited in Cho & Lee (2014). However, there is lack of clarity in literature regarding the variations and similarities in qualitative content analysis and grounded theory (ibid). Priest et al., (2002) argue that grounded theory and qualitative content analysis are considered identical approaches for interpreting qualitative data. Grounded theory is considered as a research methodology while content analysis as a method (Crotty, 2003). Additionally content analysis is treated as a research method for literal data analysis whereas grounded theory is considered as a theoretical framework (Patton, 2002).

According to Glaser (1967, 2004; 2005; 2007) and Glaser and Holton (2004) open ended questions and responses to multiple choice questions can be analysed using the Grounded Theory. The discovery of the Grounded Theory by Glaser and Strauss in 1967 is the most quoted reference for any single method for analysis of qualitative data (Thulesius, 2009). He further argues that Grounded Theory has an inductive approach for generation of theories which provide an explanation about the resolution of challenges faced by participants in research being undertaken. As such, Grounded Theory hypothesizes the goings on in the area being investigated through the "Constant Comparative Method", which is its other name. This shows continuous data comparison during collaborative research work involving coding, memoing, sorting and doing the write-up. The use Grounded Theory in data analysis differs from other methods used in qualitative data in the sense that it provides explanatory concepts instead of descriptions. The results from using Grounded Theory are a combined set of conceptual hypothesis instead of reports of facts (Thulesius, 2009). According to Glaser (1978; 1998) validity is not a major concern in Grounded Theory research but should rather be assessed on the basis of fit, relevance, workability and modifiability. A line by line coding method was used in data analysis because it is more system of coding. It's a way of breaking through things, or forcing a researcher's attention on a few words (Strauss and Corbin, 1998).

The quantitative data was analysed using the Statistical Package for Social Scientists (SPSS). In order to measure the degree of association between the independent variable (postharvest technologies) and dependent variable (farmers adoption rate), the Spearman's Rank Correlation was used. Spearman's Rank Correlation is a technique for determining the degree of correlation between two variables in case of ordinal data where ranks are assigned to different values of the variables (Kothari, 2006 & Clef, 2013). The main objective of this coefficient is to determine the extent to which the two sets of rankings are similar or dissimilar (ibid). The formula which was used by the researcher to calculate the Spearman's Rank Correlation was as follows:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2 - 1)}$$

Where: ρ = Spearman's Rank Correlation

d_i = the difference between the ranks of corresponding values xi and

n = number of value in each data set

Source: Clef (2013.)

The Spearman's Rank Correlation was done at 0.05 significance level. For values less than 0.05, the hypothesis was accepted and concluded that there was a significant positive relationship between the independent and dependent variables (Kothari, 2006; Clef, 2013).

Data analysis was an interactive combination with data collection. According to Collis and Hussey (2014), data analysis under the interpretive paradigm cannot be separated from data collection. The analysis should indicate that all evidence has been attended and analytical strategies cover the research questions, the analysis addresses all potential major rival interpretations, “the most significant aspect of the case study” and prior expert knowledge is used (Yin, 2009). Data collected using electronic recorders direct from interviewees was transcribed and studied to identify the categories of themes. The collected data was sorted, organized, coded and interpreted. Data was further summarized into tables, interpreted in percentages and presented in graphs and pie charts for easy reading and interpretation. The information derived from this analysis was used in the presentation and discussions of the findings.

Summary

This chapter provided debate on the several theoretical perspectives of research. Arising from research findings advanced by several scholars this study selected the interpretivist paradigm and case study method for data collection. The grounded theory approach was adopted for qualitative data analysis while SPSS was selected for quantitative data analysis.

CHAPTER 4: STUDY FINDINGS AND DISCUSSION

4.1 Introduction

"I'm an infant with Shakespeare; I'm kind of learning how to walk. I'm trying to decipher the code, you know? I do my research. And I get a clear understanding of what the language is. It is a tremendous process that I have to go through as I am sure all actors do, finding the gems hidden in his language" – Ruben Santiago - Hudson

This Chapter presents and discusses the study findings. The questionnaires were administered to 100 farmers located in three high maize production districts of Zambia. As indicated in Table 4.1 the gender distribution of the farmers that participated in this study was 59% male and 41% female.

Table 4.1: Gender of respondents. Source: (Author)

Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Male	59	59.0	59.0	59.0
Female	41	41.0	41.0	41.0
Total	100	100.0	100.0	

The study found that most of the farm activities such as land preparation, planting, weeding, harvesting, shelling and marketing were done by both men and women, with the former spending less time. Activities such as winnowing of grain and managing of grain kept for home consumption were the responsibility of women. During focus group discussions, women revealed that they spent longer hours in the field because men had to attend to other livelihood responsibilities (looking after livestock and doing piece-work to raise money) and engaged in social activities such as beer drinking. In a study conducted in Kenya, Diiro (2018) found that inadequate access to labour and agricultural markets by women were some of the gender disparities in the agricultural sector. Furthermore, there was low participation of women in productive resources such as engaging in income-generating activities, extension and advisory services because women spent more time performing domestic work (ibid). According to FAO (2011), nearly 50 % of the agricultural labour force in sub-Saharan Africa is made up of women. These figures range from 40% in Southern Africa to just above 50% in Eastern Africa and when food processing and preparation are included then the share contribution of women on labour-force exceeds 60% in Africa (ibid). The report further revealed that the participation of women in meetings and /or trainings was lower than that of men because husbands preferred their wives to have female facilitators. Since women played multiple roles (productive, reproductive and community management) simultaneous in society, they were constrained for labour time and flexibility (Blackden & Wodon, 2006). Additionally, women were rarely found in public spaces which provided information and knowledge because they were often too busy with domestic chores such as drawing water, collecting firewood, child care and food preparation (Mudege *et al.,* 2017). Colverson (2015) adds to the discourse on the low participation of women in meetings by reporting that due to numerous responsibilities undertaken by women, they at times failed to participate in meetings due to childcare provision and not being able to travel alone to venues where the events were held. Arising from the multiple duties undertaken by women at household level, their ability to travel for meetings, especially in the evenings, was very much restricted (Davis *et al*., 2010; Grassi *et al.,* 2015).

The marketing of maize in distant markets was mostly undertaken by men in all the target districts. However, some women were not comfortable with men undertaking the marketing of maize and other crops for fear of misuse of money. According to literature, as agricultural commodity moves along the value chain women lose control and the income generated (Gurung, 2006). It is further argued that women farmers normally experience challenges to sustain a lucrative market position (ibid). The production and marketing of the so called "women's crops" such as vegetables and groundnuts gets taken over by men when the enterprises become more profitable (Gurung, 2006). Diiro (2018) reported that men in Kenya had more control over income from farming enterprises than women.

The study further established that in female headed households, women did all the activities although they hired men to help them with more difficult tasks such as cutting of trees when starting new fields, digging of basins for conservation farming, construction of storage cribs - '*Nkokwe* or *Matala*' - and mixing of postharvest insecticides with grain. According to Tanellari *et al.,* (2014), generally farm activities, from planting to marketing, were usually done by both men and women in the male headed households. Nonetheless, there was a strong tendency for a particular gender to dominate a number of activities, arguing that women farmers normally experienced challenges to sustain a lucrative market position (ibid). If women had equal access to technology, production resources and services equal to men they would increase crop yield by 20 to 30 percent (Doss, 2018).

Women play a crucial role in smallholder farming systems and that they produce 60-80 % of the world's food (Palacios – Lopez *et al.,* 2017; Doss, 2018; CGIAR, 2014). Despite the crucial role played by women in agriculture, their contribution is not well recognised the world over (Subedi, 2008). For example, in sub-Saharan Africa women contribute about 75% of the labour force in agriculture (World Bank, 1998), contributing around 25% to 75% of the labour force along several stages of the value chain (Colverson, 2015). Although women are the de-facto heads of the family, men make most of the decisions on agricultural production (Subedi, 2008).

Time-use surveys have shown a variance within and across sub -Saharan African countries (FAO, 2011; Blackden & Wodon, 2006). Estimates of the amount of time contributed by women to agriculture in Africa varies from nearly 30% in the Gambia to 60-80 % in different regions of Cameroon (FAO, 2011; Doss, 2018). Time-use studies conducted in Zambia indicated that the amount of time women spent in agriculture usually differed depending on type of crop and activity, production stage and age of the farmer (FAO, 2011). With the exception of ploughing, women were involved in nearly all farming activities with more time spent on weeding and harvesting (ibid).

During the study women reported that they normally contributed a greater portion of their farm produce to domestic consumption than men who mostly grew cash crops. This finding is similar to the results reported by Karl (2009) that women played an important role in household food security. A study conducted by Drafor, (2014) established that the introduction of cash crops leads to an increase in women's obligation to grow food security crops while the men paid attention to cash crops, mostly with substantial labour provided by women. It was further reported in literature that women were the major producers of food in developing countries although their efforts are constrained by lack of access to resources, finance, technologies and markets (UN, 2014).

Seymour *et al.,* (2016) and Gebre *et al*., (2019) proposed that there was a growing body of knowledge suggesting that decisions regarding technology adoption usually involved suggestions from both men and women. Men and women usually performed varying farming tasks with most labour-Intensive activities being undertaken by women. Kaaya *et al.,* (2006), argued that time constraints and limited funds and inputs restricted women from investing in new technologies or adopting new and improved varieties of groundnuts. Undoubtedly, the adoption of new technologies was not only dependent on the gender of the household or farmer (Tenellari, *et al.,* 2014). Factors such as access to and quality of resources for women and asset ownership had an impact on technology adoption (ibid).

4.2 Age Distribution of Respondents

With regard to age, 50 % of the respondents were below 51 years, with a percentile range of 25 to 75 years of age (std. 13.5). This finding suggests that the respondents comprised of both young and elderly farmers. Table 4.2 illustrates the age range of the respondents.

Table 4. 2: Age of distribution of respondents. Source: (Author)

Age Group		Percent	Valid Percent	Cumulative Percent
20 - 30 yrs	16	16.0	16.0	16.0
31 - 40 yrs	17	17.0	17.0	33.0
41 - 50 yrs	17	17.0	17.0	50.0
51 - 60 yrs	13	13.0	13.0	63.0
Above 61 yrs	35	35.0	35.0	98.0
Not applicable	2	2.0	2.0	100.0
Total	100	100.0	100.0	

Although Zambia has a young population (UN, Zambia, 2013) the study found that only 33% of the youths (15 to 35 years of age) were engaged in maize production. Since maize was the most commonly grown crop it could be assumed that this was the percentage engagement in farming. It's reported in literature that Africa has the youngest population with 65% of the people aged below 35 years (AGRA, 2015; Jayne *et al*., 2017). The definition of Youth varies from tribe, culture, society and country and also varies across time, and space. The United Nations and World Bank defines youths as those people between 15 and 24 years (UNECA, 2009) while the African Union Charter defines youths as young people in the age group of 15-25 years (AUC, 2006). According to the UN, the "Definition of youth perhaps changes with circumstances, especially with the changes in demographic, financial, economic and socio-cultural settings; however, the definition that uses 15- 24 age cohort as youth fairly serves its statistical purposes for assessing the needs of the young people and providing guidelines for youth development" (UN, 2008, p. 2; Ortiz and Cummins, 2012, p. 6). Countries such as South Africa, Ghana, Tanzania and Zambia categorised youths as those between 15 and 35 years (Gyimah-Brempong and Kimenyi, 2013) and this is the definition adopted in this study. According to (Valerie and James, 2019), Africa was experiencing a huge youth bulge, which is defined as "a peak in the share of persons aged between 15-24 years in the population" (Ortiz and Cummins, 2012, p. 6). Youth bulge is a demographic development where the ratio of individuals aged between 15-24 years in the populace surges considerably in comparison to other age groups (Ortiz and Cummins, 2012). Youth bulge is as a result of a reduction in child mortality while the fertility rate of mothers remains high, a phenomena mostly popular in the least developed countries (ibid).

Similar to what is common the world over, there are more elderly people found in agriculture in Africa, which is an indication that the youthful population is deserting agriculture (Vos, 2015 and Gorman, 2013 as cited by Jayne *et al*., 2017). White (2012) argued that the youth are migrating to urban areas where there are more employment opportunities. Additionally, many young people considered agriculture as tiresome and made their hands 'dirty' (ibid). As a result there was a high level of stigmatisation from peers, and from the community who perceived those engaged in agriculture as failures (White, 2012). A study conducted by Osti *et al.,* (2015) found that there was lack of interest in agriculture among the youth in Ethiopia and Kenya as they preferred white-collar jobs and farming was viewed as employment for old people, illiterate, and the poor. The inability of agriculture to provide a reasonable standard of living pushed off farmers to low paying jobs in towns (Jayne *et al.,* 2017). According to McNulty and Grace (2009) the low pay, drudgery, and long hours of work characterized by labour intensive agricultural systems makes young men and women to shun rural areas in third world countries.

According to Adesina, as reported by Nyasimi and Kosgey (2017, p.1), the "future of African youth lies in agriculture". The Youth in Africa can innovate and widen their agricultural business if barriers to startup capital could be reduced (Kayodi, 2017). The main issues that need to be addressed in order to increase the participation of youths in agriculture include: education, markets, finance and income, land ownership, infrastructure, perceptions and aspirations (Osti, *et al.,* 2015; Vos, 2015).

The harnessing of the drive, power and creativity of Africa's youth into fruitful, competitive and money-making agribusinesses can increase agricultural production and productivity, job opportunities and wealth generation

(AGRA, 2015). Other studies indicate that Africa's agriculture sector should be modernized through provision of technology and equipment to youths as doing so could contribute to sustainable economic growth and wealth creation on the continent (Vos, 2015; Jayne *et al.,* 2017).

4.3 Education Level of Respondents

The educational level of a farmer has implications for understanding of the value chains of their farm enterprises. The study found that twelve percent of the respondents had never been to school while forty two percent had only attained primary education. The smallholder farmers that had attained secondary and tertiary levels of education were thirty-one percent and thirteen percent respectively. The study further established that 42% of the smallholders had only attended primary school level of education while 12% had never been to school. Table 4.3 summarizes the levels of education of respondents and their gender respectively.

Table 4. 3: Respondent's level of education by gender. Source: (Author)

Education standard	University	College	Secondary school	Primary School	Not been to school	Not applicable	Total
Male	1	10	25	17	4	2	59
Female	0	2	6	25	8	0	41
Total	**1**	**12**	**31**	**42**	**12**	**2**	**100**

When a comparison of the education levels of male to female farmers was done, it was found that the number of women that had attained primary to tertiary level of education was lower (33%) than that of men (53%). The farmers with secondary education were more aware of postharvest loss reducing technologies such as use of pesticides and polythene bags. Furthermore, most of the farmers with secondary school education had at one time been in formal employment resulting in having more resources for investing into technologies for reducing postharvest losses of maize. The farmers with primary or no education at all, had fewer resources to invest in farming. According to Kassie *et al.,* (2011); Minten *et al.,* (2007) as reported by Kasirye (2010), higher earnings and low poverty contributed to the adoption of improved agricultural technologies. Hojo (2004) argued that existing literature pointed towards positive effects of education on the adoption of agricultural technologies by smallholder farmers. Furthermore, there was evidence that the probability of innovation adoption was positively affected by education above a certain threshold (ibid). The results from a study conducted by Knight *et al.,* (2003) showed that education of the household head reduced risk aversion and increased the adoption of agricultural innovations in rural parts of Ethiopia. On the contrary, a study by Hojo (2004) revealed that the education of the household head and members had no significant effect on the adoption of commercial vegetable seeds. Literature indicated that investment in the education of women produced the highest rate of return of any other form of investment in developing countries (Psacharopoulus and Patrinos, 2018). They further reported that social returns to education were higher than 10 percent at secondary and tertiary education levels. Additionally, higher rates of return to education were experienced by women, suggesting that the education of girls should continue to be prioritized (ibid). Gender differences in education between men and women were some of the socio-economic factors behind individual labor allocation decisions and had a consequence on the availability of off-farm prospects available to women and men (Palacios - Lopez *et al.,* 2017).

The high percentage of farmers with primary education (42%) and those that had not attended school (12%) had implications on understanding instructions for operation of technologies particularly that the instructions are usually written in English. Therefore, the medium of instruction when training such farmers should be the local language while the learning materials need to be simplified and more interactive. The learning materials prepared under the open and distance learning mode of education would be suitable for this category of farmers. According to the Commonwealth of Learning (COL) (2015, p. 2), open and distance learning (ODL) refers to " a system of teaching and learning characterised by the separation of teacher and learner in time and/or place; uses multiple media for delivery of instruction; involves two way communication and occasional face - to - face meetings for tutorials and learner - learner interaction". The benefits of the open and distance learning mode of education are freeing learners from the constraints of time and place and offering flexible learning opportunities to individuals and groups of learners with the support of information communication technologies (ICTs) (COL, 2015, p. 2)".

4.4 Type of Maize Grown by Gender

The study established that 18% of the male respondents grew hybrid maize while 13% grew local maize or gankata. Fifty-seven percent of the respondents grew both hybrid and local maize. Of the local maize under production, 73% was grown by women. The production of a larger percentage of local maize by women fitted with their low investment levels and this guaranteed them a harvest even under adverse weather conditions. According to literature, many smallholder farmers in Africa grow traditional maize varieties (AOATM, 2011). These varieties are adapted to the local growing conditions as their development over the years was based on the farmers' criteria. These varieties are adapted to the low input and management levels and cooking tradition of smallholders. However, traditional varieties produce low yields arising from low genetic potential, poor seed selection and low management (Ibid). One of the recognised methods for mitigating postharvest losses at field level was through varietal selection (Sheahan and Barrett, 2017). Although hybrid varieties are higher yielding, they are prone to postharvest losses. Therefore, the non-adoption of hybrid maize by farmers was a rational decision to avoid grains that simply get lost in storage (ibid).

Unlike men and the youth who grew maize for the market, women produced maize primarily for food security (Karl, 2009 and UN, 2015). The other reasons advanced for the preference of local maize or gankata by women was its tolerance to insect pest damage, heavy kernels, production of more maize flour, as well as tastier nshima (thick porridge made from milled maize). A study by Ekpa *et al.,* (2018), found that in sub-Saharan Africa local maize was preferred by some consumers due to the superior grain size, kernel density, colour and food taste. Although the Zambian government runs an input subsidy programme targeting vulnerable but viable farmers, there were few female beneficiaries because they cannot afford the deposit needed to access the inputs. An analysis of men and women's participation in the Farmer Input Support

Programme (FISP) showed that more men than women had benefitted from the programme despite the females constituting the majority of the Zambian population. According to Ministry of Agriculture (2017) of the 1.6 million farmers that benefitted from FISP during the 2015/16 season, 45 percent were women.

This study further found that 37% and 20% of the male and female respondents respectively grew both local and hybrid. Under the maize production system prevailing in the study areas, hybrid maize was mostly grown for the market while the local maize was for home consumption. Figure 4.1 provides a summary of types of maize grown by gender.

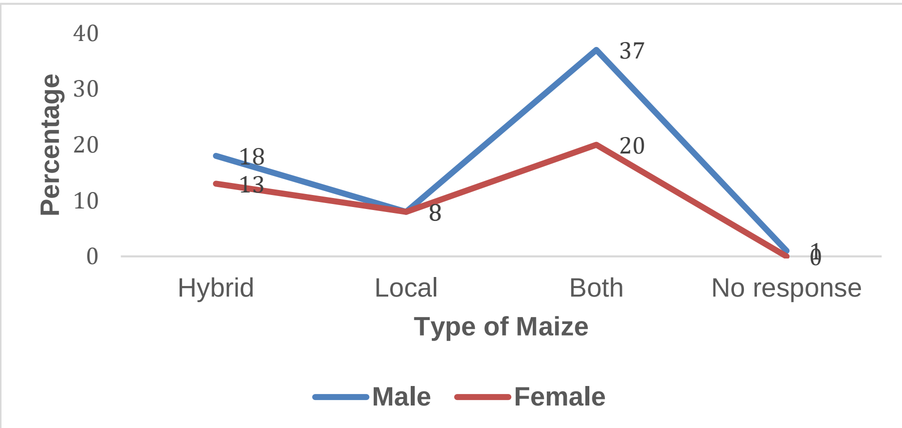

Figure 4.1: Type of maize grown by gender. Source: (Author)

4.5 Description of the Harvesting Methods

The overall quality of the grain is determined by the harvesting method which is the first critical operation in the grain supply chain (Kumar and Kalita, 2017). Maize harvesting in the study areas normally starts around mid-May and ends in July. All the respondents used the hand harvesting method by either making stokes and later stripping the cobs from the plants or removing the cobs from standing plants. The former method reduced the maize cobs not collected from the field because all the plants are cut and heaped together or stooked, leaving behind a clean field (see figure 4.2). The latter method retains some cobs on the plants and generates many small heaps of maize piled on the ground which may be missed during collection and transportation to the homestead. Although the farmers were aware of the fact that the removing of cobs from standing plants in the maize fields contributed to postharvest losses, they preferred this method because it was less time consuming than stooking. The study findings were consistent with the report by Kumar and Kalita (2017) that crop harvesting in developing countries was done manually by smallholder farmers.

Figure 4.2: Stooking of maize during harvesting in Kalomo District. Source: (Author)

The two critical factors which determined losses during the harvesting process were the harvest method and timing of the operation. If harvesting is not done at optimal maturity stage, high moisture content can contribute to losses prior and during harvesting (Kumar and Kalita, 2017). According to FAO (2018) delays in harvesting of crops can lead to quantity and quality losses because of shattering, and damage from rodents, insects, birds, and mould. Hence the need to complete harvesting soon after the maize crop is dry. Kumar and Kalita, (2017) report that in order to reduce field losses, grains are normally harvested at high moisture content (18% to 30%) but stored at moisture content of below 13%. As such, in order to maintain crop quality, minimise the cost of transportation and reduce storage losses, grain should be properly dried after harvesting (ibid). Lipinski *et al.,* (2013) report that in developing countries, 10% of the crops are lost in the field. In order to promote good ventilation within the harvested crop, it's important to remove contaminants such as weed seeds, insects, chuff and other plant materials (FAO, 2018).

With regard to addressing postharvest losses at field level, stooking is a recommended harvesting method because it facilitates drying, maize shelling and bagging in the field so that the maize gets transported to the homestead in bags rather than on the cob. FAO (2018) report that the use of sustainable mechanization in post-production operations is a more efficient method of utilisation of labour, better time management and faster accomplishment of tasks leading to a higher productivity system.

Although maize is one of the major income and food security crops in Southern Africa, most of the smallholder farmers that grow maize still use traditional methods of harvesting, threshing and winnowing during the post-harvest operations (Abass, *et al.,* 2013). They further report that the methods of handling can cause grain contamination and damage, resulting in a reduction in the nutritive value of the maize (ibid). Furthermore, these methods are labour intensive and time consuming (ibid). A study done by Abass *et al.,* (2017) and Manandhar *et al.,* (2018) showed that smallholder farmers in developing countries conduct most of the agricultural practices and preharvest and postharvest operations manually because of the low level of mechanization. If the drying crop gets rained on, fungal pathogens such as aflatoxins can develop and contaminate the maize grains (AOATM, 2011). Owing to the fact that grains are biologically active, they respire during storage with heat being a by-product of this process (ibid). Therefore, the rate of respiration can be slowed down by reducing temperature in storage which lengthens grain shelf life by reducing probability of germination (AOATM, 2011). Furthermore, temperature also affects the metabolic rates of fungi and insects. With low temperature, metabolic processes which lead to grain spoilage are reduced (ibid).

4.6 Time Spent on Harvesting

Since harvesting was done by hand, the amount of time spent on this operation was dependent upon the availability of labour and area under production. Of the 100 respondents contacted, 73% spent 2 to 4 weeks on maize harvesting while the remainder took 5 to 7 weeks. The longer maize remains in the field the more susceptible it becomes to pest attack. Nearly 44% of the respondents used family labour which varied from 3-10 members with the average being 5 family members. Male headed households tended to have more family members contributing to labour requirements of smallholders. Hired labour can be a substitute for inadequate family labor (Palacios-Lopez *et al.,* 2017).

The significant role played by women is highlighted in the harvesting and postharvest operations of maize in Zambia (FAO, 1997). The report further states that out of the eleven key harvest and postharvest operations, five are performed by both men and women (harvesting, drying, shelling, storage and milling). The operations conducted by women alone include transportation from the field, cleaning, grinding and pounding. The men are mostly responsible for construction of storage facility, transporting grain from home to the market and marketing (FAO, 1997). With regard to the amount of time spent on harvesting 29% of the farmers spent 2 weeks, 23% took 3 weeks while 4 weeks was spent by 21% of the respondents on this operation. Figure 4.3 provides detailed information regarding the amount of time spent on harvesting maize.

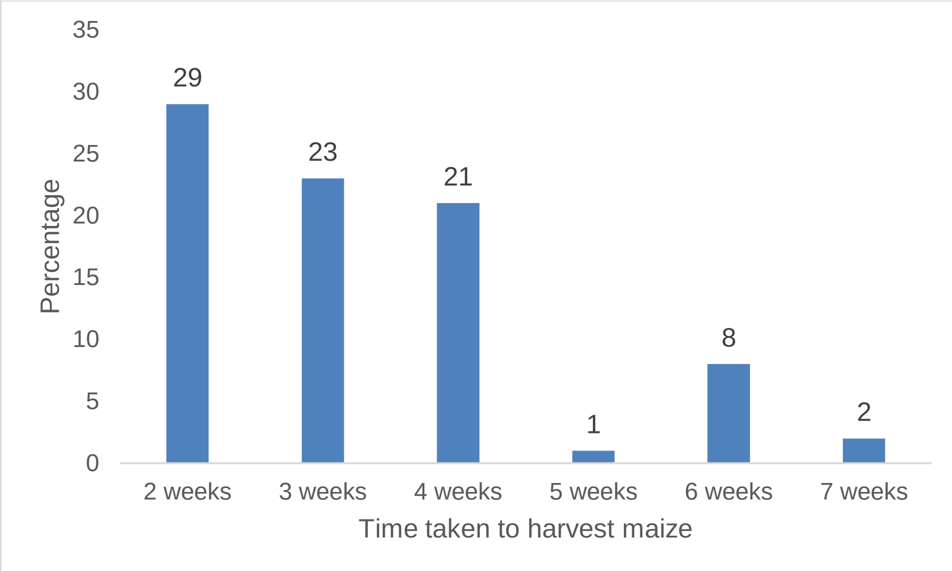

Figure 4.3: Amount of time spent on harvesting maize. Source: (Author)

4.7 Maize Drying Methods

4.7.1 Natural drying methods

Field drying: Most farmers in the study areas left the crop to dry in the field as they relied on the natural weather conditions to dry the crop. In some cases the maize plants were cut and stooked. Once the stems are cut the cobs tend to look downwards which is a desired trait particularly in the event of freak rains. This method facilitates sun drying of maize because it allows free movement of air in the field. Field drying has the disadvantage of exposing the crop to attack by livestock and pests such as rodents, birds and insects. In places where there were termites the crop at times dropped to the ground and subsequently got soiled. Furthermore, there was a risk of the crop getting soaked by rains. Kumar and Kalita (2017) and Kowuah *et al.,* (2018) reported that the most commonly used method of drying crops in developing countries was natural or sun drying. In these parts of the world sun-drying was the most economical and traditional method of drying the maize crop after harvest (ibid).

Sun drying at homestead: After harvesting the farmers placed the cobs of maize in the sun on mats, plastics, or raised platforms. The maize cobs were not placed directly on the ground to avoid contamination. Kowuah *et al.*, (2018) established that the conventional method of drying maize in Ghana involved farmers leaving the crop to dry in the field or in the open sun next to farmers' homes or on tarpaulins. This method dried the grain quickly and the heat from the sun killed some insects (ibid). The disadvantages with sun drying was that it could not easily be used during the rainy season, the cobs get exposed to damage by livestock, rodents, and birds and needed shelter to avoid morning dew (Kowuah *et al.*, 2018).

Drying was another stage of the value chain in which maize was lost. In cases where the maize crop was put on the ground before packing on the raised platforms, it got attacked by cattle, chickens, goats, termites and rats. Even when placed on raised structures, losses still occurred especially in cases where the floor of the structure was not well built particularly in cattle rearing areas where these animals used their horns to bring cobs of maize down (see figure 4.4). Drying is a critical period because it facilitates the reduction of moisture to the desired levels of below 12.5% (Kumar and Kalita, 2017; Kowuah *et al.,* 2018). The problem of maize having high moisture content mainly arises at the start of the marketing season when some farmers want to take advantage of higher prices by supplying maize with high moisture content. Drying and storage of grains is critical to guaranteeing quality and reducing postharvest losses caused by natural deterioration, pests and high crop moisture content (IICA; 2013). The report further states that the majority of smallholder farmers in sub-Saharan Africa lacked access to low-cost drying equipment and storage structures resulting in postharvest losses. Calve rely (1996) found that maize dried on raised platforms in Zambia and Zimbabwe experienced 3.5% and 4.5 % losses respectively as cited by Rembold *et al.,* 2011; Abass *et al*., 2014 and Kumar and Kalita, 2017). This research further found that grain meant for marketing later during the year and that retained for home consumption were sun dried for two to three months. In cases where insect pests attacked the maize crop from the field, substantial grain losses occurred during drying because farmers would not have applied chemicals to protect the crop against pests at this stage of the value chain.

Figure 4.4: Drying of maize on platforms at Batoka. Source: (Author)

4.8 Transportation of Maize from the Field to Homestead

Farmers in the study area transported maize from the field to homesteads using their heads and ox-carts. Transportation is a critical operation in the grain supply chain because agricultural products have to be ferried from the field to storage facilities and the market (Kumar and Kalita, 2017). There is little information on maize losses during transportation from the field to the homestead and the losses were bound to considerably vary due to the method of transport used (Hodges *et al.,* 2014). They additionally found that in sub - Saharan Africa the most basic form of transport was human transport which involved people walking and carrying things on their heads. They further report of a growing increase in low technology transport or intermediate means of transport which reduces drudgery at a low cost, thereby increasing local transport capacity. For distances of up to 20 kilometers non-motorized transport types such as ox carts, hand carts and bicycles are commonly used in the villages (Hodges *et al.,* 2014). Poor roads or lack of transport could cause damage and losses of food products due to spillage ((Kumar and Kalita, 2017). This finding is supported by Nkonya *et al.,* (1998) who found that head loads followed by ox - carts and trailers were the most common method of transporting maize from the field to homesteads in Tanzania.

Farmers in the research area were aware of grain losses incurred during transportation using wooden ox-carts particularly that the cobs were removed from the husks during harvesting. To reduce on the grains lost during transportation some farmers with more resources spread polythene sheets on the floor and sides of ox- carts. Each ox-cart load of cobs carried 6 - 7 x 50 bags of grain. The study found an insignificant number of farmers using metal ox-carts (see figure 4.5) for transportation of cobs of maize from the field. Metal ox - carts do not allow spillage of grain and were available for hire at a fee of 7 - 10 US Cents per load. According to van Leeuwen and Siyambango (1999), transport charges for ferrying products like maize over a distance of 1- 4 km amounted to less than 10 percent of the value of the load. There is a need to support investment in high quality ox-cart transport in rural areas because the fees charged for ferrying agricultural produce is less than that charged by trucks or pickup vans (ibid).

Figure 4.5: Transportation of maize using an ox-cart in Choma District. Source: (Author)

4.9 Maize Shelling

Maize shelling is an important aspect of post-harvest operation of maize. Shelling is described as the removal of grains from the cobs by the initial impact, and rubbing action as the material passes through a restricted clearance between the cylinder, and concave bars (Ayetigbo, 2001) as reported by (El Sharawy *et al.,* 2017) and Kumar and Kalita (2017). Maize shelling is one of the most important crop processing operations for separating the grains from ear heads and prepares the crop for storage, milling or marketing (ibid).

4.9.1 Methods of shelling maize

The study identified three main methods of shelling used by smallholder farmers. These methods were hand shelling, beating of maize cobs placed in bags or on raised platforms using sticks and mechanized shelling.

4.9.1.1 Hand shelling

The farmers reported that hand shelling was a traditional method which usually provided cheap and feasible ways of separating grains from cobs. Hand shelling was mostly done by children and women. Although hand shelling is very laborious and labour intensive, it causes little damage to grains. The hand shelling method allows for the separation of damaged and insect or fungal infected kernels. However, hand shelling is mostly suitable for small quantities of maize. During hand shelling the losses are about 1- 2.5% because there is no mechanical damage and the grains are collected and immediately bagged (Hodges *et al.,* 2014).

4.9.1.2 Shelling using sticks

The other manual operation involved loading cobs of maize in bags and then beating using sticks in order to separate the grain from the cobs. The supplementary method involved using raised platforms on which the cobs are placed and then beaten using sticks. The structure usually is covered with grass or plastics on the sides so that the grain does not scatter far away from the collection point (see Figure 4.6). Some farmers spread tents or plastics on which the grain drops. Farmers that could not afford tents simply let maize drop into pits which in some cases may have been plastered using cow dung. If done roughly and when the moisture content is above 12%, shelling using sticks can cause grain damage such as cracking and pulverization (FAO, 1997). This method is suitable when shelling large quantities of maize.

4.9.1.3 Mechanical shelling

Improved methods of shelling maize included use of hand operated maize shellers and motorised shellers (see figure 4.6). Hand held shellers have an output of 80 -100 kg/ hour. The motorized shellers have varying outputs which can range from 1 ton - 5 tons per hour. The study found that there were some entrepreneurs that owned motorised shellers for own use and for hire. The farmers that hired motorised shellers paid 2-ZMW 3 (2-3 US cents) per 50 kg bag of shelled maize. According to FAO (2018) agricultural mechanisation plays an important role in post-production activities such as harvesting, shelling, packaging, transportation and marketing of farm produce. The use of sustainable mechanization in post-production operations is more efficient utilisation of labour, better time management and faster accomplishment of tasks leading to a high productivity systems (ibid). Machinery is commonly used in postharvest operations such as shelling and milling of maize (FAO, 2018). Postharvest losses during manual shelling of maize for Zimbabwe was approximately 2.5% while that of mechanized shelling was 3.5% (Hodges, 2012). El Sharawy et *al.,* (2017) found that the percentage grain damage resulting from using local maize shellers ranged from 0.21 to 2.13%. Furthermore, estimates given by Hodges (2012) were that 10% - 20% quantitative grain losses occurred before commencement of processing.

The provision of machine hire services for post-production operations is becoming more popular in the study districts. Under this arrangement entrepreneurs provide postharvest handing services to farmers for operations such as shelling of maize. The efficiency of machines is better than the traditional methods of shelling using hands and manual dehulling using pestle and mortar. Due to lack of mechanization in Zambia and other developing countries, postharvest operations such as shelling are done by manually by smallholder farmers, (Abass *et al*., 2015 and Manandhar *et al*., 2018). Therefore, the use of machines in post-production operations should be encouraged (FAO, 2018).

4.9.2 Grain losses during maize shelling

The farmers reported that shelling was the stage of the value chain when most postharvest losses occurred for various reasons which included:

i. Damage due to beating by sticks;
ii. Spillage; and
iii. Destruction by cattle, goats and chickens if left unguarded during the day or t at night.

While shelling maize some farmers got overwhelmed by the large quantity of grain such that they did not mind some of it being eaten by animals or spilling (See figure 4. 6). Farmers reported that this was the stage where a lot of maize was lost. “For every 50 kg bag of maize packed we probably lose one to two medas (5 -10kg tins) due to spillage, damage by livestock such as chickens, goats and cattle. Where cattle are involved the loss is greater” revealed Ms Hilda Makaye of Kalomo. This sentiment was shared by farmers in the other two districts. This finding is supported by Abass *et al.,* (2015) who estimated that approximately 13 to 14% maize losses were recorded when processing was done manually due to spillage, mechanical damage, such as breakage, rupture and bruises. The practice of allowing some grain to be eaten by livestock was slowly changing as the harvests were getting low due to unreliable weather conditions. Female headed households whose harvests were comparatively lower than that of their male counterparts were more careful during shelling in order to minimize grain losses.

Farmers in the Philippines reported higher quantitative postharvest losses during harvesting and shelling operations. The results from the work done by Maranan *et al.,* (1996) and Salvador *et al*., (2012) as cited by Dela Cruz and Cacila (2016) showed that the postharvest operations with highest maize losses in the Philippines were drying and shelling.

Maize shelling in a raised platform in Kalomo

Maize hand shelling in Katete district

Maize shelling using a diesel sheller in Choma

Maize spillage during shelling in Choma district

Figure 4.6: Images of maize shelling and grain spillage in the study area. Source: (Author)

4.10 Quantity of Maize Produced by the Respondents

The results from this study show that 64 percent of the respondents produced 1 to 50 x 50 kg bags of hybrid maize, and 5% got 51 to 100 x 50 kg bags while 23 % did not grow this type of maize. With regard to local maize production, 50% of the respondents produced 1 to 50 x 50 kg bags while 16% and 11% got in the range of 51 to 100 and 101 to 200 x 50 kg bags respectively (see Table 4.4).

The high level of production of local maize can be attributed to high cost of fertilizers required for hybrid maize production. At the time of the study, farmers that were beneficiaries of the Farmer Input Support Programme (FISP) only accessed 2 x 50 kg bags of fertilizers which were not adequate to produce maize enough to meet their household food security. The Farmer Input Support Programme is a smart input subsidy whereby the Zambian government provides subsidized seed and fertilizers to vulnerable but viable smallholder farmers. Subsidies are smart when they aim at smallholder farmers who would not necessarily use seed and fertilizers in locations where economic yield reaction to inputs cannot be obtained (Smale *et al.,* 2011). In addition, such subsidy is meant to stir financing of input supply by private entrepreneurs and agro-dealers resulting in growth of a strong input supply system (ibid).

Table 4. 4: Comparative production quantities of hybrid and traditional varieties of maize.

Source: (Author)

Number of Bags	**Hybrid maize**	**Local maize**
	% Respondent	% Respondent
1 - 50	64	50.0
51 -100	5	16.0
101 - 200	0	11.0
201 - 300	0	2.0
301 - 400	0	6.0
401 - 500	0	1.0
Above 500	0	1.0
Not applicable	23	2.0
No response	7	6.0
Total	100	100

4.11 Type of Maize Grown by Gender

The study established that 59% and 41% of the male and female farmers in the study area grew maize respectively. The hybrid maize was mainly for the market while local maize was for home consumption. The maize grown by the smallholders was non - GMO because this type of maize in banned from production in Zambia.

4.11.1 Maize production rate by male farmers

With regard to the type of maize grown by gender the study established that 18% of the male respondents grew hybrid maize, 13% grew local maize while 37% grew both hybrid and local maize (see Table 4.5). The maize (both hybrid and local types) produced by male farmers was mostly for the market. It was easier for the male farmers to grow hybrid maize which uses high input levels because they could access commercial seed and fertilizer through the government supported Farmer Input Supply Programme. Male farmers could fford the cost of inputs as they raised additional money from a number of income generation activities such as doing piece work, dairy and commercial vegetable production. According to Nakweya (2014) five percent of male - headed households in Kenya experienced prolonged food insecurity compared with ten percent of the female-headed.

According to Gebre *et al.,* (2017) maize productivity of male-headed households was overall 44.3% higher than that of female-headed households.

Table 4. 5: Type of Maize Grown by Gender. Source: (Author)

Type of maize grown	**Gender**		**Total percentage**
	Female	**Male**	
	% respondent	% respondent	
Hybrid	13	18	31
Local	8	3	11
Hybrid and Local	20	37	57
No response	0	1	1
Total	41	59	100

4.11.2 Maize production rate by female farmers

Due to the prohibitive cost of commercial seed and fertilizers 73% (see Table 4.5) of the local maize under production was produced by female farmers as this type of maize guaranteed them a harvest even under low input conditions. The female farmers preferred to grow local maize because it produced heavier grains which had more mealie-meal than hybrids and produced tastier Nshima (thick porridge). Female farmers in the study area avoided hybrids because they easily got damaged by insect pests. The quantity of maize produced by some female headed households, however, was not adequate to see them through to the following crop harvest season. They usually ran out of food during the months of January to February. The reasons for the low production were lack of high yielding varieties, fertilizers and labour constraints. In addition, female headed households cultivated small areas due to land shortage. The coping strategies for mitigating against food shortage was through buying, engaging in food for work and borrowing from relatives. In addition, female-headed households at times sent their children to other farms to work for food or cash. The other sources of money for buying food included selling of vegetables or remittances from children or relatives that are in employment. According to Davis (2010) female farmers usually lacked control of production assets and technologies. FAO (1990) reported that female headed households were clustered on the poorer section of society and usually with fewer resources than male-headed households. The challenges faced by female-headed households were dependent upon the extent of access to capital. In addition, the absence of male labour had led to reducing crop productivity and production and thereby increasing dependence on child labour among female-headed households (FAO, 1990). As such, the availing of labour saving technologies to women is critical (ibid). According to Owotoki (2005) as reported by (Ashagidigbi *et al*., 2017), the gender disparities in revenue earnings, expenditure, consumption and control over assets and ownership were critical factors in household food security. Furthermore, female-headed households were more prone to food insecurity than male-headed households (FAO, 2011; Lutomia, 2019). According to Nakweya (2014) nearly ten percent of female - headed households in Kenya experienced prolonged food insecurity compared with five percent of the male-headed households. Female heads face numerous adverse situations in labour markets resulting in low crops yields and adverse outcomes on the livelihood of their households (Gebre *et al.,* 2017). However, if female headed households were given same resources as male-headed households, their productivity would increase by 42.3 % (ibid).

Kassie *et al.,* (2014) argued that female-headed households had less access to production assets, extension and health services. Furthermore, traditional practices which marginalised female heads or lowered the status of women and girls were the causes of the imbalances between men and women. The acknowledgment of the role played by women to agriculture and gender equity was cardinal to the attainment of food security in the world (Ashagidigbi, 2017).

4.12 Maize Marketing

The maize marketing outlets identified by respondents included grain traders (32%), Food Reserve Agency (FRA) (27%), combination of FRA and grain traders (16%), FRA and community members (8%). The market share for community members and millers was 3% and 1% respectively (see Figure 4.7).

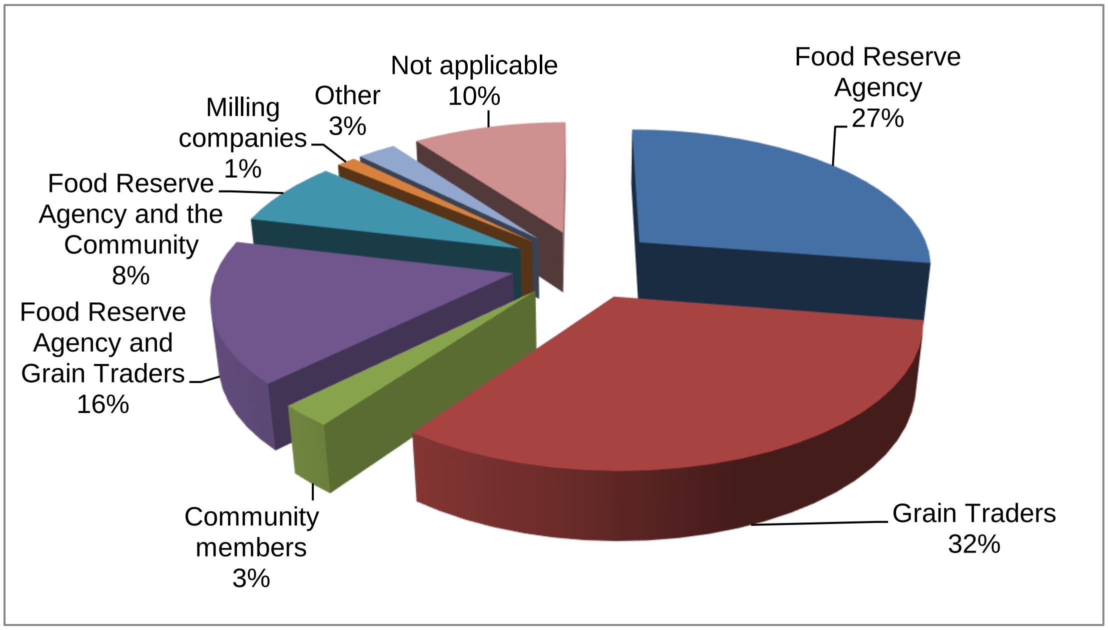

Figure 4.7: Maize marketing outlets. Source: (Author)

In a bid to cash on the high prices offered by millers to grain traders that delivered maize early in the season when the stocks from the previous seasons were low, some of the grain sold by farmers had more than 13 percent moisture content. The grain traders were willing buy grain with high moisture content because they paid a lower price. After sun drying such grain for up to five days it was ready for delivery to the millers or large grain storage facilities where it attracted premium prices offered at the beginning of the marketing season. Figure 4.8 shows images of sun drying of maize on tents at a marketing depot in Choma district and maize being traded at a depot in Katete District. Mburu and Massimo (2005) and Mango *et al.,* 2018 argued that smallholder farmers got lower prices for agricultural products compared to grain traders who get higher margins.

Maize drying prior to delivery to the market in Choma | Maize marketing depot in Katete

Figure 4.8: Maize drying and marketing at local depots. Source: (Author)

The maize grain buying depots were equipped with scales for weighing grain and samplers or maize probes for checking quality of the grain delivered by farmers (refer to figure 4.9 for the image of a sampler). When farmers delivered maize to FRA depots, it was sold in 50kg bags where as private buyers were not strict on weight of bags because their pricing was on kilogram basis. Therefore, when farmers delivered grain to FRA depots the bags had to weigh exactly 50kg otherwise such maize had to be re-bagged. During re-bagging there was grain spillage. The research further established that some unscrupulous farmers delivered rotten maize to the marketing depots hoping that it would not be detected. Figure 4.9 shows images of good quality grain and rotten maize delivered to marketing depots in Kalomo and Katete districts.

Figure 4. 9: Good quality and rotten grain delivered to marketing depots by smallholder farmers. Source: (Author)

Although the marketing of farm products is an important activity in rural development, smallholder farmers who are the main producers of maize still face marketing challenges in Zambia (Kaputo, 2008; Chapoto *et al*., 2015). The development of the smallholder farmer sector in sub-Saharan Africa mainly depends on the availability of ready markets (Mburu and Massimo, 2005). Some of the challenges faced by smallholder farmers include poor and impassable roads in most rural areas affecting transportation of maize to the market. Since farmers have to hire transport to deliver maize to the market their bargaining power is reduced due to the limited time spent of this activity and thereby getting low prices (Mburu and Massimo, 2005). The other marketing challenges are poor access to market information and inconsistent government policy on maize pricing resulting in farmers at times selling their maize at giveaway prices (ibid). Tefera *et al.,* (2011 b) estimated 20 to 30 % grain losses between the field and the marketing of maize in Kenya. This is within range given by Abass *et al*., (2015) for farmers in Tanzania that reported an estimated 25% to 40% crop loss between the field and marketing stages.

4.13 Quantity of maize marketed within 3 months after harvest

The research sought to establish the quantity of maize which smallholders off-loaded on the market within 90 days after harvest. According to Figure 4.10 nearly 75% of the respondents marketed up to 50 x 50kg bags of maize within three months after harvest. This was done to enable farmers have money to meet obligations such as school fees, medical bills, paying off debts and for domestic use. This maize was mostly sold to grain traders as the Food Reserve Agency usually delayed in commencement of crop marketing due to late release of money by government.

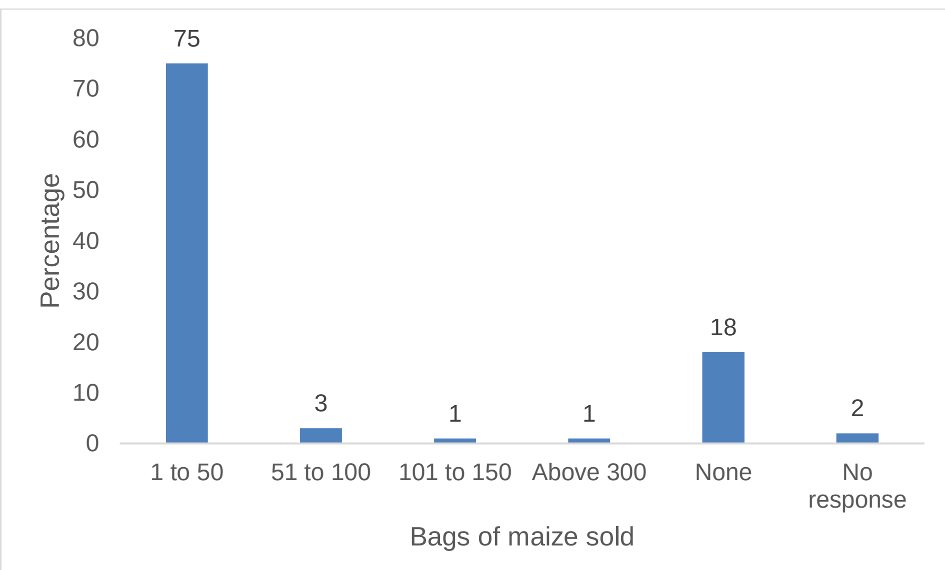

Figure 4.10: Bags of maize sold within 3 months after harvest. Source: (Author)

The finding that some smallholder farmers sold their maize soon after harvesting is supported by Stathers *et al.,* (2013) who reported that farmers sell their crops after harvest in order to raise cash for addressing the financial burden. Furthermore, Abass *et al*., (2015) found that smallholder farmers were bound to sell their crops soon after harvest because of cash needs for household expenditure. Hodges *et al.,* (2014) reported that a study conducted in Malawi by Schulten and Westwood (1972) established that the rate of postharvest losses between local improved and hybrid maize varieties differed considerably. During the first three months, losses were minimal. This explains why farmers opt to sell hybrid maize soon after harvest and retain local/ improved varieties for home use. Likewise, Stathers *et al., (*2013,) found that farmers who grew hybrid varieties of maize sold their crop soon after harvest due to susceptibility to storage pests.

4.14 Quantity of maize marketed beyond 3 months after harvest

As indicated in Figure 4.11, fifty one percent of the farmers sold up to 50x50 kgs bags of maize beyond three months after harvest. At this time of the marketing season, FRA is the preferred buyer due to the better prices it offers in comparison to that of grain traders. After three months from harvest there are few private sector buyers because maize becomes more expensive as its price gets bench marked against the price determined by government through the Food Reserve Agency. The practice of selling the entire crop after harvest and later in the year buying the grain back at higher prices contributes to rural poverty (Abass *et al*., 2015). Therefore, smallholder farmers should be encouraged to store their maize until prices rise so that they can improve retains to investment (ibid). The majority of farmers in Tanzania marketed most of their maize soon after harvest to traders while the remainder was sold in distant markets where the crop was transported by animal drawn ox- carts, head-loads and motor vehicles (Abass *et al*., 2015).

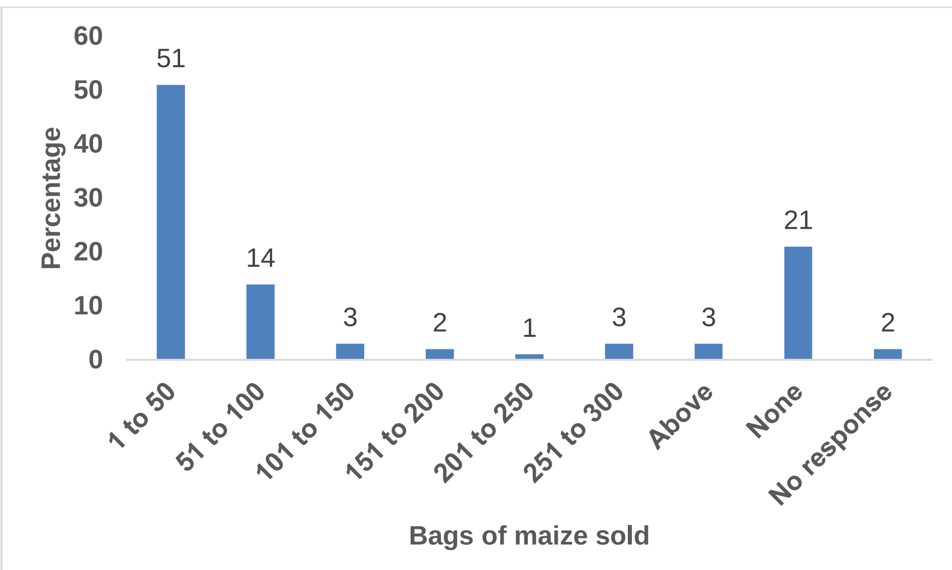

Figure 4.11: Bags of maize sold beyond 3 months after harvest. Source: (Author)

4.15 Labour Requirement for Postharvest Activities

4.15.1 Hired labour

Labour is a critical input in postharvest activities as farmers that had access to both family and or/ hired labour completed the value chain activities faster. According to this study 26 % of the respondents were dependent on hired labour while 64% used family labour for undertaking post-harvest activities. Twenty percent of the respondents hired more than three workers to help with harvesting and shelling of maize. During focus group discussions women reported that female-headed households mostly used family labour as they could not meet the cost of hired labour. Women hired male labour for operations such as ferrying of maize from the field to the homestead using ox-carts, placement of maize cobs on raised platform for dying, and loading of bags into ox-carts or trucks for transportation to the market. Men were further hired for post-harvest activities such as mixing grain with insecticide dusts like Actellic 10% because of its labour intensiveness.

4.15.2 Family labour

The study established that 97 percent of the respondents reported family members being involved in postharvest activities such as harvesting, transportation of produce from the field, shelling, winnowing, bagging, storage, marketing and control of storage pests. Women spent more time than men in postharvest activities because the latter were involved in other livelihood activities. During focus group discussions, the women revealed that in recent years there had been an increase in the number of men involved in postharvest activities particularly bagging, storage, marketing and control of storage pests due to gender trainings organised by NGOs.

4.16 Ranking of Postharvest Losses of Maize from Harvesting to Marketing

Postharvest losses occurred at all stages of the value chain from harvesting to marketing. In response to the question which required respondents to rank postharvest losses along the value chain, the smallholders reported that they experienced different levels of post-harvest losses along the value chain. Seventy four percent of the respondents graded post-harvest losses at harvesting to have been high to extremely very high. Post-harvest losses during transportation from the field to the homestead were considered to be high to extremely very high by 50% of the smallholders. Eighteen percent of the respondents were of the view that postharvest losses during grain drying were high to extremely very high. The shelling operation was rated as high to extremely very high by 77% of the smallholders. Postharvest losses during storage and transportation to the market were judged to be high to extremely very high by 14% of the smallholders. This suggested that most of the postharvest losses of maize occurred during shelling and harvesting operations. Figure 4.12 gives summarized information on levels of post-harvest losses of maize experienced by the smallholders from harvesting to marketing. A study conducted in Ghana reported farm handling losses of 8.33%, transportation losses of 0.33% and warehouse losses of 15.74% resulting into total handling losses of 24.40% (Alhassan and Patrick, 2018).

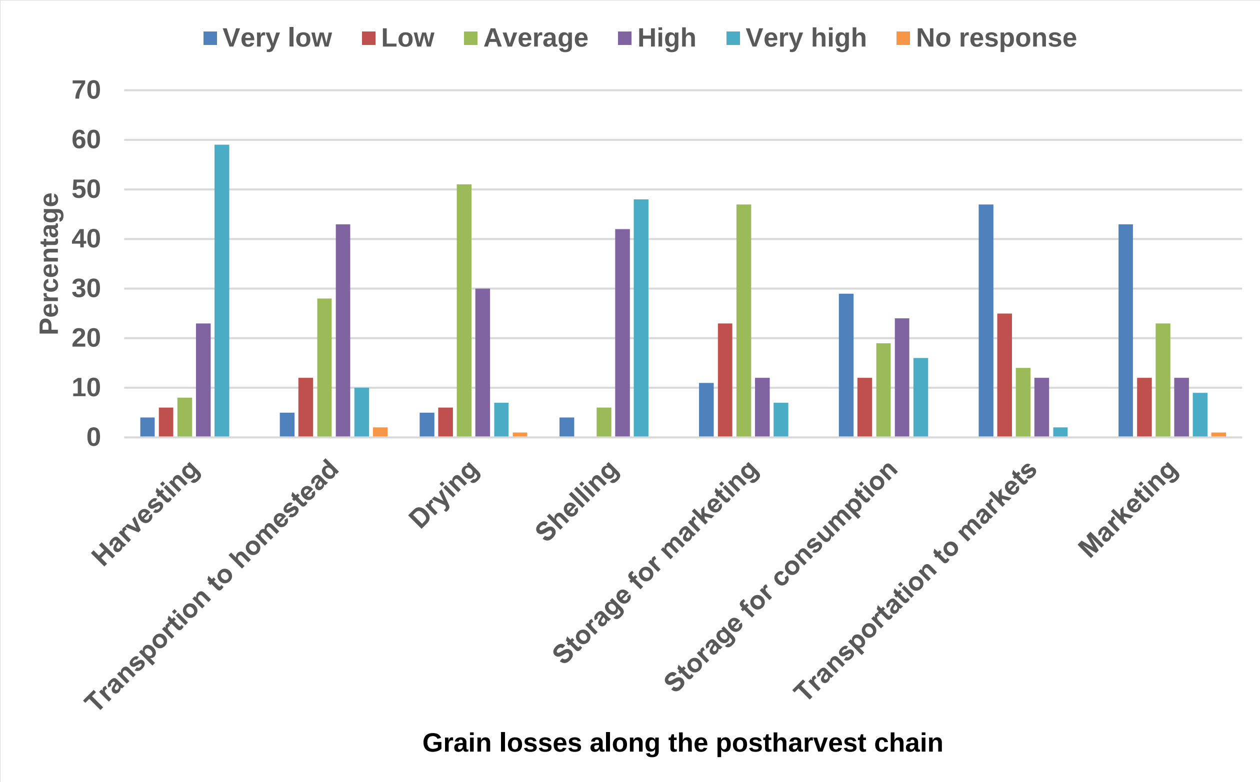

Figure 4.12: Postharvest losses of maize experienced by the smallholders from harvesting to marketing. Source: (Author)

Detailed analysis of the postharvest losses through ranking established that major losses occurred at shelling, harvesting, and transportation from field to homestead and drying. Other losses occurred at storage for consumption, during marketing, storage after harvest and transportation to market. The ranking of postharvest maize losses experienced by respondents which is summarized in Table 4.6 was as follows:

Ranked number 1: Grain losses during shelling

With regard to the guess estimates of postharvest losses incurred along the value chain, the respondents reported that they experienced the highest grain losses during the shelling operation. According to a study conducted in Ghana, the estimated average postharvest losses of unpicked maize was 1.6 % while 6.6% was due to poor shelling methods by farmers while transportation losses were 2.5 % (Alhassan and Patrick, 2018).

Ranked number 2: Post harvest losses during harvesting

The harvesting operation was ranked second in terms of the stage of the value chain where postharvest losses occurred particularly when farmers did not practice stooking. The smallholders considered the practice of maize stooking better for minimizing losses because the cutting and heaping of maize stalks created a cleaner field which made it easier to see any cobs of maize which might have dropped to the ground. The farmers that did not practice stooking were of the view that cutting and heaping of maize stalks was time consuming, and this was more common among female-headed households which were labour constrained.

According to Abass *et al*., (2015) maize losses during harvesting were estimated at 1.5% in Northern Tanzania. In related studies, maize farmers in Ghana reported high post-harvest losses during harvesting operations of about 37% of the overall postharvest operations.

Ranked number 3: Maize losses during transportation from field to homestead

Transportation of maize from the field to homestead was ranked as the third stage of the value chain where losses occurred. Farmers transported maize from the field to the homestead using ox-carts, head-loads and bicycles. According to Sawicka (2019) transport was an important operation of the grain supply chain, as produce has to be moved from the field to processing plants, from the field to warehouses, and processing plants to the market. Men normally transported maize using ox-carts and bicycles while head-loads are common among women and children (ibid). The losses which occurred during transportation were mainly spillage of grain or cobs dropping from ox-carts (Sawicka, 2019). Kumar and Kalita (2017) reported that in developing countries, poor road infrastructure along with the improper and poorly maintained modes of transportation results in large grain spillage and high contamination. Grains are usually transported in bags on bicycles, small motor vehicles, open trucks or bullock carts (Kumar and Kalita, 2017; Sawicka, 2019). They further revealed that due to the poor quality bags commonly used during transportation and even storage, there were high spillage rates due to leakage from the bags. Similarly, Abass *et al.,* (2015) established that in Northern Tanzania approximately 2.5% crop losses occurred during transportation from the field to the homestead either by bicycles, ox-carts and head-loads.

Ranked number 4: Postharvest grain losses during drying

The period of drying was another stage of the value chain in which maize was lost. In cases where the maize was placed on the ground before packing in the raised platforms, it was attacked by cattle, chickens, goats, pigs, termites and rats. Even when maize was dried on raised platforms, losses still occurred if the floors of these structures are not well built and in cattle rearing areas the animals use their horns to get the maize down. The grain meant for marketing later during the year and that retained for home consumption was dried for two to three months. Farmers found it difficult to make a self- assessment of losses suffered during this phase of the value chain. In cases where insect pests infested the maize while in the field, substantial losses occurred during drying due to lack of insect pest control measures. In related studies, Calverely (1996) found that maize dried on raised platforms in Zambia and Zimbabwe experienced 3.5% and 4.5 % losses respectively as cited by Rembold *et al.,* 2011; Abass *et al*., 2014 and Kumar and Kalita, 2017.

Ranked number 5: Maize losses during storage for home consumption

Maize losses during storage for home consumption was ranked fifth by the respondents. During focus group discussions there was divided opinion among respondents about the level of losses. The farmers that considered losses to be high based their argument on the fact that the grain damage by insects in some cases resulted in total destruction of the grain, particularly in the case of severe infestation by weevils. With regard to estimated losses incurred during storage of grain for home consumption, nearly 50% of the farmers reported that storage losses varied from extremely very low to moderately low while the rest gave a range of moderately high to extremely very high. Farmers that applied chemicals to protect the maize from weevil damage were the ones that reported low storage losses. The self-estimated losses given by farmers in Katete district were that for every 7 x 50 kg bags (one ox-cart load) of grain stored in the Nkokwe, at least 1x 50 kg bag would be lost while in Choma and Kalomo districts the estimates were around 20 to 30 kgs. Observation of the maize stored in the Nkokwe in Songwe Village of Katete during the month of October showed more than 50% weevil infestation. The farmers reported that the maize grain which was infested by insect pests in October would completely be damaged by December - January leading to a loss in value, quality and quantity. What saved farmers from incurring more severe grain losses was that since the harvests were so low, there was little grain to be lost beyond January as by that time most households would have run out of maize.

Crop storage plays an integral part in ensuring domestic food supply (Thamaga-Chitja *et al.,* 2004). Storage is a method or practice of preserving agricultural products for future usage; it's a provisional period during shipment of agricultural produce from farmers to processors and from processors to consumers (Nukenine, 2010; Thamaga-Chitja *et al.,* 2004,). With regard to smallholder farmers in Africa, the major reason for storage was to guarantee household food security (Nukenine, 2010). According to Hodges *et al.,* (2014) farmers that store maize for 2 to 9 months suffer postharvest losses of 13% to 18% and in larger grain borer infested areas, the figures of grain losses are 13% to 22%. Kumar and Kalita (2017) found that as a result of technical inefficiency, 50%-60% of cereal grains can be lost during storage in developing countries. However, grain losses can be reduced to 1%-2% with the application of modern technology. Adams and Harman (1977) as reported by Hodges et al., (2014) measured storage losses in Zambia and found 4-5% weight losses. Further research on maize in Kenya (De Lima 1979) and Malawi (Golob 1981a&b) as cited in Hodges *et al*, (2015) upheld that grain weight loss during the normal 9 month storage period was 2-5%. Although there are a multiple causes of postharvest losses, poor storage, lack of training and limited data are considered to be the key drivers (U.S. State Department, 2013). In the case of cereals, microorganisms such moulds and bacteria, insects and rodents are responsible for most of the losses (Kumar and Kalita, 2017; Lipinski *et al.,* 2013; Mendoza *et al*., 2017b and World Bank, 2011).

Ranked number 6: Postharvest losses of maize during marketing

Postharvest losses of maize during marketing was ranked 6th by the farmers. They reported that they did not experience any significant grain losses during marketing of maize in distant markets. Occasional spillage losses occurred if bags of maize burst open due to poor handling. Farmers that failed to meet the standard set by FRA for buying maize suffered spillage losses caused by re-weighing of grain into 50 kg bags. Access to agricultural markets by smallholder farmers is essential for energising agricultural expansion, improvement and as well as for the reduction of postharvest losses (Dorosh *et al.,* 2012; Tefera 2012) as reported by Hengsdijk and de Boer (2017).

Ranked number 7: Storage before marketing

With regard to losses during storage, this stage was ranked 7th by respondents who considered it low because the grain was usually stored in bags and placed in dwelling houses. Grain bags kept outside storage structures were more prone to damage by rodents, pigs, goats and cattle in livestock rearing areas. Some of the stored grain is sold when the market prices become more attractive (Nukenine, 2010; Thamaga-Chitja *et al.,* 2004).

Ranked number 8: Grain losses during transportation to the market

Grain losses during transportation to the market was ranked 8th by smallholders. Transportation of maize to the market was mainly by bicycles, ox-carts or hired motor vehicles. When farmers deliver maize to distant markets, they hired vehicles. In line with COMCEC (2016) farmers used ox-carts to transport maize to nearby markets. The farmers reported that grain losses during transportation to the market were very minimal unless where damaged or old poly bags were used. Kumar and Kalita (2017) confirmed that leakage of grain from poly bags during transportation to the market in developing countries resulted in postharvest losses. This finding is confirmed by Hodges (2012) who found that maize losses during transportation from the store to the market was 1% in Madagascar and that this was the figure commonly quoted in literature. The distance from the farmers' household to the main road and market were factors associated with postharvest losses in Ethiopia (Hengsdijk and de Boer (2017). They further found that households living further away from a main road or market suffered more losses during transportation to the market.

Table 4. 6: Ranking of postharvest losses by respondents. Source: (Author)

Postharvest chain	Average	Moderately high	High	Very high	Extremely high	Total score	Av. score	Rank
Harvesting	6	8	15	47	12	88	17.6	2
Transportation to homestead	9	19	29	14	7	78	15.6	3
Drying	31	19	11	5	2	68	13.6	4
Shelling	13	29	17	31	0	90	18	1
Storage before marketing	20	5	7	4	3	39	7.8	7
Storage for consumption	9	10	11	13	8	51	10.2	5
Transportation to market	7	7	5	7	2	28	5.6	8
Marketing	18	5	6	6	9	44	8.8	6

4.17 Training Received by Respondents in Postharvest Management

Fifty-three percent of the respondents had not received any training in postharvest management. Forty-seven percent of the respondents had attended one or two-day workshops or meetings conducted by mostly government extension agents (see table 4.7). During these trainings there was hardly any reading or reference materials given to the farmers. Of the farmers that were trained 46% reported that the training had been beneficial as it increased their knowledge about storage pests and the methods of control. The explanation given by the other respondents was that the trainings had been for very short duration for them to have grasped something they could apply on their farms. Demonstrations of some of the technologies used to reduce postharvest losses would have been more useful. Some farmers got information on postharvest management from neighbors that had been trained or listened to radio programmes. The provision of training in postharvest management is cardinal in reducing postharvest losses (Kitinoja *et al.,* 2011).

Table 4. 7: Training in postharvest management. Source: (Author)

Gender		Have you ever been trained in postharvest management		Total
		Yes	No	
What is your gender	Male	37 78.7%	22 41.5%	59 59.0%
	Female	10 21.3%	31 58.5%	41 41.0%
Total		47 100.0%	53 100.0%	100 100.0%

4.16. 1 Training in postharvest management received by male farmers

The male farmers in the study areas had some information about postharvest management which they received during the trainings organized by agriculture extension staff. Of the 47% of smallholder farmers trained in postharvest management 79% were men. The training courses organized by government extension services tend to be male dominated because most of trainers are male. Most male farmers don't send their wives to such trainings as they are not comfortable to have them trained by male extension workers. The male farmers reported that they dominated the training programs because traditionally extension training focused on cash crops where men were more involved than women. Furthermore, there was unsupportive infrastructure at training centers for women and children. The women could not easily leave the household because of the daily domestic workload.

The male farmers reported that they dominated the training programs because traditionally extension training focused on cash crops where men were more involved than women. Furthermore, there was unsupportive infrastructure at training centers for women and children. The women could not easily leave the household because of the daily domestic workload. In sub - Saharan Africa agricultural training, research and development is tailored to men's needs (Walker, 2015).

4.16. 2 Training in postharvest management received by female farmers

The study findings showed that knowledge in postharvest management was very low among female farmers as trainings organised by the extension service had mostly been attended by men. As indicated in Table 4.7 twenty - one percent of the smallholder farmers trained in postharvest management were female. The low number of trained female farmers was consistent with an FAO report which highlighted the fact that although women provide more than 50% of the labour force to agriculture in sub - Saharan Africa they were usually not able to participate fully in trainings due to the heavy work load (FAO, 2015). Kaminski and Christiaensen (2014) argue that education combined with easy access to markets can greatly reduce postharvest losses. In addition, capacity building of farmers in postharvest management can reduce postharvest losses (AUC-FAO, 2012). The incorporation of postharvest information in the school curriculum and extension service training plans can assist to place prominence on prevention of losses, maintenance of quality and nutritive value after harvest and guarantee food safety (Kitinoja *et al.,* 2011). Nakweya (2014) argued that if women were provided with support and training in the adoption of improved farming methods, female-headed households could become food secure. Kassie *et al.,* (2014) argued that less training and educational opportunities for women was another contributing factor food insecurity. Therefore, factors that prevent women farmers from participating in the agricultural training programs should be considered when planning for any training activities.

4.18 Revenue Reduction Due to Postharvest Maize Losses

The issue of whether farmers considered post-harvest losses as a loss in revenue or food security generated varied responses. Sixty three percent expressed the view that postharvest losses were a reduction in their income. The 37% that had a different view, said that prior to this study, they had never related grain loss to income. Since the spillage of grain was a normal occurrence during harvesting, transportation, drying, shelling and marketing which farmers had experienced since childhood, they had never related it to money loss. Grain spillage, therefore was something they expected to happen every harvesting season.

The financial side of food loss reduction is not yet well understood (Goldsmith *et al*., 2015). For example, it's rather difficult to comprehend why farmers tolerate losses or even deliberately enhance crop losses in their operations (ibid). Kitinoja *et al.,* (2010) points to the lack of clear evidence on the financial gains accruing from reducing postharvest losses. De Gorter (2014) argues that farmers' income was influenced by a reduction in postharvest losses due to an increase in the quality and quantity of grain available for sell. Furthermore, De Gorter (2014) cautions that since trying to achieve the desired postharvest loss reduction levels might be too unrealistic, it might be more judicious investing in other hunger eradicating approaches. However, other scientists call for a need to measure the cost associated with investment in postharvest loss reducing technology and the anticipated returns (Rosegrant *et al*., 2015).

4.19 PHL Reducing Technologies Used in the Study Area

The farmers in the study areas used chemicals such as Actellic Super and Aluminium phosphide and to a small extent natural additives such as leafs of *Gliricidium sepium,* ashes and cow dung. Due to inadequate knowledge about chemical control measures, some farmers did not apply any chemicals for fear of being poisoned and lack of conviction about the safety of treated grains. There was exposure of smallholder farmers to harmful fumigants such as aluminium phosphide which were supposed to be handled by trained personnel. Manandhar *et al.,* (2018) found that in many countries, phosphine was handled by licensed personnel. The study further noted the misuse of fumigants as they were applied for preventive rather than curative purposes.

According to Nagnur *et al.,* (2006), Murdock (2003) as reported by Manandhar *et al.,* (2018) smallholder farmers mix the maize grain with chemicals and natural preservatives such as plant leafs and ashes. Furthermore, the use of chemicals and different additives together with the traditional storage systems can protect grain from pests such as mould, insects and rodents. Manandhar *et al.,* (2018) and Hodges (1986) report that methyl bromide and phosphine or phostoxin (commercial name) are used as fumigants for stored grain in metal silos, cemented or mud plastered granaries in developing countries. Insects such as *Prostephanus truncatus* can easily be controlled using fumigants in grain with less than 13% moisture content. However, Abass *et al., (*2017) argue that the use of insecticides to staple foods should be avoided. Maize treated with Actellic Super is not liked by smallholder farmers because they consider it to have a different taste from that of untreated maize (ibid).

The study further established that although a broad range of technologies and practices were available which would improve the quality and reduce the quantity of grains lost during postharvest handling and storage (World Bank *et al.,* 2011; Kiaya 2014) the smallholder farmers were not aware about availability and associated benefits and cost of these innovations. The available technologies included the hermetic storage airtight or sealed storage, metal silos, plastic drums, burnt brick bins, and cemented bins (Ferrumbu) and pesticides. Other solutions included training in improved grain handling and storage and creation of institutional arrangements such as the warehouse receipt system (WRS).

4.20 Ranking of Postharvest Loss Reducing Technologies and Practices Used by Farmers

The determinants of the technology choice included the level of production, climatic conditions and willingness and capacity to pay, which had social, educational, cultural and economic implications of adoption. Therefore, the identification and elimination of constraints to the application of existing technologies is a prerequisite to the reduction of postharvest losses. The study attempted to confirm the practices and technologies which farmers were using to reduce postharvest losses. The responses made by the respondents are summarized in Figure 4.13 while the Table 4.8 provides a simple ranking of practices and technologies used by the smallholder farmers in reducing postharvest maize losses.

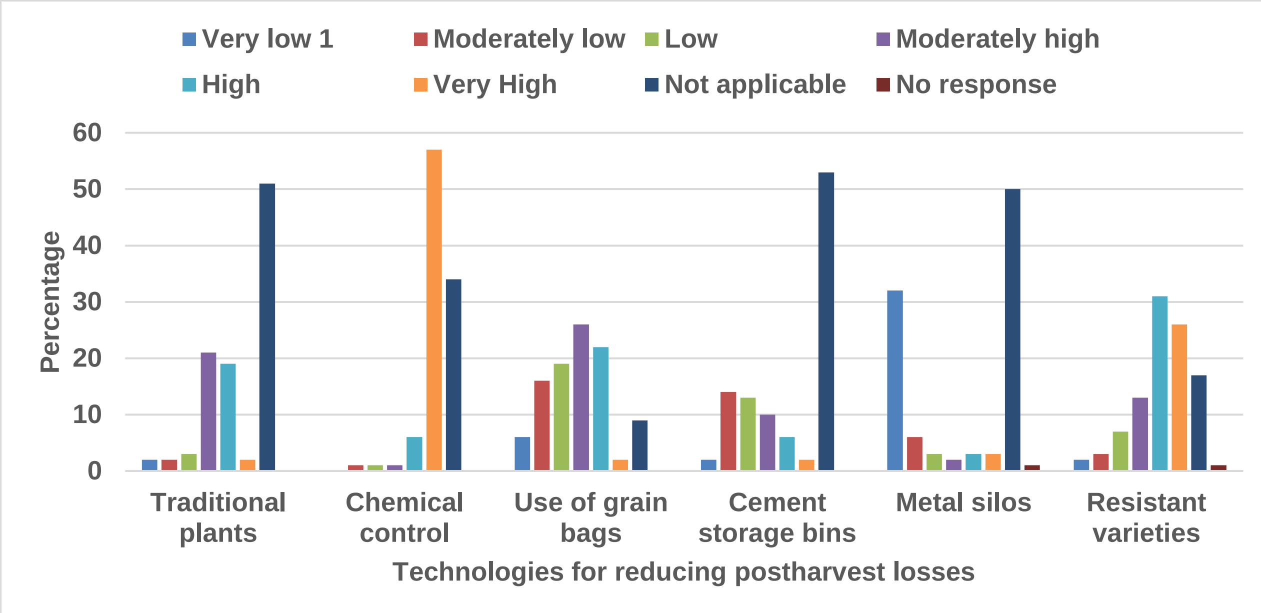

Figure 4.13: Postharvest loss reducing technologies used by smallholders*. Source: (Author)*

According to Table 4.8, the use of polythene bags was the most common technology used by farmers to reduce post-harvest losses. This was not surprising because farmers are advised by Ministry of Agriculture staff to use new polythene bags for packaging of maize for the market. Furthermore, the Food Reserve Agency of Zambia has in recent past distributed polythene bags to those farmers wishing to sell their maize to the Agency. The growing of local varieties of maize was the second most important practice used to reduce postharvest losses because of its tolerance to storage insects. The use of chemicals to control insects which cause postharvest grain losses was ranked third.

Table 4. 8: Ranking of postharvest loss technologies by respondents. Source: (Author)

Technology	moderately low	low	moderately high	high	very high	Total	Average	Rank
Chemical control	1	1	1	6	48	57	11	3
Plant extracts	2	3	21	1	2	29	5.8	5
Poly bags	16	19	26	22	2	85	17	1
Brick/cement bins	14	13	10	6	2	45	9	4
Metal silos	6	3	2	3	3	17	3.4	6
Resistant varieties	3	7	13	31	26	80	16	2
other	0	0	0	2	1	3	1	7

4.21 Adoption of Recommended Postharvest Loss Reducing Technologies by Respondents

The study sought to establish reasons for the low adoption of the recommended postharvest loss reducing technologies among smallholders. The justification given by the respondents for the low technology adoption was ranked and Figure 4.14 provides a summary of their responses.

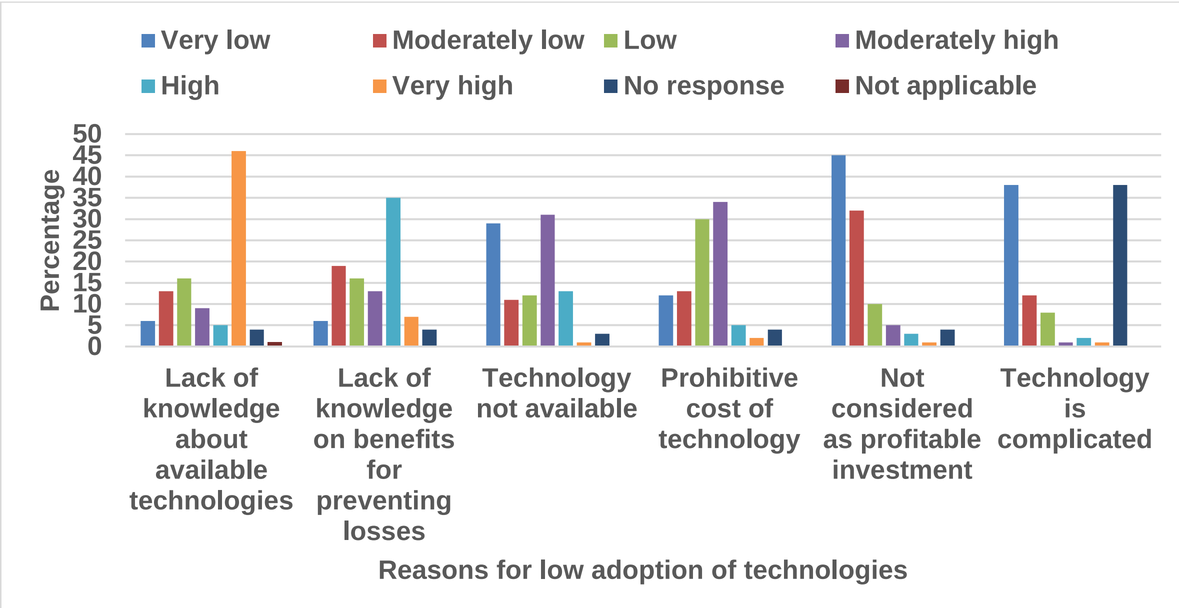

Figure 4.14: Respondents' reasons for low adoption of postharvest technologies. Source: (Author)

The challenges faced by the smallholder farmers in the adoption of postharvest technologies were used in creating the ranking presented in Table 4.9.

Table 4. 9: Ranking of challenges faced by smallholders in adopting postharvest loss reduction technology. Source (Author)

Justification	Moderately low	Low	Moderately high	High	Very high	Total	Average	Rank
Lack of awareness	13	16	9	5	47	90	18	1
Lack of knowledge on benefits	19	16	13	35	6	89	17.8	2
Prohibitive cost	13	30	34	5	2	84	16.8	3
Technology not available	11	12	31	13	1	68	13.6	4
Unprofitable investment	32	10	5	3	1	51	10.2	5
Complicated technology	12	8	1	2	1	24	4.8	6
Other reasons	0	1	0	0	0	1	0.2	7

The factor which was ranked first for the low adoption of postharvest loss reducing technologies was lack of awareness about the available technologies followed by lack of knowledge regarding the benefits of adopting the same by smallholders. During focus group discussions, the respondents confirmed that lack of awareness about the available postharvest reducing technologies was the major reason for the low adoption.

"*Kwiina mbonga waula chibelesho nchotana bona. Alimwi welede kuziba mpindu njonga wajana na wachuula echo chibelesho. Tachuulwi ma ulwa ." (There is no way in which a farmer can buy a technology which they are not aware of its existence. In addition, once a farmer is made aware of the existence of a technology, they need to be clear about the benefits of using such technology and the associated cost. It's not just a matter of investing into technology but a farmer has to be very clear about what they are about to spend money on")* underscored the farmers in Choma district during focus group discussions.

The third factor advanced for the low adoption of technologies was the anticipated prohibitive cost. During focus group discussions, the farmers said that their view about any new technology was that it would be too costly. For example, during the period of promoting the ferrumbus, the adoption of this technology was low because of the cost of the cement and chicken wire mesh which were the main materials needed for construction. Therefore, the farmers used their past experience on ferrumbu construction in assuming that the cost of the new technologies for reducing postharvest losses would be too prohibitive.

The unavailability of the technology was ranked fourth. The argument by the farmers was that if the technologies for reducing postharvest losses were readily available, they would have been stocked in the local agro- shops. The farmers did not consider it profitable to invest in technology for reducing postharvest losses. The perception that the technology was too complicated was ranked last. Some of the technologies such as pesticides whose application required mixing with grain was given as an example of a complicated technology because it required making calculations on mixing and required male labour.

"Ife azimayi timavutika ku sankaniza Shumba ndi chimanga. Ntau zambili, tima lipila azibambo kuti atitandize nchito yemwe iyi" (Women face challenges when mixing actellic dust with maize grain due to its labour intensiveness. As a result we have to pay men to treat our maize with insecticides) lamented the women of Songwe village.

4.22 Amount of Money Farmers Were Prepared to Invest in Postharvest Loss Reducing Technologies

With regard to investment in postharvest reducing technologies, nearly all the respondents were of the opinion that since technology was meant to assist them increase income and food stocks, it was worthwhile investing in its acquisition. The challenge that the farmers had regarding investment into technology was lack of awareness of its existence. As of October 2017, there were no agro-shops in Choma, Katete and Kalomo towns that were stocking technologies such as PICS or ZeroFly bags, metal or plastic drums. Of the 100 farmers interviewed only one farmer in Katete District had used PICS bags whereas 5 others used either metal or brick- silos. In Choma District, only one farmer had built a cement plastered silo. With regard to use of metal ox-carts for transportation of maize, this was mostly popular among farmers in the Batoka area under Choma District.

The farmers were of the view that improved access to information on the existence of technologies, the benefits, operation and cost would assist them in deciding on the levels of investment to make. About 70% of the respondents were willing to invest between 100 - 1000 ZMW (10 - 100 US$) while 28% would consider spending 1,000 - 5, 000 ZMW (100 - 500 US$) in technologies for reducing postharvest losses. (See figure 4.15).

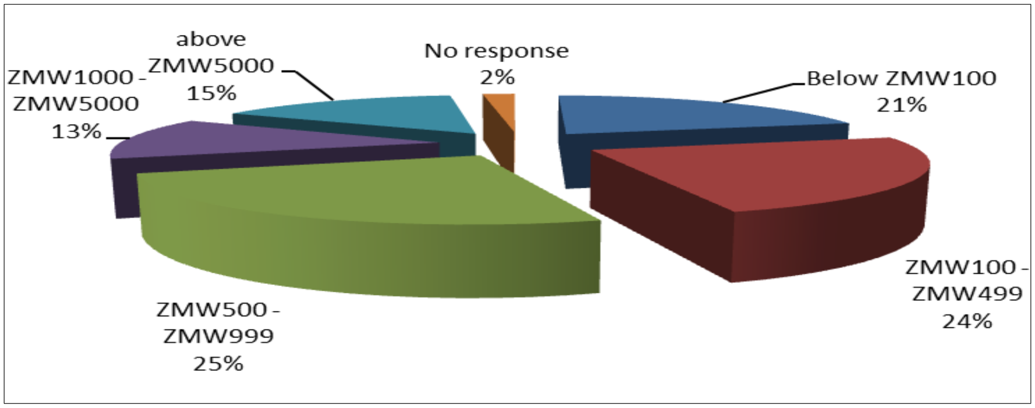

Figure 4.15: Proposed investment levels in postharvest technologies. Source: (Author)

This was a positive response because most of the time farmers want to be given free handouts from government, under what is locally referred to as, "government delivering development to the people". The wish of the farmers was to have easy access to technology for reducing postharvest losses similar to the way mobile phone technology had become accessible to people in the villages. The farmers' desire to own postharvest reducing technology can be summarized by the question asked by a grain trader in Choma and I quote; "*How come there is no machine which works like a magnet that can be used to pick up spilled grain*?"

Farmers particularly in Choma and Kalomo districts were interested in investing in technology for reducing postharvest losses because they could easily raise capital from their beef and dairy enterprises. The task at hand for the technology manufacturing companies, technology suppliers and their agents is to improve information dissemination about the available technologies.

4.23 Maize Storage Pests

When farmers were asked about storage pest damage, 96% reported their maize being attacked by a variety of pests such as maize weevils (*Sitophilus zeamais*,) larger grain borers) (LGB), (*Prostephanus truncatus*), rats (*Rattus ratus*), *and termites Microtermes spp*: *Isoptera*: Microtermitidae and fungi.

Besides weevil attack, the maize was further infested by a caterpillar which could not be identified by the farmers as they had never seen it before. Since the growing maize crop had been attacked by a new pest called *Tuta absoluta*, the farmers assumed that it was the same pest destroying the grain. Even the grain traders in Katete town had a problem with this pest which could not easily be killed by chemicals. After sending samples to the Centre for Agriculture and Bioscience International (CABI) it was confirmed that the pest was larvae of the larger grain borer (*Prostephanus truncatus*).

According to Mihale *et al*., (2009) insects are responsible for 15 -100 % and 10-60 % of the pre and post-harvest losses of grains in developing countries respectively. Shiferaw *et al.,* (2011) report that maize is attacked by many insect pests during all stages of growth to storage. In related studies, *Sitophilus* zeamais, *Prostephanus truncatus, Rhyzopertha dominica* and *Sitotroga cerealella* were reported in some parts of Ghana to be the main cause of damage of stored products (Opit *et al.,* 2014). According to Bhusal and Khanal (2019) the maize weevil (*Sitophilus zeamais* Motsch.) and Angoumois grain moth (*Sitotroga cerealella*) were the most important insects in stored maize. However, Smith (2015) reported that Africa was unlikely to benefit from the current massive funding to agriculture unless the disturbing role of pest occurrences, particularly the sudden outbreak episodes were dealt with. The researcher further argued that agricultural systems will continue to be under pressure as the incidence of crop pests fluctuates and the regularity in the upsurge of sudden pest epidemics escalates due to influence of climate change. Different statistics propose that one sixth of the global food production is lost due to pest attack in the field and further losses which occur in storage (Smith, 2015).

About thirty species of insects commonly infest grain and that most of these are either beetles or moths although there are some other types (Befikadu, 2018). A storage pest in a grain store is any creature that causes some loss in the quantity and/or quality of grain (ibid). The worst pests cause the greatest financial losses by increasing the cost to farmers and grain handling companies or authorities through pest control (Emery and Cousins, 2018). The most common pests in grain stores are insects and there are many different types with the maize weevil being a typical pest species (Bhusal and Khanal, 2019). Some of the pests are very important because they can cause big financial losses; others are much less important and do little or no damage (ibid).

Most insects found in stores have a remarkable capacity for rapid population growth (Jian, 2018). However, the initial invasion of a commodity is by relatively fewer insects. Pests such as grain weevils may increase in number by nearly one hundred times in each generation when conditions are favorable (USDA, 2015). For grain weevils this means temperatures of between 28°C and 35°C and grain moisture content between 12% and 15 *% (*Emery and Cousins, 2018). Furthermore, Suleiman *et al.,* (2018) found that grains with less than 10% moisture content are not attacked by maize weevils. In stored food population, growth is not at its maximum for a long time because conditions within the grain store become unfavorable once a substantial population has developed (ibid). Overcrowding of insect pests causes production of excess heat and moisture which will eventually slow population growth and force the insects to migrate from the grain to find a fresh source of food (Emery and Cousins, 2018).

According to literature, postharvest losses have been ascribed to storage pests with the maize weevil [*Sitophilus zeamais* (Motsch.)] contributing 10 - 20% of the losses whereas the larger grain borer [(*Prostephanus truncatus*) (Horn)] causing between 30-90% of the losses (Nhamucho, *et al.,* 2017). Furthermore, Muatinte *et al.,* (2014) report that *Prostephanus truncatus* has caused 60% yield loss in maize and cassava chips whereas losses of up to 45 % to 100% have been recorded in West Africa. The pest flies from heavily populated or food deficit environments to new hosts, which are usually farmers storage facilities. Crops such as maize and dried cassava get attacked either randomly or due to already existing infestation where the males are releasing pheromones (Nhamucho *et al.,* 2017). *Prostephanus truncatus* (Horn) normally gets attracted to maize and cassava over short distances. Studies have demonstrated that there is no long-range attraction of the adult pest to maize cobs or grain or cassava. This arises from the fact that wood is the major host of this pest. In a period of 20 years after introduction of *Prostephanus truncatus* in Kenya, the weight loss of maize in storage increased from 4.5% to 30% (Nukenine, 2010).

4.23.1 Maize weevil (*Sitophilus zeamais* Motschulsky)

4.23.1.1 Pest status

The maize weevil is a serious primary pest of whole cereals and can cause substantial weight losses amounting to 5-10%, sometimes more (Bhusal and Khanal, 2019). The maize weevil is a common pest in tropical and sub-tropical regions (Suleiman *et al.,* 2015). Heavy infestation of adult and larvae of maize weevil causes postharvest losses which have become increasingly important constraints to storage entomology and food security in the tropics (Ojo and Omoloye, 2016). Weight losses of about 30 to 40 % of agricultural products may occur in heavy pest infestations (CABI, 2005). Both adults and larvae feed internally on maize grain and infestation may start in the field (while the cob is still on the plant) but severe damage happens in storage (ibid).

4.23.1.2 Development of maize weevil

As a primary pest of stored maize, the weevil is capable of penetrating the whole kernel of grain in which immature stages develop leaving the maize emptied of its seed and nutritional values, resulting in outright loss of visual appeal in local and international markets (Nwosu, 2018). The female maize weevil excavates a hole in the grain where it lays an egg and seals it in place with a waxy egg plug. Development period varies from about 35 days under optimal conditions to over 110 days in unfavorable conditions (Akol *et al*., 2011). Eggs, larval and pupal stages are all found inside the tunnels and chambers bored in the grain and are as such not usually visible (ibid). According to Suleiman (2018) pupae development happens within the kernel and under ideal conditions ranging from 27°C and 31°C and 40% to 75% relative humidity, the life cycle of the maize weevil takes 5 to 8 weeks to complete. The type of food in combination with the existing environmental conditions play a significant role in the body size of the maize weevil, since fundamental nutrients influence the metabolic activities in the insect pest (Ojo and Omoloye, 2016).

4.23.1.3 Anatomy of maize weevil

The maize weevil has a narrow snout-like forward extension of the head, which carries the mouthparts (Akol *et al.,* 2011). For image of maize weevil refer to figure 4.16. The antennae are “elbowed” in form, and are held in a right-angled position when the insect is at rest. The body colour can range from light to dark brown, and often has four large reddish-orange spots on the wing cases (Akol *et al.,* 2011; Mason and McDonough, 2011). The larvae of maize weevils are white, fleshy and legless (Akol *et al.,* 2011).

Figure 4.16: Image of maize weevil. Source: (Keyslucidcentral.org)

4.23.1.4 Economic importance of the maize weevil

According to literature the maize weevil, *Sitophilus zeamais* causes both qualitative and quantitative losses of stored maize grain in Africa (Ojo and Omoloye, 2016; Nwosu, 2018; Bhusal, 2019). The damage caused by the pest can result in maize grain weight loss ranging from 20% to 90% for untreated maize grain (Ojo and Omoloye, 2016). The extent of damage is dependent on factors such condition of storage structures, physical and chemical properties of the grain (ibid).

The maize weevil is the most serious pest of maize grain (Adedire *et al.,* 2011, Boxall 2002; Abass *et al*., 2014). Furthermore, according to Markham *et al.,* (1994) as reported by Tri Rahardjo *et al.,* (2017), storage insect pest damage, particularly by *Sitophilus* zeamais Motsch, is considered to be a growing major problem in Africa. The maize weevil is a primary pest of stored maize and can penetrate and infest whole kernels of maize grain in which the immature stages of the pest develops leaving the grain emptied of its nutritional and seed value (Lale and Ofuya, 2001; Nwosu, 2018).

4.23.1.5 Control methods of the maize weevil

The most common control methods of the maize weevil include the use of chemical insecticides, biological control and botanical insecticides (Ojo and Omoloye, 2016). However, according to (Nwosu, 2016) conventional synthetic insecticides are the major deterrent in the fight against weevil infestation in stored maize. The maize weevil is mainly controlled using insecticides such as Actellic Gold Dust (Pirimiphos – Methyl) and to some extent Aluminum Phosphide. The former is used for prevention of weevil infestation while the latter is for fumigation of grain already infected by weevils. Pirimiphos-methyl penetrates the insect cuticle and disrupts nerve conduction through inhibition of acetylcholinesterase (Image Care, 2020). Thiamethoxam is considered to act by interfering with the nicotic acetylcholine receptor of the nervous system of insects (ibid). According to Ojo and Omoloye (2016), the conventional control method of the maize weevil is application of botanical insecticides, biological control and chemical insecticides. Umeozor (2009) and Akpodiete *et al*., (2019) report that the most common methods used in the control of *Sitophilus* zeamais include chemical use of botanicals, biological control, hermetic storage, controlled atmosphere and cultural control.

Other methods used to control weevils include the application of plant extracts of *Gliricidium sepium*, cattle manure, growing of tolerant maize varieties and practicing good hygiene in stores (Ojo and Omoloye, 2016). The use of plant and inert materials may be a safe, cost-effective and environmentally friendly method of protecting maize grain against insect pest infestation among resource poor farmers who store small quantities of grains Obeng-Ofiri (2010). However, there is lack of information on the use of plant materials by rural farmers in Africa for stored-product protection (ibid). In spite many promising plants for use as grain protectants, neem (*Azadirachta indica*) is the only plant which has been used globally for the development of several commercial products for insect pest control (Obeng-Ofiri, 2010). Although many plant species have been tested as protectants against the maize weevil in stored grain, there is little information regarding the use of botanicals to suppress insect pest development of cereals (Suleiman *et al.,* 2018). The results from a study conducted by Suleiman et al., (2018) showed that leaf powders and organic extracts of plants such as *Senna obtusifolia* were found to be very effective botanicals in interfering with activities of the maize weevils. In spite advocacy on research in risk-free alternatives to the commonly used insecticides the results have been below expectations (Arthur and Throne, 2003) as reported by (Nwosu, 2018). They report that the reasons for this is that most of the plant and animal materials tested for insecticidal activities lack fast action and have residual effects.

4.23.1.6 Importance of hygiene and sanitary measures in controlling weevils

Since the larvae of maize weevil develop inside the grain, it's not easy to detect the pest unless where there is heavy infestation (AkoL, *et al.,* 2011). In order to reduce weevil infestation in storage, it's recommended that good sanitary measures are undertaken and that the cleaning of storage facilities should be undertaken prior to storage of a new crop (Taruvinga *et al.,* 2014). Good store hygiene can reduce severe maize weevil infestation (AkoL, *et al.,* 2011; Kumar and Kalita, 2017). Lale (2001) and Nwosu (2018) report that residues of infected crop commodities can be a source of new infestation. Therefore, the adoption of proper hygienic practices can reduce possibilities of new pest infestation from residues (Nwosu, 2018). Fumigating of grain stores can assist to eradicate residual infestations and the selection of only uninfested material for storage is recommended (AkoL, et al., 2011). In addition, they advised that selection of resistant maize varieties contributes to the reduction of severe weevil infestation. Although very labour intensive, the use of sieves to remove adult insects from grain can reduce pest population. In addition, the application of inert dusts such as clays and ash to grain can reduce weevil infestation by causing death from desiccation (Obeng-Ofiri, 2010).

4.23.1.7 Maize quality and safety after weevil control process

Befikadu (2014) and Nwosu (2018) report about the importance of ensuring that maize grain used to feed humans should be of good quality and safe. Therefore, the chemicals used to control weevils should not be toxic to humans. Acting from safety concerns, the use of natural materials is being encouraged at the expense of synthetic insecticides in storage pest control (Olotuah, 2013). The type and nature of the grain protectant affects the quality of the grain (Pomeranz, 1982). Gillespie *et al*., (2006) reported that the biological control of the maize weevil is yet to be successful, whereas host-plant resistance and biopesticides offer more possibilities. Despite the success made by scientists in developing maize varieties that are tolerant to maize weevil, these efforts have not met the intended objective as some of the improved varieties still get destroyed by weevils under storage (Nwosu, 2018). Some of the constraints towards major progress on the postharvest control of the notorious weevil in maize grains include inadequate knowledge of genetic bases of resistance, methodological challenges, biotic variation and detrimental genetic linkages (ibid). According to Tri Rahardjo *et al.,* (2017), one prospect to protect maize from storage pests is through the development of resistant genotypes to *Sitophilus zeamais*. The use of plant derived pesticides and varietal resistance in postharvest control of maize weevil is economically justified and socially acceptable (Lale, 2002). Therefore, the general crop husbandry strategy for preservation of grain quality should integrate an effective postharvest insect pest management component.

New and effective grain storage technologies suitable for control of weevils by smallholder farmers have been developed (Nhamucho *et al.,* 2017). These storage methods include hermetic technologies such as the super grain bag, metal and plastic silos (Nhamucho *et al.,* 2017) and the Purdue Improved Crop Storage bags (Kharel *et al.,* 2018). In hermetic technology, the depletion of oxygen inside the container suffocates and kills the pests before they cause considerable grain damage (Nhamucho *et al.,* 2017; Kharel *et al.,* 2018). The use of Purdue Improved Crop Storage (PICS) triple-layer hermetic storage bags has conserved maize grain with less than 0.5% dry weight losses over a six month period of storage in field tests, in the absence of the use of chemicals (Hell *et al.,* 2010).

4.23.2 The Larger Grain Borer (*Prostephanus truncatus*) (Horn) (Coleoptera: Bostrichidae*)*

4.23.2.1 Pest status

The Larger grain borer (LGB) *(Prostephanus truncatus***)** was introduced into Africa from Mesoamerica region in the late 1970s (Hodges, 1986 and CABI, 2017). First established in western Tanzania, it has now become widespread in both East and West Africa. Grain losses may average 10% but in extremes can rise to 30% (CABI, 2017). The larger grain borer can destroy all the stored maize grain resulting in hunger, food insecurity and reducing future maize production for farmers who use the saved grain as seed (Nhamucho, *et al.,* 2017). The larger grain borer is native to extreme south of the United States of America (USA), Central and South America (CABI, 2011; Arthur, 2019). A closely related beetle to the lesser grain borer, the larger grain borer is a serious primary pest of farm stored maize and dried cassava roots. Both larvae and adults (See figure 4.17) can attack dry maize which is still in the field but severe damage happens in storage (Gueye *et al.,* 2008; CABI, 2011). Crop infestation may begin in the mature standing maize crop. The pest covers long distances during transportation of maize and entered Africa through Tanzania in the late 1970s (Hodges, 1986; Gueye *et al.,* 2008 ;). The pest spread to all East and most Southern African countries such as Malawi, Namibia, South Africa and Zambia.

Figure 4.17*:* Images of larvae and adult LGB. Source: (G. Goergen, IITA)

Since outbreak of the larger grain borer in 1981, there has been rapid and steady spread of the pest across the African continent (Kega and Warui, 1983; Harnisch and Krail 1984; Hodges, 1986) as reported by Osipitan (2015). The spread of the larger grain borer in Africa covers 15 countries which include; Benin, Burkina Faso, Burundi, Ghana, Kenya, Malawi, Mozambique, Namibia, Niger, Rwanda, South Africa, Tanzania, Togo, Uganda and Zambia (Gueye *et al.,* 2008; Arthur *et al.,* 2019). Refer to figure 4.18 for the map showing distribution of the larger grain borer in Africa.

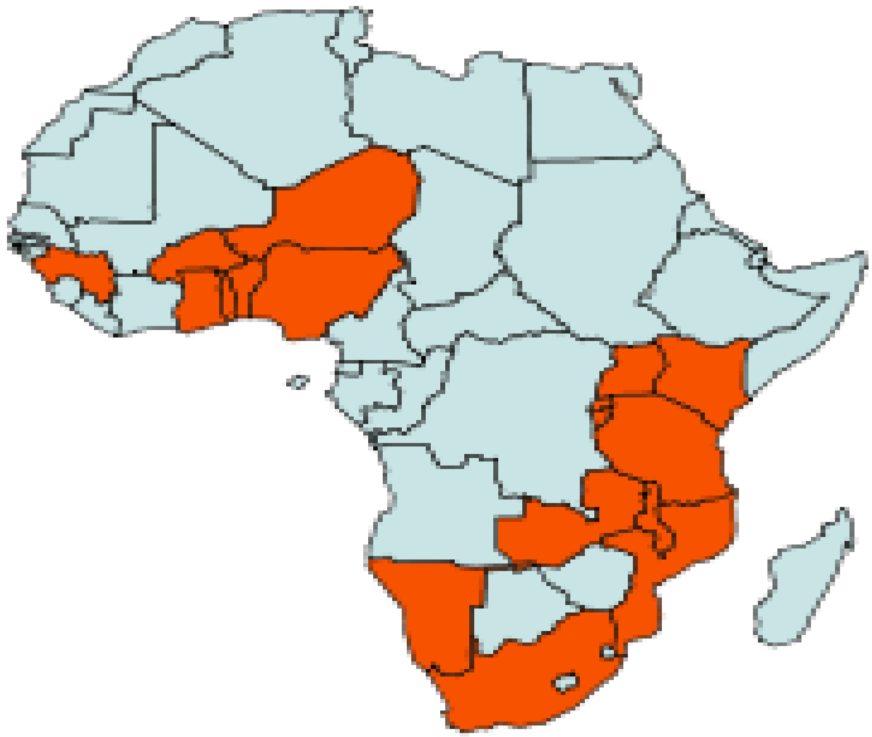

Figure 4.18: Distribution of Larger Grain Borer in Africa (red marked). Source: (www.infonet-biovision.org)

Adult larger grain borers drill into maize husks or grain and cassava, creating clean holes and burrow by producing large quantities of dust (Nang'ayo *et al.,* 1993, 2002*; Nansen et al.,* 2004*)* as cited by Osipitan (2015). The females make small egg laying chambers at right angles to the main tunnels (Infonet Biovision, 2019). The pest lays eggs in batches of 20 which are covered with finely chewed maize dust. The larvae hatch after about 3 to 7 days at 27°C and live on the maize dust produced by the adult's feeding activity (infonet-biovision, 2019). The last instar larva of the larger grain borer builds a pupa case from frays stuck together with larval secretion, either within the grain or the surrounding dust. Larva development to adult stage takes 25 to 27 days on a maize diet, optimum conditions of 32°C, 70% relative humidity, and about 13% grain moisture content (ibid). Development of the larvae takes longer under cooler and drier conditions. Adults disperse over short distances by flying. Males live for shorter periods (45 days) than females (61 days) (Tefera *et al;* 2010; Infonet -biovision, 2019).

4.23.2.2 Destructive stage of the larger grain borer

Both larvae and adults damage the grain although only the adults make tunnels. In severe cases of damage the grain weight losses can be around 30% after 3-6 months (Hodges, 1986). Furthermore, the larger grain borer is an extremely voracious pest with the capacity to damage 40% loss in stored maize grain in 6 months ((Hodges *et al.,* 1986; Osipitan *et al*., 2015). Figure 4.19 shows images of maize cobs attacked by the larger grain borer.

Figure 4.19: Image of maize attacked by the larger grain borer. Source: (infonetbiovision.org and lucidcentral.com).

4.23.2.3 Host range of the larger grain borer

Besides attacking a wide range of food stuffs such as wheat and sorghum, LGB also attacks wooden structures which may act as a source of infestation for the subsequent crop harvests (Tefera *et al.,* 2010; Meikle *et al.,* 2002a;). According to literature the application of appropriate pest management practices can reduce losses to acceptable levels (Gueye *et al.,* 2008). In order to prevent the spread of the larger grain borer and other insect pests, strict control measures should be applied to large grain shipments (Tyler and Hodges, 2002). They argued that since a substantial quantity of grain movement in sub-Saharan Africa is done by cross border traders that at times use bush paths or carry small packages of grain on public transport, it would be difficult to subject such grain to phytosanitary measures. In view of the foregoing, long term prevention of further spread of LGB in sub-Saharan Africa might be unrealistic (Tyler and Hodges, 2002).

The larger grain borer which was first reported in Nakonde District of Zambia (bordering Tanzania) in 1993 has spread to most provinces of Zambia (FRA, 2017). The importation of huge quantities of larger grain borer infested maize from Tanzania in 1995 led to the spread of the pest to food deficit parts of Zambia where the relief maize was distributed as famine relief (FAO, 1997).

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4.23.2.4 Control measures of the larger grain borer

Since immature stages of the large grain borer develop inside maize grain, it's quite difficult to detect the pest unless where there is high infestation (Infonet -Biovision, 2019). The scientific method used to detect the pest is through use of traps baited with a chemical attractant (pheromone) produced by the male pest (ibid). Chemicals and traditional materials such as the use of botanical products are some of the strategies used by smallholder farmers to control the larger grain borer (Nhamucho *et al.,* 2017). The common chemicals are fumigants such as phosphine gas and actellic super (ibid). Hermetic technologies can also be used in the control of the larger grain borer (Nhamucho et al., 2017; Kharel *et al.,* 2018). In already infected grain, fumigants such as aluminum phosphide are used to control the larger grain borer (ibid). Meikle *et al.,* (2002) proposed that resources are required for effective evaluation and improvement in the control methods. Biological control was initially contemplated after the unintended introduction of the larger grain borer in Africa in the early 1980s (Muatinte *et al.,* (2014). Since the introduction of the *Teretrius nigrescens* (Lewis) (the natural enemy to the larger grain borer) in Africa, several methods have been used by different scientists to evaluate the effectiveness of this biological control method (Holst and Meikle, 2002 and Muatinte *et al.,* 2014). The results of the various studies on use of biological control methods have not been conclusive leading to increasing uncertainty about biological control strategies (ibid).

Cultural practices such good store hygiene can be used in the control of the larger grain borer. Suleiman *et al*., (2013) proposes the following store hygiene activities:

- Elimination of residual infestation in the stores by cleaning or fumigation;
- Cleaning of grain stores between harvests;
- Removal and burning infested residues before the new harvest is stored; and
- Soaking of used sacks in boiling water to destroy residual infestations.

Timely harvesting of maize reduces damage by the larger grain borer. Research conducted in Benin showed that maize harvested 3 weeks after physiological maturity gave better monetary returns from 8 months of storage compared to maize harvested 7 weeks after physiological maturity (Infonet-biovision, 2019). According to Borgemeister *et al., (*1998) maize left in the field for long periods of time after physiological maturity resulted in severe damage from the larger grain borer after 8 months. Furthermore since larger grain borer infestation is low in the first 3 months after physiological maturity, it's advisable to market the maize within that period (Infonet-biovision, 2019). The grain kept under storage for home consumption should be treated with pesticides particularly in cases where the larger grain borer is prevalent in the area (ibid).

4.23.3 Rodents

4.23.3.1 Pest status

Although insects are the main cause of postharvest losses in maize storage (Boxall, 2002; Abass *et al.,* 2014, Kumar and Kalita, 2017) literature demonstrates that rats and mice (collectively known as rodents) cause substantial problems in grain storage and in certain instances they pose a major storage challenge (Belmain *et al.,* 2015; Ognakossan *et al.,* 2018). According to Makundi *et al*., (1999) rodents are regarded as the major cause of losses of agricultural products in several developing countries. A review of literature indicated that rodents cause about 77 million tons of food loss annually worldwide (John, 2014). Furthermore, Tanzania loses US$45 million every year in reduced maize yield (Leirs, 2003) and in some areas of South America, rodent related damage to crops can amount up to 90% of the total annual production (Rodriquez, 1993) as reported by Bedoya- Perez *et al.,* (2019). According to Swanepoel *et al.,* (2017) rodents in Africa cause between 20 and 50% food losses. It's further reported that the damage caused by rodents to crops impacts nearly 280 million undernourished people in the world (Stenseth *et al*., 2003; Meerburg *et al*., 2009b) as cited in Bedoya- Perez *et al.,* (2019).

The problem which rodents cause to humans is the loss of money due to damage to crops, buildings and transmission of diseases (Bedoya- Perez *et al.,* (2019). AEPMA (2019) and Swanepoel *et al.,* (2017) Lund (2015) posit that rats and mice cause considerable economic damage to agricultural crops and food stores. According to Smith and Meyer (2015) other than feeding on and contaminating food, rats and mice cause substantial damage to farm structures through gnawing and chewing behavior. They further found that the destruction of electrical wires is both a nuisance to farmers and also possess a fire risk (AEPMA. 2019).

Rodents are a problem to farmers as they cause losses of crops through direct consumption (Mutungu *et al*., 2003; Bekele *et al.,* 2003) spoilage (Mdangi *et al*., 2013) and spreading of diseases (*Katakweba et al.,* 2012). Singleton *et al.,* (2010) argue that there is possibility of an underestimation of losses caused by rodents in the postharvest supply chain. Food grains appear to be prone to rodent attack and the losses caused are not adequately understood (ibid).

In East Africa, the house rat (*Mus musculus*), roof rat (*Rattus rattus*) and the natal multimammate mouse (*Mastomys natalensis*) are the most common species of rodents associated with postharvest losses in storage (Makundi *et al.,* 1999). A study conducted in Kenya showed that rodent contribution to postharvest losses in off-farm maize stores was 11% (Mwangi *et al.,* 2017) while on farmers stores it was 30% (Ognakossan *et al.,* 2018). They further explained that in rural on-farm storage, rodents contribute 63% to total postharvest losses because rural storage is associated with poor hygiene and a high proportion of non-rodent proof grain stores (ibid).

Results from research showed that rodents are a significant cause of postharvest losses of on farm maize storage in the tropics and have a negative influence on food nutrition and safety (*Ognakossan et al.,* 2018). Other than quantity losses arising from physical damage of grains, rodent infestation in storage can contribute to quality losses and raise food safety and public health issues (Meerburg *et al,* 2009 and Belmain *et al.*, 2015).

The nutritive value of the grain gets reduced significantly through removal of the germ by rodents. Rodent droppings on grain may harbor pathogens which could make the maize unfit for human consumption (Meeburg et *al.,* 2009 and Hodges *et al.,* 2014). Furthermore, Stejskal *et al.,* (2005) report that the development of fungus on stores might be catalyzed by rodent urine which raises water activity of the affected site and increases the nitrogen availability. In addition, the dissemination of fungal spores could be supported by the feeding habit of the rodents (Vander Wall, 1990). Rodents also cause germination failure of seeds meant for planting and damage to storage materials and equipment (AEPMA, 2019; Swanepoel *et al.,* 2017).

On the other hand, the real extent of the quantitative and qualitative losses caused by rodents to maize under storage and the rodent species linked to these losses is not readily available. Research on postharvest losses in on-farm maize storage caused by rodents in SSA has been minimal (Swanepoel *et al.,* 2017) as the focus has been on insect storage pests (Boxall 2002 and Affognon *et al.,* 2015). Therefore, rodent control should be among the strategies for mitigation of postharvest losses (ibid).

4.23.3.2 Development of rodents

Rats and mice breed throughout the year and for this reason the numbers of rats and mice in a store can increase rapidly if no action is taken for their control Bonwitt *et al.,* 2017). Rats normally live for about one year and females can begin to breed when they are four months old often producing five families in their lifetime. Each family may average eight individuals and once the young rats also begin to breed the number of animals increases very rapidly (Bonwitt *et al.,* 2017). Tobin and Fall (2005) report that rodents begin to breed when they are about two months old and as with rats, large numbers of animals can arise from a single pair of mice.

4.23.3.3 Anatomy of rodents

Because of the way in which their teeth are made rodents are continually kept sharp which enables rats to destroy electric cables and masonry (AEPMA, 2019). Owing to the fact that the incisors grow continually, rats are forced to gnaw steadily in order to wear them down (Tobin and Fall, 2005)

4.23.3.4 Signs of rodent infestation of grain

Grain stores and the surrounding area should frequently be inspected for rodents. Some of the signs for rodent infestation are:

i. Droppings and urine

The appearance, shape and size of dropping can give a clue as to the species and level of infestation (Berman, 2014). Black rat or house rat (*Rattus rattus*) droppings are around 15 mm long and are shaped like a banana. The droppings of a mouse are between 3 and 8 mm in length and irregular in shape. Mouse (*Mus musculus)* droppings are between 3 and 8 mm in length and irregular in shape. While the droppings of Norway rats (*Rattus norvegicus*) are around 20 mm in length and are found along their runs (IRRI, 2019). Urine traces are shining in ultraviolet light. Where available, ultraviolet lamps can be used to look for traces of urine (ibid).

ii. Runs and tracks

Black rats do not have any fixed runs and can leave analogous oily stains at points which they frequently pass, for example, when climbing over roof beams. Runs of Norway rats are found along the foot of fences, walls, or across rubble (IN.gov, 2020). These rats pass through overgrown territory usually hidden by long grass. The animal's fur coming into contact with the wall leaves dark, greasy stains (IRRI, 2019).

iii. Live animals

Rodents are nocturnal animals and any sight of animals during the day is an indication of advanced level of infestation.

iv. Foot prints and tail marks

Rodents leave footprints and tail marks in the dust. To confirm rat and mice infestation, scatter some dust on the floor in several areas and later check for foot prints ((IN.gov, 2020)

v. Burrows and nests

Rodents build nests in corners as well as the roof area of stores or in burrows outside the grain stores. Rat holes have a diameter of between 6 cm and 8 cm, while mice holes are around 2 cm in diameter (IN.gov, 2020)

vi. Tell-tale damage

Rats mostly only eat the embryo of maize. The damage by rats can be identified largely from fragments of grain that is nibbled at (gnaw marks). Mice leave behind sharp and small grain leftovers. Further signs of rodent attack include damaged sacks where grain is spilled and scattered and small heaps of grain under stacks of grain bags (Infonet-biovision, 2020; IN.gov),

4.23.3.5 Importance of keeping rats and mice out of food stores

Preventing the entry of rats and mice into stores is the best method for protecting stored grain and other food commodities. It is important to note that the cost of modifying an old store to keep out rats and mice may greatly exceed the losses caused by the pests. Therefore it is much easier to include the features necessary to keep rodents out when building a new store. Preventing entry is done by blocking points through which rats and mice can pass and knowledge of their habits is very helpful in detecting where these entry points are located.

4.23.3.6 Methods of controlling rats and mice in stored maize grain

Much as there are many different types of rats and mice and that some have different habits such as spending more time in climbing, the methods of control are similar for most types (IRRI, 2019). Protection of grain and similar commodities from damage by rats and mice during storage is best achieved by making buildings rodent proof or if this is not possible by using poisons. Other methods are available and it is important to know whether these are likely to be useful in protecting stored grain. Traps can be useful if there are very few rats and mice to be caught but if there is a large infestation, traps will have little significant effect on the population. Two main types of traps are available; the break-back and the cage trap. There are also a variety of local traps which differ from country to country (IRRI, 2019).

The control of rodents using traps appears not to be successful as studies have shown. Traps have been used to control rodents but adaptation has made them develop neophobia (fear of objects), which has helped them elude traps and avoid getting killed (Musso, 2016). According to (Eisen *et al*., 2018) intensive lethal trapping inside homes appears to be effective at reducing rodent abundance, but control was short lived after trapping ceased. Research has shown that severe fatal trappings of rodents inside rural households in Mozambique significantly reduced rodents within domestic food stores (Belmain *et al*., 2002).

The use of domestic predators such as cats (*Felis catus)* in the control of rats and mice is a common strategy globally (Mahlaba *et al.,* 2016). Nevertheless there is lack of scientific evidence regarding the impact of such measures in the control of rodents in agriculture (ibid). According to Dielenberg and Mcgregor (2001) several reviews which focus on the opportunities for exploiting the impact of predators on the behavior and physiology of their prey for pest management have been conducted by researchers. The results of a study on the impact of the presence of cats and dogs at the homestead suggested that the rodent activities can be discouraged by the presence of domestic predators (Mahlaba *et al.,* 2016).

When practicing preventive rodent control due consideration should be taken on the location of new grain stores. Specific attention should be paid to ventilation openings, doors, brick work and connections between walls and roofs. There should be prompt repairs to damaged food stores (Tobin and Fall, 2005). Combining good store management and preventative measures can assist to deal with factors which promote development of rodents. (Smith and Meyer 2015; Musso. 2016; IN.gov, 2020) recommend the following good hygiene practices and technical measures for control of rodents:

- Rats can jump to a height of about one metre so all windows and ventilators less than a metre from the ground must be covered by screens;
- Small mice can enter 6 mm openings; holes in screens should therefore be no greater than 6 mm wide;
- All openings larger than 6 mm, such as where electric cables or water pipes enter buildings, must be filled with cement/concrete;
- Wooden doors are no barrier against rats and mice and should be protected by covering the lower 30 cm of both the door and door frame with a metal plate;
- Rodents are very good at climbing and jumping, all pipes and cables connected to stores must be provided with protective screening plates to block entry of these pests at roof level;
- Overhanging trees also provide rodents with opportunities to enter stores at roof level, and this can easily be remedied by cutting back tree branches as necessary;
- All openings where the roof and walls join (eaves) including openable windows must be covered with metal screens; and
- Maintain the area surrounding the grain store free of vegetation so that rodents have no cover, particularly that they dislike crossing open areas;
- Drain stagnant water from the area around food stores as it can be used as drinking water by rodents;
- Keep grain stores clean in order to remove places where the rodents can nest or hide;

- Remove any spilled grain from stores as it can attract rodents;
- Store grain bags in clean stacks set up on pallets or dunnage and provide one meter space around the stack to facilitate inspection; and
- Do not store empty or old grain bags in stores which have grain.

Integrated pest management (IPM) is the commonly used method in management of rodents (Singleton *et al.,* 1999). FAO (2018, p.1) defines integrated pest management as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms". The IPM model is the combination of all available pest control methods with preventative measures to reduce subsequent pest population increases, while ensuring that these techniques are economically justified and do not pose a risk to human health and the environment". IPM usually involves physical interventions (use of traps and preventions), monitoring, sanitation and rodenticides (Bennett *et al.,* 2003). There is no single rodent control method which will be effective in all circumstances and therefore IPM programmes offer best prospects for long-term success because they combine several methods which can deal with different rodent species under diverse environments (Tobin and Fall, 2005).

4.23.4 ***Termites*** **(Microtermes spp: Isoptera: Microtermitidae)**

4.23.4.1 Pest status

Termites are social insects which play an important role in vegetation growth and biodiversity, organic matter decomposition, soil formulation and fertilization (Loko et *al.,* 2017). Winged termites of the genus Macrotermes are consumed by people in Africa and other parts of the world (ibid). However, termites are renowned as pests which cause a lot of damage to homes, food stores and agricultural products such as cereals, legumes, roots and tubers, and fruit trees (Smith, 2015 and Akol *et al*., 2011). Termites cause harvest losses in the range of 20 - 45% (ibid). Termites are usually called "white ants" even if they are not ants but rather close relatives of cockroaches (*Periplaneta americana*). Although termites are a very large insect group found globally, Southern Africa has the largest number of genera (Akol, *et al., 2011;* Mphosi *et al.,* 2009).

Results from a study conducted in Benin, showed *Amitermes evuncifer, Macrotermes subhyalinus*, *Trinervitermes oeconomus*, *Macrotermes bellicosus*are as the most damaging termites (Loko *et al.,* 2017). The damage by termites has in fact been recorded in the majority of crops grown in the southern African region (Smit & Van den Berg; 2003) as reported by Mphosi *et al.,* (2009). Major termite damage occurs to maize in the field, particularly during dry conditions (Anyango *et al*., (2019) and Mphosi *et al.,* (2009). Termites are beneficial to agriculture as they produce organic matter from woody tissues of plants and dead wood, which helps to restore organic matter to the soil and plays the role of ecological indicators (Anyango *et al*., (2019) and Okonya, and Kroschler (2013).

4.23.4.2 Damage caused by termites

Termites are destructive to maize in the field, during drying, grain bags and wooden storage structures (Kumari *et al.,* 2013; FAO, 2014). One of the consequences of termite damage to stored maize grain is attack by secondary pests such as fungi (Infonet-Biovision 2020).

4.23.4.3 Control of termites in maize

The control of termites in agriculture and industry is dependent mainly on soil chemical termiticide applications, particularly in African countries (Baïmey *et al.,* 2017). The application of insecticides is to create a barrier to prevent termites from accessing the plants. Cultural practices such as increasing seed rate, crop rotation, and harvesting at the right time, treatment of poles for wooden storage structures can reduce termite damage (Akol, *et al., (2*011). They further found that farmers in Benin had identified the absence of effective pesticides for termite control, harmfulness of chemicals to humans eating treated termites, and the lack of government recommended control measures as the major challenges associated with termite pest management.

Other physical measures for control of termites include mixture of repellent plant material or protection of base of the granary using wood ash (Kumari *et al*., 2013). They further propose the creation of a solid basement made from concrete platforms resting on poles and formation of barriers using timber such as teak which is resistant to termite attack. The application of wood ash, neem leaves and used engine oil into pole holes can repel termites (ibid).

According to research, products of Neem (*Azadirachta indica* A. Juss), a member of the Meliaceae family contains phytochemicals which are used in pest control and human health (Campos, *et al.,* 2016). For example, *Microtermes obesi* and *Odontotermes spp* were repelled by a layer of neem cake placed between pods of groundnuts and soil surface (Gold *et al.,* 1989) as reported by Abudulai *et al.,* 2013). According to Infonet-Biovision (2020) a study conducted by Sharma *et al*., (1990) showed a reduction in weight loss of wood pieces caused by termites after treatment with neem oil and leaf extract.

One of the recommended cultural practices in areas prone to termite infestation is to transport the harvested crop to the homestead soon after harvest to avoid termite damage (Infonet-Biovision 2020). Much as termites are pests they also play a critical role in ecological functions which promote sustainability of agriculture. The most effective possibility for termite control is prevention. The protection of food storage structures is considered more sustainable than destruction of termite mounds. Regular inspections of storage structures should be conducted in order to prevent termite damage (Kumari *et al.,* 2013).

4.24 Maize Storage in the Study Area

As far as the maize storage structures were concerned 70% of the respondents were using the traditional storage structures called “Nkokwe” or “ Matala“ in Chewa and Tonga languages used in Eastern and Southern Provinces of Zambia. In Chambuli village of Katete some farmers used both traditional and metal bins (Images are given in figure 4.20) silos acquired from the CIMMYT and World Lutheran Federation postharvest projects.

The study established that 21% of the respondents (particularly women) had resorted to storage of maize in dwelling houses. This was a new practice caused by a rise in the theft of maize from traditional structures and the need to hide maize from prying eyes of neighbors, relatives and government or NGOs officials conducting food surveys. In the 1980s it was a sign of pride to show-off the amount of food a household had harvested by storing it in traditional storage structures which revealed the contents. Due to unpredictable weather conditions experienced in recent periods, households are not willing to share their food as they had no assurance of producing additional food in the coming season.

Figure 4.20: Traditional maize storage structure and metal bin in Katete. Source: (Author)

In spite the amount of time and effort spent by FAO in the 1980s-90s promoting the cement bins (ferrumbu), this technology was only adopted by a few smallholder farmers. It was either considered too expensive or did not fit in the circumstances of the smallholders or not considered as a priority. As a result very few ferrumbu structures were still operational as a number of them had been abandoned by smallholder farmers in the study areas. The ferrumbu was built using chicken wire mesh and cement mortar. A wooden frame made from light tree branches forms the shape which holds the chicken wire in place until outside cement mortar gets applied. The foundation is usually made of stone. The top opening can be covered with either a cone-shaped lid or flat cement lid (made from chicken wire mess plastered with cement mortar). The burnt brick plastered bin is another storage structure which was promoted by FAO in the 1980s no longer used by farmers.

4.24.1 Storage of maize for consumption

The form in which farmers stored their maize for home consumption was investigated and the findings were that 52% of the respondent’s stored shelled maize, 40 % unshelled while the rest (7%) stored both shelled and unshelled maize. The reasons advanced for storage of maize in the shelled form was that it was easier to store and manage (37%) and that it facilitated the application of chemicals to control storage pests (29%). With regard to storage of unshelled maize, the respondents considered it as a traditional practice (12%) which mostly used traditional storage structures. Summarised information is available in Figure 4.21. During focus group discussions some farmers mentioned their preference to store local maize on the cob was due to its tolerance to storage insect pests.

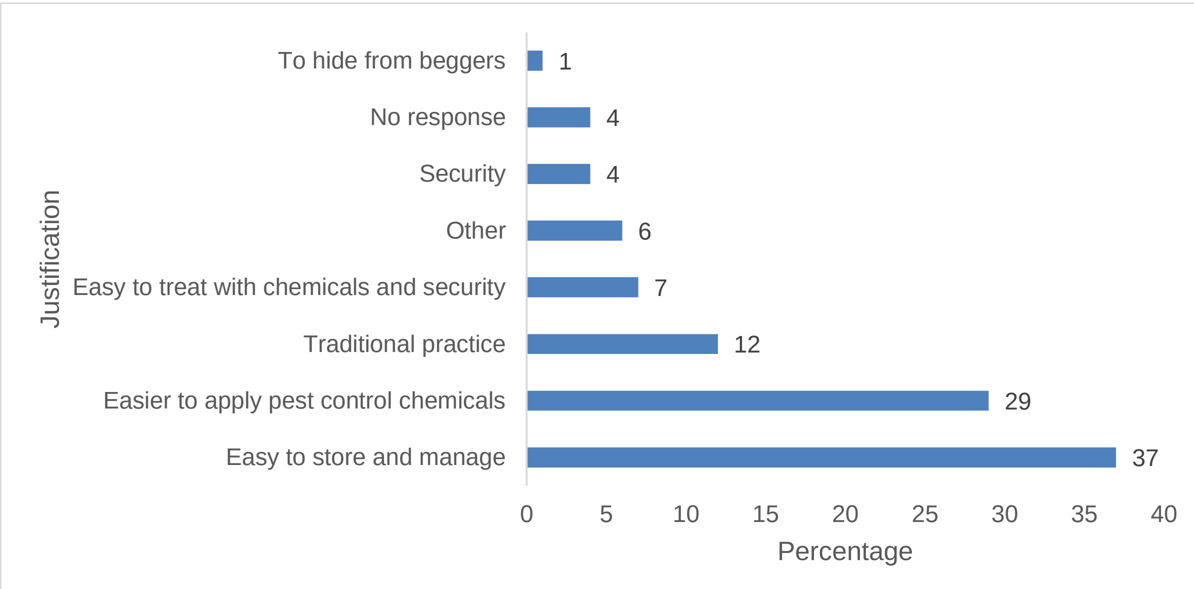

Figure 4.21: Justification for storing maize in the shelled and unshelled form. Source: (Author)

Poor grain storage technologies and ineffective drying practices contribute to the loss of up to one third of the grain produced by smallholders in sub-Saharan Africa (De Groote and Masinde, 2018). According to Weinberg *et al.,* (2008) large quantities of maize are stored under hot and humid conditions after harvest and that most farmers lack adequate knowledge, technology and methods of drying grains. Since maize grains are biologically active, they respire during storage with heat being a by-product of this process. Therefore the rate of respiration can be slowed down by reducing temperature in storage which lengthens grain shelf life by reducing probability of germination Weinberg *et al.,* (2008). Temperature also affects the metabolic rates of fungi and insects. With low temperature, metabolic processes which lead to grain spoilage are reduced (ibid). The storage of maize while it's moist can result in rapid deterioration and promotion of growth of insects and micro-organisms such as bacteria and fungi (Ekechukwua and Norton, 1999).

Being hygroscopic in nature, maize absorbs and releases moisture. Regardless of the drying method used after harvest, if maize gets exposed to moist and humid conditions during storage, it tends to absorb moisture from the surroundings (Devereau *et al.,* 2002) resulting in deterioration due to high moisture content. According to Oyekale *et al.,* (2012) in order to maintain high quality maize in storage, the grain should be protected from weather (relative humidity and temperature), insects and growth of microorganisms. Similarly, Kaleta and Górnick (2013) report that grain which has high moisture content is susceptible to damage by microorganisms and therefore should be dried to maintain quality. Tuite and Foster (1979) found that mould development was enhanced by insects within the grain as they increase temperature and moisture content. The growth of fungus on maize grain is promoted by hot and humid weather conditions (Egal *et al.,* 2005). Besides temperature and moisture, atmospheric air can have an effect on stored grain. The moisture content (mc) of a crop is usually given on a wet basis (wb) and is calculated as (% mcwb) (Akhtaruzzaman *et al.,* (2017). Since moisture content is at times calculated on 'dry basis' (db), it's important to be clear about what has been used (ibid).

According to Karunakaran *et al.,* (2001), and Kaleta and Górnicki (2013) grain managers and farmers need to be knowledgeable about deterioration rates of high moisture grain under storage to enable them either to hasten grain drying or change the storage environment in order to maintain grain quality. According to Suleiman *et al.,* (2013) several studies have reported that fungal infestation in maize can cause a reduction in nutritional value, color change, decrease in overall quality and quantity of maize. They further stated that *Aspergillus flavus* and *Fusarium* spp as the major fungi associated with determination of grain in storage. The fungus produce mycotoxins (particularly Aflatoxins) on maize grain which presents a major health risk to humans and livestock (ibid).

4.24.2 Factors affecting maize storage

Studies conducted by Gonzales *et* al., (2009); Lawrence and Maier (2010) and Suleiman *et al.,* (2013) established that temperature and moisture content were the two key factors affecting the subsequent quality of grain, dry matter losses, biochemical reactions, allowable storage time and general storage management of grain. Padin *et al*., (2002) asserted that 5-15% total weight loss after harvest of pulses, cereals and oilseeds are normally acceptable. By improving storage conditions there would be a 10-20% increase in food supply in the world (Christiansen and Kaufmann, 1969) as quoted by Kaleta and Górnicki, 2013.

Moisture content is responsible for biological and biochemical activities which occur in cereal grains (Suleiman *et al*., 2013; Jayas and White, 2003) as cited by Abass *et al.,* (2017). Similar to other stored products, maize grain is hygroscopic in nature (Akhtaruzzaman *et al*., 2017). Therefore, there is a need to monitor and reduce the moisture content of the grain and the surrounding atmosphere for safe grain storage. Devereau *et al.,* (2002) explained that maize consists of varying levels of moisture content and a constant amount of dry matter. When grain has high moisture content, it heats up and can develop mould and therefore moisture plays a prominent role in grain storage (Brewbaker, 2003) as cited in Suleiman *et al*., (2013). The rule of the thumb is that the higher the moisture content the more prone grain is to insect and mould infestation (GRDC, 2018 and Suleiman *et al*., 2013).

4.24.3 Interaction between relative humidity and temperature in storage

According to Lawrence (2005, p.225), relative humidity is commonly defined in one of two ways, either as "the ratio of the actual water vapor pressure to the equilibrium vapor pressure over a plane of water (often called the saturation vapor pressure), or as the ratio of the actual water vapor dry mass mixing ratio to the equilibrium (or saturation) mixing ratio at the ambient temperature and pressure". It is the amount of water vapor that is contained in the air as a proportion of the amount of water vapour required to saturate the air at the same temperature (ibid). Research results show that there is a direct relationship between temperature and relative humidity and that an increase in temperature causes grain to lose moisture to the surrounding air, in so doing increasing relative humidity (Devereau et *al.,* 2002). A 10 °C rise in temperature can cause a 3% increase in relative humidity in most cereal grains (Suleiman *et al.,* 2013). The varying of temperature and relative humidity causes loss of nutrients and stimulates mould growth (Shah *et al.,* 2002). With regard to nutrient loss, maize stored for 6 months at 45 °C and 12% relative humidity showed 20.4% reduction in protein soluble sugars (Rehman, 2002). In related work, Samuel *et al.,* (2011) explained that maize harvested in the tropics retained a certain amount of moisture even after drying and when exposed to air there was an exchange of moisture between the grains and the surrounding until equilibrium is reached. Yakubu (2011) found that fluctuations in temperature and relative humidity in the tropics increases the growth of insects and mould which promotes spoilage of grain.

4.25 Pest Control Methods in Stored Maize

The pest control methods used by farmers were discussed at length during focus group discussions. The results from the interviews were that 58% of the farmers were using pesticides to control pests while 4 percent used traditional methods like cow dung, ash and smoke from the kitchen. Application of a chemical commonly known as Shumba or Actellic Gold Dust (Pirimiphos-methyl) (See Figure 4.22) was the primary insecticide used by farmers to control weevils although phosphine fumigation was also used at a secondary level. The farmers reported a wide variation in the use and effectiveness of the chemicals used. For effective control against inspect pests, the chemicals are supposed to be thoroughly mixed with maize grain. The study sought clarification from 22% of the farmers that had responded "not applicable" to the question regarding the protection of maize from pests. Their response was that they did not use any control measures.

Actellic gold dust (Pirimiphos-methyl) is an insecticide for use against storage pests, such as grain weevils (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncatus*), the red flour beetle (*Tribolium castaneum*), and lesser grain borer (*Rhyzopertha dominica*) in maize and other crops such as beans, groundnuts, rice, soya beans and pigeon peas (Silveira *et al*., 2009). It preserves grain for a period of 9 months. Pirimiphos - methyl penetrates the insect cuticle and disrupts nerve conduction through inhibition of acetylcholinesterase (Mujeeb and Shakoori, 2012). Thiamethoxam is considered to act by interfering with the nicotic acetylcholine receptor of the nervous system of insects (ibid).

According to Smith (2015), arising from the increased damage to crops caused by pests, there is likely to be an increased dependence on pesticides. Correspondingly, the increased use of pesticides is likely to pose a threat to food safety. Food poisoning is a global public health problem with self- poisoning responsible for one third of the global suicide cases (Gurjar *et al.,* 2011).

Figure 4.22: Images of Actellic Gold Dust and Shumba Super Dust. Source: (Author)

Some of the female respondents considered the application of Actellic Gold Dust to maize grain rather tiresome, as the operation needed male labour to ensure thorough mixing. Actellic Gold Dust can be applied directly to maize grain, or the liquid solution sprayed to bags of maize grain. When using the dust formulation, farmers are required to mix 500 gm of Actellic Gold Dust to 10 x 50 kg bags of maize grain. Farmers are required to first make a premix of the chemical and one bag of maize and then this mixture should be admixed to the remaining 9 bags of maize grain. The mixture of the chemical and maize grain should thoroughly be done for effective control of storage pests. Refer to figure 4.23 on the procedure for mixing the pesticide and maize grain. Some farmers, however, tend to under-apply the chemical in order to treat large quantities of maize grain. When the grain is under-treated with Actellic, it becomes susceptible to storage insect pests in less than 9 months after application.

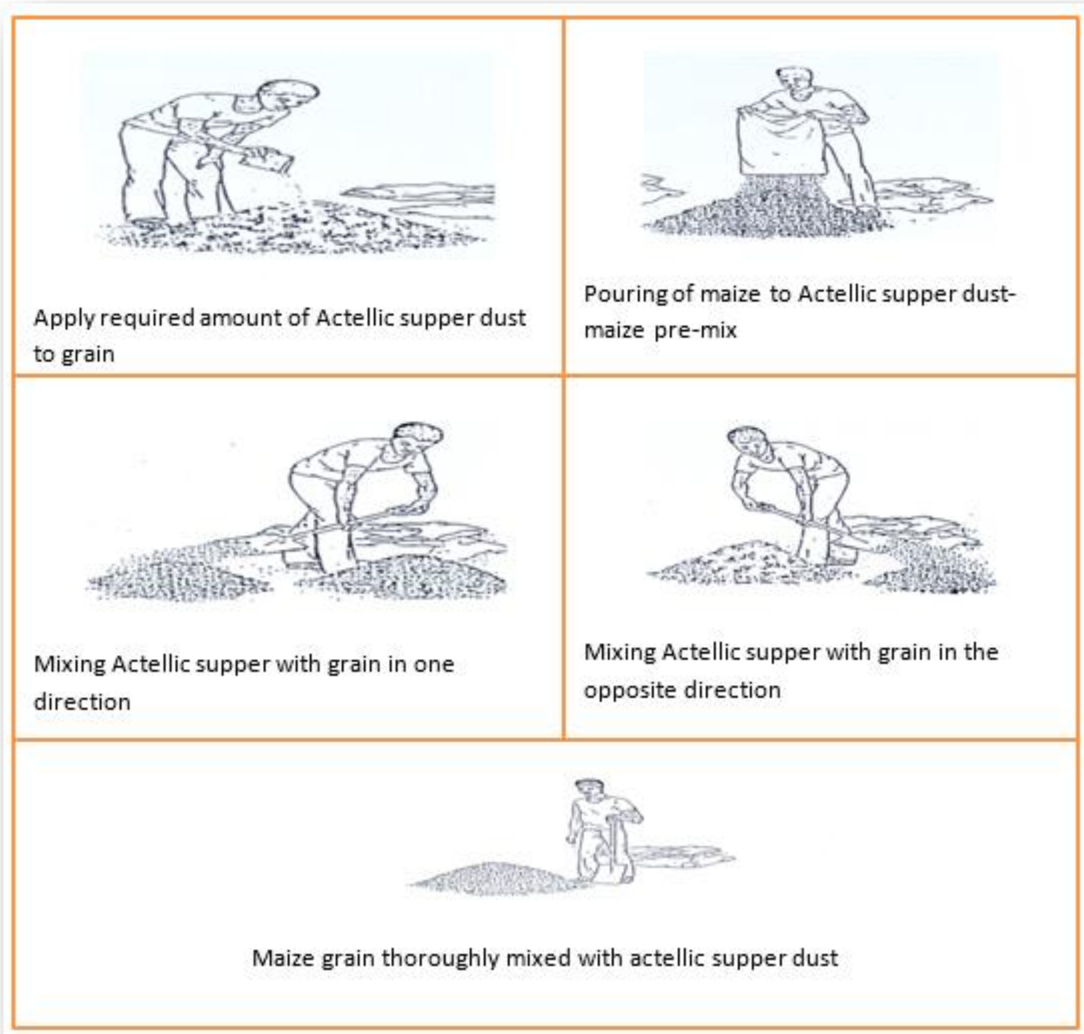

Figure 4.23: Procedure for mixing of Actellic Supper Dust with maize. Source: (Author)

Aluminium phosphide is mainly used as a fumigant for pest control and is a source of phosphine gas (Image of the product is given in figure 4.24). This inorganic compound can also be used as a wide band gap or energy gap semi-conductor. It is a reducing agent which indicates that it acts as an electronic donor in a chemical reaction. This chemical is not supposed to be handled by untrained people because it can be toxic if handled carelessly (Hodges and Farrell 2004; Gurjar *et al.,* 2011). As such smallholder farmers are not allowed to handle this fumigant. Since the farmers at times apply phosphine to grain bags stored in the dwelling houses, their families get exposed to this toxic chemical. During the study there were reports of some farmers that had gotten poisoned from a fumigant that had been applied to bagged maize stored in the dwelling house.

Since some of the agro-dealers are ignorant of the toxicity of aluminum phosphide, they do not advise farmers about the conditions under which the pesticide is supposed be used. The author witnessed a situation where the person selling Shumba failed to advise the farmer on how to apply the Pirimophos-methy to maize grain. Instead the farmer was advised to find out from neighbors or friends on how the chemical was supposed to be applied.

Figure 4.24: Images of aluminium phosphide tablets. Source: (exportersindia.com and indiamart, com).

Due to widespread use of chemicals for a long period of time, some insect species have developed chemical resistance (Emery *et al.,* 2018). In certain cases even insects which have only been exposed to one chemical, may develop resistance to other related chemicals (ibid). If application of insecticides is poorly done, eggs, pupae and larvae of pests are bound to survive and this would increase the next generation of insect pests (GRDC, 2018). Other than using different types of chemicals which maybe too expensive, the best method to reduce chemical resistance is proper application (ibid). In the case of reducing phosphine resistance, it's better to ensure its application is done under gas-tight environments (GRDC, 2018). Practicing grain store hygiene and proper use of chemicals can reduce insecticide resistance (Emery *et al.,* 2018)

4.26 The Unified Theory of Acceptance and Use of Technology Model

If technology for reducing postharvest losses is not used, it will remain ineffective despite its technical merits and attributes. In recent years the issue of technology adoption by smallholder farmers has received a lot of attention because of the critical role it plays in the attainment of food security (Langyintuo *et al.,* 2008). The welfare and the food security situation of smallholder farmers can be improved through the adoption of improved agricultural technologies (Mendola, 2007). Therefore one of the biggest challenges is understanding the reasons for acceptance or non – acceptance of postharvest loss reducing technologies by smallholder farmers. According to literature technology adoption has been found to be connected to the education and wealth levels of the farmers and the extent to which neighbours have adopted the same technology (Kinuthia and Mabaya, 2015). This argument was extended by Foster and Rosenzweig (2012) who proposed that lack of credit, lack of credit markets and externalities and low education could be key hindrances to technology adoption. Isham (2002) proposed that social capital was a permanent contribution to the decision of whether or not to adopt a technology. Furthermore, farmers with a large labour force and those with neighbours using improved technology have better access to information and tend to be early adopters of technology.

The rationale for conducting this research was to establish the reasons or factors for the low adoption of technologies for postharvest loss reducing technologies among smallholder farmers. The research adopted the Unified Theory of Acceptance and Use of Technology (UTAUT) model to establish the factors affecting the adoption of the said technologies. In this regard, variables of knowledge expectancy, performance expectancy, effort expectancy, attitude towards using the technology, social influence and facilitating conditions were identified as factors influencing intent and behavior of users of postharvest loss reducing technologies. Age and education played a moderating role. The UTAUT Model which was developed by Venkatesh and other scientists aims to clarify user intentions to use an information system and successive usage behavior (Venkatesh *et al., 2003;* Venkatesh *et al.,* 2016 and Williams *et al*., 2015). The UTAUT model was used to assess the respondent's opinion towards the adoption of postharvest loss reducing technologies. With regard to testing the reliability of the results obtained in this study, Cronbach's Alpha Reliability Test Method was applied. The analysis of data from the study showed that Alpha Coefficient was at 0.681 which was close to 0.7. Since a higher value of Cronbach's Alpha Coefficient is considered to be a better measure of reliability it can be inferred that the results were reliable (Whitley, 2002; Robinson, 2009). The reliability of the study results was confirmed by the findings from the work done by Venkatesh *et al.,* (2003). Refer to Tables 4.10 and 4.11 for the reliability statistics and Cronbach's alpha results respectively.

Table 4. 10: Reliability statistics. Source: (Author)

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
	0.698	6

Table 4. 11: Cronbach's alpha results. Source (Author)

UTAUT Constructs	**Cronbach's Alpha**
Knowledge expectancy	0.656
Effort expectancy	0.501
Performance Expectancy	0.782
Attitude towards using the technology	0.650
Facilitating Conditions	0.598
Social Influence	0.580

4.26.1 Correlation analysis

Table 4.12 gives Spearman's correlation analysis which was used to evaluate the relationship among the six variables. Spearman's rank correlation coefficient is used to identify and test the strength of a relationship between two sets of data (Spearman, 1904; Liu *et al*., 2018). It's based on ranked values for each variable rather than raw data. Spearman's correlation is usually used to evaluate relationships involving ordinal variables. The relationships are normally illustrated using correlation coefficients (ibid). Notwithstanding the fact that correlation coefficients have drawbacks (such as not being able to explain non-monotonic associations), they are still popularly used because they are simple to use and the results are easy to deduce (Spearman, 1904; *Liu et al*., 2018).

The results from the study show that there was strong significant correlation between knowledge expectancy and performance expectancy ($p=0.05$). This means that there were differences between young and old farmers in the application of knowledge on postharvest management. Since the older farmers were more experienced they tended to have greater insights about postharvest management issues. In addition, there were differences in the application of knowledge in the postharvest losses between and among farmers based on gender (sex) as well as level of education ($p\leq0.05$). Similarly, attitude towards technology and facilitation expectancy; knowledge and effort expectancy; attitudes, facilitation, social influence and knowledge expectancy, respectively, affected the application of knowledge on postharvest management ($p\leq0.05$).

Attitude towards technology, facilitation conditions, social influence and performance expectancy, were insignificant ($p>0.05$). Here the differences didn't matter. That is, farmers with negative or positive attitude towards technology still managed to apply technologies on postharvest management. This actually makes sense especially in clusters where farmers use traditional or local technologies. The reason being that while farmers grow- up with traditional or local technologies, when it comes to modern technologies they require rigorous training for them to understand the operations of the said technologies.

Table 4. 12: Spearman's correlation (n=100).) Source: (Author)

	Age	Gender	Education	KE	EE	PE	AT	FC	SI
Age	1.000								
Gender	-.068	1.000							
	.502								
Education	-.181	.370	1.000						
	.072	.000							
KE	-.003	.184	-.020	1.000					
	.974	.067	.843						
EE	-.002	-.010	-.092	.463	1.000				
	.985	.922	.362	.000					
PE	.105	.101	.007	-.197	.014	1.000			
	.298	.317	.945	.050	.890				
AT	-.163	.007	.135	.477	.451	-.015	1.000		
	.105	.948	.180	.000	.000	.879			
F	-.070	.133	-.150	.301	.598	.071	.227	1.000	
	.491	.187	.136	.002	.000	.484	.023		
SI	.093	-.010	-.162	.480	.737	-.047	.301	.413	1.000
	.356	.923	.108	.000	.000	.639	.002	.000	

Correlation is significant at the 0.05 level (2-tailed).

4.26.2 Descriptive analysis

This section attempts to provide a better understanding of reasons behind the farmers' adoption or low adoption of postharvest loss reducing technologies. All the items under the study had 5 interval scores, with 1 being the lowest score while the highest score was 5.

4.26.3 Knowledge expectancy

As indicated in Table 4.13 most of the respondents gave a 4 and 5 score for knowledge expectancy, and that their interaction with postharvest loss reducing technologies was easy to understand. The technologies and practices which the farmers were familiar with included; use of polythene bags recommended by FRA, application of pesticides to grain, use of ferrumbus, use of cow dung and plant extracts. The practices were growing of storage insect tolerant maize varieties, stooking of maize in the field and practicing hygiene in grain stores. The respondents (89%) understood the benefits of using postharvest loss reducing technology in maize. With respect to recalling the use of technology, 61% of the respondents reported that it was easy for them to remember how to perform the tasks using PHL reducing technologies they were familiar with. While female farmers faced challenges in mixing of insecticide dusts with maize, other farmers had problems recalling the mixing ratios of the pesticides. The respondents (59%) were of the view that their interaction with PHL loss reducing technologies was easy to understand.

Table 4. 13: Knowledge expectancy (KE). Source: (Author)

Variable	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
KE1: I understand the benefits of using PHL technologies to reduce maize losses	2 2.00%	1 1.00%	8 8.00%	49 49.00%	40 40.00%
KE2: It's easy for me to remember how to perform the tasks using PHL technologies	2 2.00%	9 9.00%	22 22.00%	49 49.00%	18 18.00%
KE3: My interaction with PHL technologies is easy for me to understand	3 3.00%	11 11.00%	27 27.00%	42 42.00%	17 17.00%

4.26.4 Effort expectancy

The results in Table 4.14 reflect the insight of respondents on effort expectancy. With respect to effort expectancy, 73% of the respondents found postharvest reducing technologies they were familiar with easy to use. Fifty four per cent of the respondents reported that they had found it easy learning how to operate postharvest loss reducing technologies. Moreover, the respondents reported (51%) that they rarely got confused when using postharvest loss reducing technologies. Forty five percent of the respondents were of the view that they rarely got frustrated when using postharvest loss reducing technologies. With regard to making errors when using postharvest loss reducing technologies, 32% of the farmers confirmed making errors while 36% rarely made errors. The rest were not clear about the errors they made when undertaking postharvest activities.

Table 4. 14: Effort expectancy (EE). Source: (Author)

Effort expectancy	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
EE1:Learning to operate some of the PHL technologies was easy for me	2 2.00%	13 13.00%	31 31.00%	41 41.00%	13 13.00%
EE2: I rarely become confused when I use the PHL technologies	1 1.00%	22 22.00%	26 26.00%	41 41.00%	10 10.00%
EE3: I rarely make errors when using PHL technologies	5 5.00%	27 27.00%	32 32.00%	28 28.00%	8 8.00%
EE4: I rarely get frustrated when using PHL technologies	3 3.00%	20 20.00%	32 32.00%	34 34.00%	11 11.00%
EE5: Overall, I find PHL technologies easy to use	2 2.00%	3 3.00%	22 22.00%	62 62.00%	11 11.00%

4.26.5 Performance expectancy

Most of the respondents gave a score of five on this construct. Generally the interviewees agreed that postharvest loss reducing technologies would make them more productive through quicker accomplishment of tasks and thereby having greater control over their work. The opinion of 92% of respondents towards acquisition of postharvest loss reducing technologies was that it would enable them accomplish postharvest tasks faster. The use of postharvest loss reducing technology would enable respondents (92%) save time which could be used for other productive activities. Furthermore, using PHL reducing technologies would reduce the amount of time interviewees (85%) spent on unproductive activities. With regard to technology appropriateness, (81%) of the respondents considered some of the postharvest loss reducing technologies to be rigid and inflexible to interact with. The case in point was technologies such as cement bins (ferrumbus) and large capacity metal bins which could not be moved in the event of a farmer relocating to a new location. Table 4.15 provides summarized information of performance expectancy.

Table 4. 15: Performance expectancy (PE). Source: (Author)

Performance Expectancy	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
PE1: Using PHL technologies gives me greater control over my work	2 2.00%	3 3.00%	14 14.00%	56 56.00%	25 25.00%
PE2: PHL technologies enable me accomplish tasks quicker	0 0.00%	1 1.00%	7 7.00%	65 65.00%	27 27.00%
PE3: Using PHL technologies reduces the amount of time I spend on unproductive activities	2 2.00%	4 4.00%	9 9.00%	52 52.00%	33 33.00%
PE4: Some of the PHL technologies are rigid and inflexible to interact with	8 8.00%	5 5.00%	5 5.00%	37 37.00%	45 45.00%
PE5: Using PHL technologies saves me time	0 0.00%	3 3.00%	3 3.00%	48 48.00%	44 44.00%

4.26.6 Attitude towards using technology

Table 4.16 shows the views of interviewees on attitude towards using PHL technologies. Majority of the respondents were of the opinion that using postharvest loss reducing technologies was a good idea. Ninety two per cent of the interviewees were of the view that using postharvest reducing technology on their farms was a wise idea while 91% considered use of technology on their farms would be a positive move. Furthermore, the opinion of 89% of the respondents was that using postharvest reducing technology on their farms would be a good idea whereas 84% considered using technology as favourable.

Table 4. 16: Attitude towards using technology. Source: (Author)

Attitude towards using technology	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
ATT1: All things being equal, my using of technology on my farm is good	0 0.00%	3 3.00%	8 8.00%	56 56.00%	33 33.00%
ATT2: All things being equal, my using of PHL technologies on my farm is wise	0 0.00%	1 1.00%	7 7.00%	56 56.00%	36 36.00%
ATT3: All things being equal, my using of PHL technologies on my farm is favorable	1 1.00%	2 2.00%	13 13.00%	59 59.00%	25 25.00%
ATT4: All things being equal, my using of PHL technologies on my farm is positive	1 1.00%	1 1.00%	7 7.00%	55 55.00%	36 36.0 0%

4.26.7 Facilitating conditions

With regard to facilitating conditions 91% of the respondents agreed to strongly agree that they had resources to use in the acquisition of postharvest reducing technologies. The availability of knowledge and ability to use some of the postharvest reducing technologies were given a rating of 73% and 74 % respectively. The ability to confidently use and having control over some of the postharvest loss reducing technologies were given a 67% and 64% evaluation by the respondents. Summarised information is in Table 4.17.

Table 4. 17: Facilitating conditions. Source: (Author)

Facilitating Conditions	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
FC1: I am able to confidently use some of the PHL technologies	1 1.00%	5 5.00%	27 27.00%	53 53.00%	14 14.00%
FC2: I have the knowledge to use some of the PHL technologies	2 2.00%	2 2.00%	23 23.00%	59 59.00%	14 14.00%
FC3: I have the resources to acquire some of the PHL technologies	1 1.00%	2 2.00%	6 6.00%	69 69.00%	22 22.00%
FC4: I have the ability to use some of the PHL technologies	1 1.00%	5 5.00%	20 20.00%	57 57.00%	17 17.00%
FC5: I have control over some of the PHL technologies	4 4.00%	9 9.00%	23 23.00%	52 52.00%	12 12.00%

4.26.8 Social influence

The respondents reported that their intention to adopt PHL technologies was influenced by close friends, peers, influential people and opinion leaders in the community. Eighty eight percent of the interviewees confirmed that close friends had a high level of influence on their adoption of technologies. Eighty six percent of the respondents expressed the view that people in the community whose opinion they valued preferred that the farmers use postharvest loss reducing technologies. The other category which had an influence on the respondents' (73%) technology adoption included people considered important in society. The respondents (72%) reported that peers influenced the adoption of postharvest loss reducing technologies. Table 4.18 provides a summary of interviewees' perception of social influence on using PHL technologies.

Table 4. 18: Social influence. Source: (Author)

Social Influence	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
SI1: People who influence my behavior think I should use PHL technologies	4 4.00%	2 2.00%	21 21.00%	50 50.00%	23 23.00%
SI2: People who are important to me think I should adopt PHL technologies	1 1.00%	1 1.00%	15 15.00%	61 61.00%	22 22.00%
SI3: My close friends think I should adopt PHL technologies	2 2.00%	1 1.00%	9 9.00%	31 31.00%	57 57.00%
SI4: My peers think I should adopt PHL technologies	1 1.00%	5 5.00%	22 22.00%	52 52.00%	20 20.00%
SI5: People whose opinions I value prefer that I use PHL technologies	2 2.00%	1 1.00%	11 11.00%	59 59.00%	27 27.00%

The low rate of adoption of newly pioneered technologies and techniques can be explained by lack of awareness (Vermaut, 2017). It’s important to understand how individuals and institutions manage these innovations as successful application was dependent upon their acceptance and use (ibid).

4.27 Research Discussion and Development of Models

This sub-chapter discusses the research findings. The study established that smallholder farmers experienced postharvest grain losses which varied across seasons, and was influenced by labour availability, gender, education and resource base. The farmers reported grain losses during harvesting, transportation from the field, drying, shelling and storage for home consumption. Due to labor constraints and weak resource base female headed households experienced more losses than male headed households. Smallholder farmers that had received secondary and tertiary education experienced fewer losses as they had more disposable income for investing in storage pest control, hiring additional labour for harvesting, shelling and processing stages of the maize value chain. Postharvest losses tended to be more severe during the years which were associated with a bumper harvest because farmers had large quantities of maize to handle. The guess estimates given by farmers were that for every ox - cart load of the harvested maize (6 - 7 x 50 kg bags), at least 20 kgs of grain was lost during harvesting due to cobs being left in the field, and damage by livestock, insects, rodents and mould.

Manandhar *et al.,* (2018) and FAO (2011) established that postharvest losses occurred due to technical, managerial and financial challenges during harvesting, storage and preservation in the developing world. Furthermore, Abbas *et al.,* (2017) found that pre-harvest and postharvest operations such as drying, shelling, winnowing, sorting, transportation and storage were manually conducted by smallholder farmers in developing countries because of the low levels of investment in agricultural mechanization.

The smallholder farmers in the study areas were using grain storage structures which included nkokwe, wooden platforms, dwelling houses, roofs and fireplaces. This finding is confirmed by an FAO (2017) report that smallholder farmers in developing countries use on-farm and domestic storage systems which include local cribs, wooden platforms, roofs, fireplaces, structures/bins fabricated with steel net or wire, and underground pits. Similar findings by Manandhar *et al.,* (2018) were that smallholder farmers in the developing world use traditional grain storage structures and handling systems like cribs for grain storage and woven bags. However these structures cannot protect the already insect infested grain and are not effective against mould (ibid). Kumar and Kalita (2017) added to this discussion by reporting that most smallholder farmers in Kenya and Malawi used nkokwe (traditional cribs) for storage of maize grain.

In order to improve the effectiveness of the traditional systems that farmers were using for storage of grain, some of them applied chemicals such as actellic super and aluminium phosphide and to small extent natural additives such as leafs of *Gliricidium sepium*, ashes, and cow dung. Some farmers did not apply any chemicals to their maize because of lack of conviction about the safety of the treated grain. There was exposure of smallholder farmers to harmful pesticides such as fumigants which were supposed to be handled by trained personnel. Due to inadequate knowledge about chemical control measures by smallholder farmers, there was misuse of fumigants as they were applied for preventive rather than curative purposes. This finding is supported by Manandhar *et al.,* (2018) who found that in many countries, phosphine was handled by licensed personnel.

According to Nagnur *et al.,* (2006) and Murdock (2003) as reported by Manandhar *et al*., (2018) smallholder farmers mix the maize grain with chemicals and natural preservatives such as plant leafs, and ashes. They further contend that the use of chemicals and different additives together with the traditional storage systems can protect grain from pests such as mould, insects and rodents (ibid). From related studies, Manandhar *et al.,* (2018) and Hodges (1986) report that methyl bromide and phosphine or phostoxin (commercial name) are used as fumigants for grain stored in metal silos, cemented or mud plastered granaries in developing countries. Additionally, insects such as *Prostephanus truncatus* can easily be controlled using fumigants in grain with less than 13% moisture content. However, Abass *et al., (2017)* argue that the use of insecticides to staple foods should be avoided and that maize treated with Actellic super is not liked by smallholder farmers because it has a different taste from that of untreated maize.

The thesis established that although a broad range of technologies and practices were available which could improve grain quality and reduce the quantity of grains lost during postharvest handling and storage (World Bank *et al.,* 2011, Kiaya 2014) the smallholder farmers in the study areas were not were not aware of their availability, associated benefits and cost of these innovations. The available technologies which the smallholder farmers could use included the hermetic storage, metal silos, plastic drums, burnt brick and cemented bins and pesticides. Other solutions included training in improved grain handling and storage and institutional arrangements such as the warehouse receipt system (WRS). The determinants of the technology choice included the level of production, climatic conditions and willingness and capacity to pay, which had social, educational, cultural and economic implications for adoption. Therefore, the identification and elimination of constraints to the application of existing technologies is a prerequisite to the reduction of postharvest losses

4.27.1 Technologies and practices available to smallholder farmers in Zambia for reducing postharvest maize losses

As indicated in figure 4.25 the technologies and practices which were available to smallholder farmers for the reduction of postharvest losses of maize grain included; chemical pesticides, hermetic storage (PICs bags, zero fly bags, super grain bags, metal and plastic drums, metal silos, burnt brick silos, ferrumbus), metal ox-carts, motorised maize shellers, growing of composite varieties, stooking during harvesting, training in postharvest management and the warehouse receipt system.

4.27.1.1 Chemical pesticides

One of the challenges faced by the world is that of protecting crops from insect damage leading to widespread misuse of chemicals for pest management (Kitinoja *et al.,* 2010). Various life stages of insects cause economic damage and affects the quality of food grains in farmers' stores and public warehouses (Upadhyay and Ahmad, 2011). The synthetic chemicals are traditionally used for control of insects and their harmfulness puts the health of farm workers, livestock and consumers at risk. This has led to the revival of interest in bio-pesticides due to their low environmental side effects and cost (Hikal *et al.,* 2017). The use of plant compounds such as oils, esters and fatty acids, and alkaloids has become an alternative to chemical compounds like repellents, growth retardants, attractants and feeding deterrents. One of the advantages of botanical pesticides is that of being selective in their control of insects as they do not kill beneficial natural enemies, provide residue free food and are environmentally friendly (Hikal *et al.,* 2017; Upadhyay and Ahmad, 2011).

In several studies, oil extracts and leaves of wormseed *(Chenopodium ambrosioides* L) (Chenopodiaceae) were reported to be used to control insect pest damage during storage. Kalita and Kumar (2017) found that certain plant species and their extracts with natural pesticide ability were traditionally used to protect grains in several African and Asian countries.

In a study conducted by Kumar *et al.,* (2007) on effectiveness of oil from wormseed in control of fungal damage in wheat, compared with synthetic fungicides such as Benzimidazole (Benomyl), the oil was found to be more effective with minimum inhibitory concentration lower than that of fungicides. In another study involving crude cotton oil and soya beans oils, only the former showed significant effectiveness in controlling *Sitophilus* zeamais in maize in the first 4 months after storage. Other studies have shown that *Gliricidium sepium* can control fungal, insect or viral attack in crops and it has been reported that its mulch has fungicidal properties (Steward, 1966) as cited in CABI (2018). The main challenge with use of plant materials as pesticides is that of low oil yields which might be expensive to use on a commercial basis although certain plant leaves can be used by smallholders as natural insecticides (Kumar and Kalita, 2017**).**

4.27.1.2 Hermetic storage

According to the Standing Committee for Economic Commercial Cooperation of the Organization of Islamic Cooperation (COMCEC) (2016), drying and storage are considered to be the most probable postharvest loss points in the grain value chain. Arising from its flexibility, hermetic storage system has been used to store a few kilograms to many tons of grain in sub-Saharan Africa (Abass *et al.,* 2017).

Hermetic Storage (HS), which at times is referred to as airtight or sealed storage is becoming a popularly used storage method for grains and other crops in the developing world because of its effectiveness and non-use of pesticides (Manandhar *et al.,* 2018 and World Bank, 2011). The additional advantage of HS includes its ease of installation, use of simple infrastructure and favorable cost. The hermetic storage method forms an automatic modified atmosphere of high carbon dioxide concentration using waterproof plastics or materials. Since the structures are airtight, the biotic component of the grains develops a self-inhibitory atmosphere over time due to increased carbon dioxide concentration caused by its respiration metabolism (Rodriquesz *et al.,* 2008; Kumar and Kalita, 2017). The carbon dioxide concentration in the hermetic structures indicates the biological activity of grains. Permeability of the plastic bag and the gas partial pressure affects the movement of the oxygen and carbon dioxide in and out, whereas concentration of these gases in the bag is influenced by the balance between these exchanges and the respiration of the grain (ibid). Furthermore, due to increased respiration, higher initial moisture content tends to increase the carbon dioxide concentration (Rodriquesz, *et al.,* 2008). Hermetic storage has been known to be very effective in preventing storage losses (less than 1%) during long distance shipments (Kumar and Kalita, 2017). Results from Action Research Trials conducted in Uganda and Burkina Faso by the World Food Programme showed that hermetic storage units were very effective in killing insect pests without use of any fumigants (Costa, 2014).

Several hermetic storage options such as supergrain bags, Purdue Improved Crop Storage (PICS) bags and metal silos have been developed and are extensively under promotion (Kumar and Kalita, 2017). These bags are viewed as cost - effective and practical storage technology being widely promoted in several countries (Costa, 2014). PICS bags which were originally produced for storage of cowpeas, involve a triple bagging of the grain hermetic atmosphere. The bag is made of a double thick layer (80 µm) high density polyethylene (HDPE) and has a third woven nylon bag. Once the bags are fully loaded with grain, they are sealed airtight. This cuts off oxygen to any insects in the bags of grain and disturbs their metabolic pathways and kills them by dehydration (Murdock *et al.,* 2012).

The Purdue Improved Crop Storage Bags (PICS) technology has been adopted by many African and Asian countries. In 2016 private sector in Africa and Asia sold 2.8 million bags making the bags sold since 2007 to reach more than 10 million bags (Smith, 2015). Between 2007 and 2017 the PICS programme trained 5 million farmers in 56,000 villages in sub-Saharan Africa (ibid). There has been an increase in the number of farmers adopting the PICS technology because:

i. Its efficient and cost effective;
ii. Postharvest loss is a big challenge among grain traders and smallholder farmers; and
iii. It offers a cheaper solution than other feasible and competitive technologies.

The creation of awareness of the PICS technology has been conducted by agro dealers, NGO/donor supported projects and the World Food Programme. The PICS partners provide awareness, training, media activities and conducting regular road shows. Furthermore, PICS bags are incorporated into programmes for:

i. School feeding
ii. Postharvest loss mitigation
iii. Health and nutrition
iv. Food security
v. Seed security
vi. Climate change adaptation and resilience

The consolidation of the distribution networks for expanding the sales of PICS bags should involve:

i. Use of information communication technology (ICT) such as mobile phones to fast track access to the PICS technology;
ii. Recruitment and capacity building of vendors/distributors;
iii. Developing a joint market strategy with vendors/distributors; and
iv. Develop last mile distribution.

The supergrain bag technology commercially produced by GrainPro Inc. is another commonly used hermetic storage and water resistant and option (Kumar and Kalita, 2017). These bags are made of a single thick layer of high density polypropylene (78 µm) and used as liner along normal woven polypropylene. The other option for hermetic storage is ZeroFly bags which are made with a pyrethroid incorporated polypropylene yarns and designed to prevent pest infestations (Kumar and Kalita, 2017). These bags are a product of Vestergaard, Switzerland.

4.27.1.3 Metal silos

A metal silo is a strong hermetically sealed structure (usually cylindrical), built using galvanized steel sheets (FAO, 2008, Yusuf & He, 2013; Kumar and Kalita, 2017). The structures have been found to be very effective for grain storage over long periods of time and preventing insect and rodent damage (Tefera *et al.,* 2011; Abass *et al.,* 2017). Metal silos can also be made from painted aluminum sheeting which prevents corrosion and improves their appearance (FAO, 2008; Yusuf & He 2013, Kumar and Kalita, 2017). Metal silos are considered as one of the critical technologies for reducing postharvest losses and improving food security of smallholder farmers (Abass *et al.,* 2017; Kumar and Kalita, 2017). The adoption of metal silo technology by smallholder farmers, however, remains low due to the relatively prohibitive initial investment cost and limited technology for metal silo fabrication (World Bank, 2011; Manandhar *et al.,* 2018).

Figure 4.25: Technologies and practices for reducing postharvest maize losses available to smallholder farmers in Zambia. Source: (Author)

Results from a study done in West Africa by Baoua *et al.,* (2018) in which a comparison was made between the performance of PICS bags and SuperGrain bags showed that grain damage by the cow pea weevil (*Callosobruchus maculatus)* was lower under PICS bag storage. In another comparative study of the efficacy of metal bins and hermetic bin bags (Supergrain and GrainSafe) conducted in India by Somavat *et al*., (2015) showed that after 9 months of storage there was no insect pest attack of clean wheat grains stored in hermetic bags. With regard to the artificially infested grains, there was a 2% to 8% bored grains for metal silos and 0.33% grain damage for hermetic bags. The results from a study done in Burkina Faso and Ghana to evaluate the performance of PICS bags and woven bags (50 Kg capacity each) for maize storage showed insect infestation varying from zero to greatly infested (Baoua *et al,.* 2018). After six and half months of storage, PICS bags indicated 95%-100% insect pest mortality and had preserved the 100 seed grain weight, viability and germination. In addition, moisture content of maize in PICS bags remained unchanged. The aflatoxin levels in maize stored in woven bags was higher than that of PICS bags (Baoua *et al.,* 2018).

4.27.1.4 Warehouse receipt system

Warehouse Receipt System (WRS) or inventory credits are another practice available for smallholder farmers to use in reducing postharvest grain losses. The Zambian Commodity Exchange (ZAMACE) started operations 2016. It's the authorized agency for implementing the warehouse receipt system under the Agriculture Credits Act of 2010 (ZAMACE, 2017). As of 2017, ZAMACE had registered 7 certified warehouses which increased to 11 by 2019. A warehouse receipt is a document issued by warehouse operators as evidence that specified commodities have been deposited at a particular location. The warehouse receipt has the potential to improve the supply of rural finance by directly easing collateral constraints and simultaneously enhancing the risk profile of farmers by fostering improvements in output markets that can lead to higher farm incomes (ZAMACE 2016). Furthermore, the WRS does not only remove the challenges of the farmer having to physically move the commodity when trading but also removes the storage burden of a farmer as they wait to sell the commodity at a future date (ibid). When supported by legal provisions these receipts are called warrants. They guarantee quality, offer a secure system under which the stored agricultural commodities can operate as collateral, traded or used for delivery against financial instruments such as futures contracts. These receipts state the ownership of a given quantity of commodities with detailed characteristics and stored in a particular warehouse (ZAMACE, 2016).

The WRS has the following benefits:

- Leveling market prices by facilitating commodity sales during the entire year as opposed to just after harvest;
- Credit mobilization to agriculture by establishing secure collateral for the producers, processors and traders;
- Reducing transaction costs by guaranteeing quantity and quality;
- Contribution to the reduction of postharvest losses due to better storage conditions - i.e. it encourages farmers to store in proper warehouses;

- Enhancing market power of smallholder farmers by facilitating the point in the price cycle at which they sell their crops;
- Improving credit access and food security in rural areas through reduced risk in agricultural commodity markets;
- Assisting to upgrade the standards and transparency of the storage industry through better regulation and inspection;
- Offers a way of decreasing the role of government in agricultural commercialization; and
- Facilitating the establishment of commodity markets with market information and international trade and boosts competition in the industry (ZAMACE, 2019).

ZAMACE estimates that as of 2019 the participation of smallholder farmers in the Exchange activities was not more than 30%. One critical area which ZAMACE has failed to deliver to the grain depositors is payment of advance money against the issued receipts prior to selling of the maize. This is one space which ZAMACE hopes to resolve with the Ministry of Agriculture, who are the principal Appointee of the Exchange.

The views of ZAMACE regarding maize losses in Zambia, was that smallholder farmers incurred losses due to poor handling and inadequate storage. The losses at industry level were due to poor handling caused by negligence. While the industry standards allowed grain losses to a maximum of 3%, the companies that were certified by ZAMACE fell in the region below 1%. On the government side, the Food Reserve Agency had tremendously reduced losses due to a reduction in the grain purchased from 2 million tons to 500,000 tons. Furthermore, there had been an increase in skills and grain quality management to an extent that the grain from FRA storage facilities had become comparable to any other private sector store.

The dearth of access to credit is a major challenge for many smallholder farmers (Giovannucci, 2000). Making credit available to farmers has always been a challenge particularly where the industry is dominated by smallholders (Shalendra *et al.,* 2016). They further observe that the situation has been made more difficult by the lack of collateral by the smallholders. The Warehouse Receipt System offers a viable avenue for the delivery of credit to smallholder farmers as it permits the use of stored stocks of commodities as collateral against the loan (ibid). Warehouse receipts are an important and effective instrument for generating liquidity and improving access to credit (Giovannucci *et al*., 2000). The additional benefits of such schemes includes leveling the supply of commodities and prices in the market, improving incomes of farmers and reducing postharvest losses (ibid).

Although the Warehouse Receipt System (WRS) had the potential to improve access to credit by particularly smallholder farmers facing challenges to access credit, the development of the process of obtaining loans against the warehouse receipts remains underdeveloped in Zambia (ZAMACE, 2015).

4.27.1.5 Stooking of maize during harvesting

Stooking of maize during harvesting is one of the practices which farmers were using to reduce losses of maize cobs not harvested from the field. This harvesting method is more commonly practiced in male-headed households where labour constraint is not critical as in female-headed households. Smallholder farmers in developing countries undertake postharvest operations manually because of low level of mechanization (Abass *et al.,* 2014 and Manandhar *et al.,* 2018).

4.27.1.6 Motorised shellers

Since farmers experienced the highest percentage of postharvest losses during shelling of maize, the use of motorized shellers could contribute to a reduction in grain losses. The reasons for the higher losses included spillage, scattering of grain when beating with sticks, cracking of grain from the impact of sticks (especially when the grain is not sufficiently dry), consumption by domestic animals and the long period of undertaking this operation. When the moisture content of maize is above 12%, shelling using sticks can cause grain damage such as cracking and pulverization (FAO, 1997). Therefore the use of mechanised shellers can reduce the amount of time taken to complete shelling and the quantity of grain which gets damaged. The problem in Zambia at the moment is the low numbers of farmers or entrepreneurs that provide the shelling service in the villages. It's reported by FAO that agricultural mechanisation plays an important role in post-production activities such as harvesting; shelling, packaging transportation and marketing of farm produce (FAO, 2018).

4.27.1.7 Training in postharvest management

Training of smallholder farmers in postharvest management is another approach which can contribute to the reduction of postharvest losses. During the course of the study the author was involved in training of 300 small-scale grain traders and smallholder farmers in Malawi, Mozambique and Zambia. The objective of the training was to strengthen the capacity of smallholder farmers and grain traders to reduce post-harvest losses of maize during handling and marketing and to transition from bags to bulk storage. The results of the post training follow-up indicated an increase in the quality and quantity of grain marketed by individuals that participated in grain handling training (Chikoye *et al.,* 2017). The evaluation further revealed that small-scale grain traders had no use for the 30 ton metal silos storage structures which were being promoted by donors because they sold their maize to millers soon after buying it from farmers. Furthermore, smallholder farmers preferred one ton metal silos because of the cost effectiveness and suitability to the operating environment of the target group (ibid). These results demonstrated the benefits of strengthening the capacity of actors along the postharvest value chain (Chikoye *et al.,* 2017).

These results were underpinned by the AUC-FAO (2012) finding that capacity building of smallholder farmers contributes to the reduction of postharvest food losses. Likewise, Kaminski and Christiansen (2014) reported that when training of smallholders is supported by access to the market and enhanced infrastructure it can greatly contribute to a reduction in postharvest losses. However, Gitonga *et al.,* (2013; 2015) argued that adoption of some technologies by smallholder farmers might increase the costs of labour and capacity building.

4.27.1.8 Targeting of farmers operating in groups

The most common approach used in most postharvest loss interventions has been to target individual farmers or grain traders rather than going through farmer led business entities such as cooperatives, farmer organisations, community producer companies, community agro dealers or any other business entities run by farmers or grain traders. Where attempts of targeting traders or farmers through institutions like what was done in Eastern province of Zambia and Angonia region of Mozambique during the SADC Grain Management Training Programme run in the mid-2000s, the maize trading activities continued well after the project life ((Chikoye and Chisala, 2006). For example, in Mozambique where the grain traders operated under an association, they won a tender to supply maize to the World Food Programme (WFP). In instances where the project targeted individual grain traders, it was difficult for them to win big contracts because they lacked economies of scale for bulking huge quantities of grain for supply to large grain marketing companies (Chikoye and Chisala 2006).

The training in grain handling should target cooperative management, cooperative extension workers, cooperative zonal leaders, community agro dealers (CADs) and lead farmers (LFs) who would in turn train farmers using the Farmer Field Schools (FFS) Model. The benefit of providing training to farmers is that once their knowledge and skills in grain handling is strengthened it might trigger interest in the acquisition of postharvest loss reducing technologies.

4.27.1.9 Domestication of postharvest projects

The Artisans that were trained in the manufacturing of metal silos in Katete District during the CIMMYT supported Effective Grain Storage Project (EGSP, Phases I and II), implemented in Kenya, Malawi, Zambia and Zimbabwe between 2012-2016 did not take manufacturing of silos as a business. During the study, some Artisans trained under the EGSP I and II confirmed that the project was designed in such a way that the silos they manufactured were supplied to the project and not sold directly to the smallholder farmers. The Artisans were not supposed to directly deal with the farmers that wanted to have silos fabricated. This approach did not promote institutionalisation and sustainability of the project intervention.

On the other hand, during implementation of the Postcosecha project in five Latin American countries (El Salvador, Guatemala, Honduras, Nicaragua and Peru) in the period 1983-2009, there was an increase in the number of metal silos distributed to farmers after the Swiss Agency for Development Corporation (SDC) withdrew support in 2003 (Streit., and Bauer.R. 2015; SDC, 2008; FAO, 2017). Of the 670,000 silos distributed under the Postcosecha project nearly 46% were distributed during the period 2004-2009 after SDC support had ended in 2003 (ibid). This was a clear demonstration of institutionalisation and sustainability of project intervention which was not found in postharvest intervention projects that had been implemented in Zambia and the SADC region. The foregoing highlights the importance of incorporating project activities into local programmes for sustainability purposes.

CHAPTER 5: MODELS OR FRAMEWORKS FOR INCREASING THE ADOPTION OF POSTHARVEST LOSS REDUCING TECHNOLOGIES

5.1 Introduction

"You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete" – Buckminster Fuller

This chapter presents models for increasing the adoption of postharvest loss reducing technologies which were developed using research findings and review of literature. The models developed were the Community Agrodealer Postharvest Management Model (CAD-PhMM) and the Farmer Cooperative Postharvest Management Model (FCPhMM). The CAD-PhM Model is suitable in locations where Community Agrodealers (CADs) run business in rural areas while the FCPhM Model is recommended for locations where farmers operate commercial cooperatives. Therefore, manufacturers or promoters of postharvest loss reducing technologies should target community agro-dealers (CADs) or farmers that are members of business oriented organisations such as cooperatives for technology diffusion.

5.2 Community Agro-Dealer (CAD) Model

In Zambia, community agro-dealers (CAD) are legally registered as business entities which normally operate in rural areas. An agro-dealer is a "locally-based entrepreneur who sells seeds, fertilizers and agro-chemicals to poor farmers in remote areas" (Chinsinga, 2011, p.5). Agrodealers are small-scale independent stockists or input dealers who play an important role in distributing agricultural inputs (Odame and Muange, 2012). Community agrodealers are those stockists or entrepreneurs that operative in rural areas. Agrodealers play a crucial role in the input value chain by ensuring farmers access to agricultural inputs and at times provide output markets (Poulisse, 2007). This model is driven by profit seeking individuals who at times operate on commission basis from manufacturers or suppliers of inputs. A community agro-dealer is usually both a farmer and agribusiness person in the community. This model creates business linkages involving CADs, farmers and private sector. The demand for goods and services by the farmers is created through demonstrations conducted by the CADs. The CADs acquire and sell agro inputs and technology from private suppliers as commission earners. Other services such as land preparation, planting, crop protection, and commodity aggregation and storage of produce are provided by CADs in response to market demand. Aggregation of inputs, technology and produce assists to meet the market volumes resulting in reduced transaction costs. The business linkages built with private sector ensure sustainability of the operations of CADs. In so doing, a CAD operates as the centre for promoting business in the community for both external input and technology providers and producers.

Under the CAD model each CAD works with five lead farmers (LFs) who in turn work with 20-50 farmers (see figure 5.1). Some of the CADs operate as agents for agro input suppliers from big towns or town based large agro-dealers. Certain CADs operate as agents for seed companies and pesticide suppliers because they are located at community level. The CAD set-up facilitates the availability of agro inputs at village level. The CADs are trained and mentored by large agro-dealers or town based input suppliers.

After the training, CADs with the help of lead farmers, promote new products by carrying out demonstrations to farmers.

The CADs and LFs provide knowledge and skills on improved production practices and appropriate technologies. This is the channel which can be used to diffuse some of the postharvest loss reduction technologies to the rural based smallholder farmers. The CAD Model has been very successful in six districts of Eastern province of Zambia where it was used under the USAID supported Feed the Future Program (FFP) which ran from 2011 – 2016.

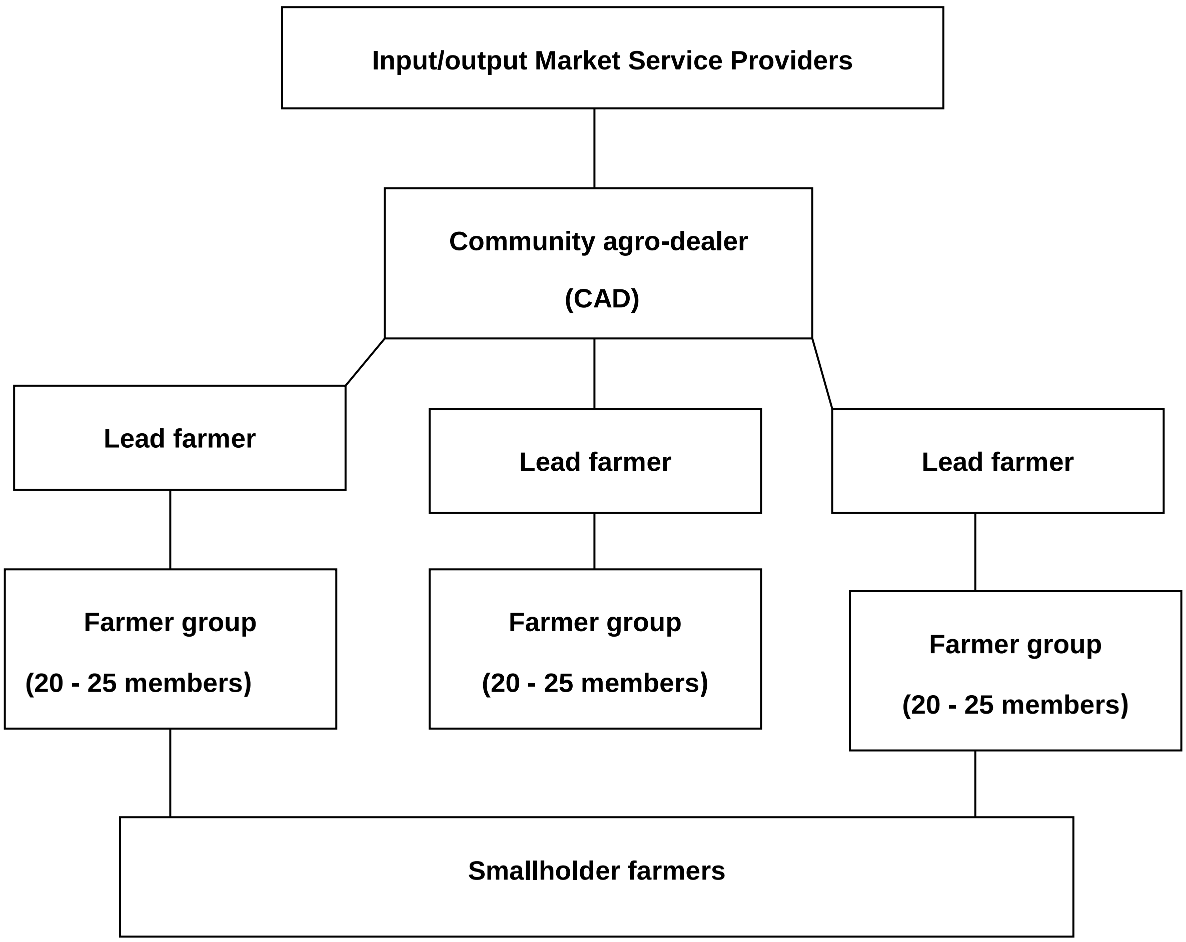

Figure 5. 1: Community Agro Dealer Model. Source: (Author)

5.2.1 The community agrodealer postharvest management model

The Community Agrodealer Postharvest Management Model (CAD-PhMM) has been developed out of the CAD-model. The CAD-Postharvest Management Model involves the manufacturers or suppliers of technology channeling their innovations through the CADs to the smallholder farmers. This model further brings on board training and extension providers. The role of training and extension is to provide additional support to CADs and lead farmers on the availability and operations of the postharvest loss reducing technology. Figure 5.2 demonstrates the CAD-Postharvest Management Model.

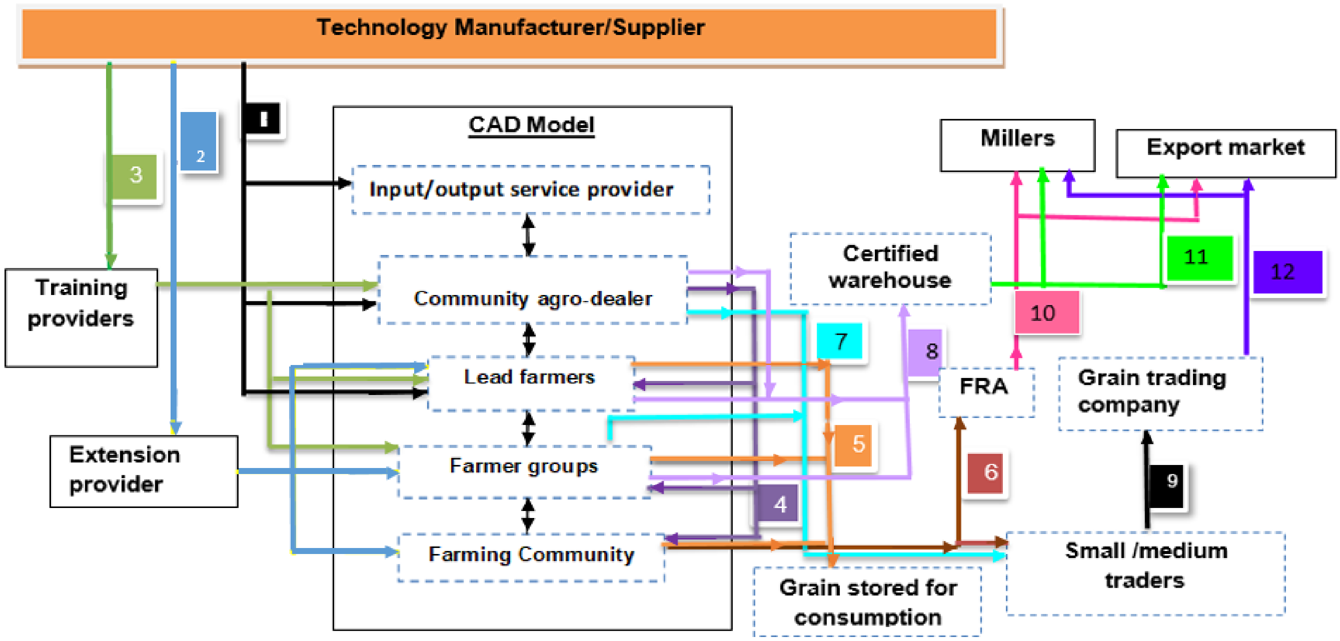

Figure 5. 2. CAD Postharvest Management Model. Source: (Author)

Key for the CAD Postharvest Management Model

1 Technology manufacturer can engage input/output service providers and community agrodealers (CADs) to market their technology on commission basis. Furthermore, the technology provider trains CADs and lead farmers on operations of the technology.

2 The extension providers get information from the manufacturer about the available technology. The extension provider subsequently passes this information to lead farmers, farmer groups and at times smallholder farmers at community level.

3 Training provider gets information from the manufacturer of technology. Thereafter, the training provider trains community agro dealers, lead farmers and farmer groups on the available postharvest reducing technologies.

4 On the output market side, the CAD buys grain from lead farmers, farmer groups and smallholder farmers at community level.

5 Lead farmers, farmer groups and smallholders at community level store grain for consumption at household level.

6 Smallholder farmers at community level can sell their maize to small/medium scale grain traders and FRA.

7 CADs, farmer groups, smallholder farmers at community level can sell maize to small/medium scale grain traders who subsequently sell the grain to commodity trading company.

8 CADs, farmer groups and lead farmers can deposit the bulked grain into certified warehouses.

9 Small/medium grain traders sell their maize to grain trading companies.

10 FRA can sell its maize to millers and export markets.

11 Certified warehouse can sell its grain to millers or export market.

12 Grain trading company can sell its grain to millers or export markets.

5.3 The Farmer Cooperative Business Model

A cooperative is an association of persons that is owned and controlled by people to meet their economic, social and/or cultural needs and aspirations through a jointly owned and democratically controlled business (LaMarco, 2018; BC COOP, 2020; ICA, 2020). Cooperatives usually tend to be more focused on providing services to members than in investment. A cooperative can be created for several different reasons or to fulfil a number of different needs, joint processing of products, purchasing and marketing (bulk purchases or sales) (ICA, 2020).

Input and marketing cooperatives are established by farmers to undertake supply of inputs, and marketing of produce and facilitate access to technology. Although various types of cooperatives play an important role in promoting rural development, dairy cooperatives have special characteristics which make them suitable (Uotila and Dhanapala, 1994) for promoting PHL reducing technologies. They further report that these attributes include promotion of development in remote rural economies, which contributes to improvements in the standards of living of the rural farmers (ibid). Smallholder dairy farming cooperatives provide regular income to the farmers than field crop production where farmers normally access cash once in a season after selling their harvest crops (Mumba, 2012). In addition, smallholder dairy farming assists farmers to get involved in the mainstream of cash economy and wealth creation. Although the daily operations of the cooperatives are managed by full time employees, the board members provide the governance oversight. The dairy cooperatives appear to be an ideal model for getting postharvest technologies to farmers for the following reasons:

i. Dairy cooperatives are a channel used to disseminate technology in smallholder dairy farming. For example, dairy cooperatives in Choma and Kalomo districts have introduced technologies such as fodder production, bio gas, artificial insemination and construction of milking parlors;
ii. Dairy cooperatives are run on business lines as they are involved in bulking of milk throughout the year. In addition, other dairy cooperatives operate farm equipment rental services where farmers hire machinery for farming operations such as planting and crop harvesting;
iii. The membership of certain cooperatives in Zambia comprise of people in employment (2- 5%), business people (5-10%), retirees (10- 20%), villagers (65-70%). The members who are in employment, business or in retirement have more capital to invest in technology, are risk takers and innovative. This group can lead other farmers into investing in postharvest technology;
iv. Some of the cooperatives have trained staff that offer extension services to members. Once trained in postharvest management, this personnel can assist in the dissemination of PHL reduction technologies and training of cooperative members;
v. Cooperatives have members charged with the responsibility of training others at zonal level. These members can work with the extension workers in promoting technology dissemination. According to WFP (2014) intensive training of farmers contributes to the success of newly introduced PHL technologies;
vi. The cooperative members are familiar with the stop order system whereby they get their money deducted from their milk sales revenue whenever they buy items on credit through the cooperative. The stop order method can be used for repayment of postharvest equipment acquired by farmers through the cooperatives; and
vi. The cooperatives have experience in brokering equipment, drugs and stock feeds for their members (LaMarco, 2018; ICA, 2020).

5.3.1 Farmer cooperative postharvest management model

The Farmer Cooperative Postharvest Management Model (FCPhMM) was developed from the Cooperative model. Arising from discussions held with board members and management of smallholder dairy cooperatives with support from study findings and literature, the Farmer Cooperative Postharvest Management Model was developed as an ideal vehicle for enhancing the adoption of postharvest technologies among the smallholder farmers in Zambia. Figure 5.3 shows the Farmer Cooperative Postharvest Management Model.

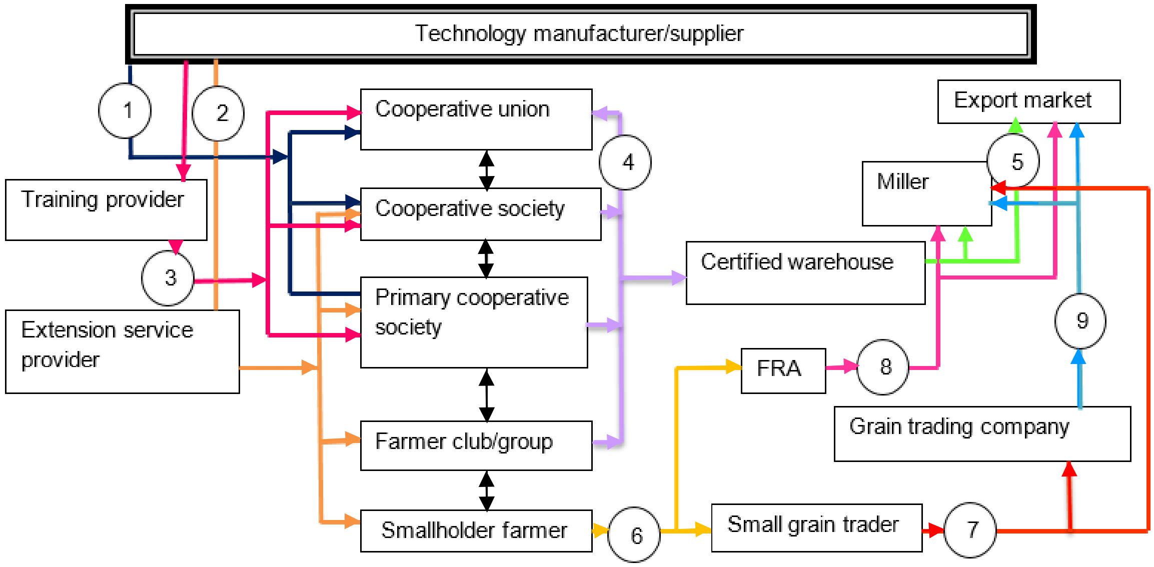

Figure 5. 3: Farmer Cooperative Postharvest Management Model. Source: (Author)

Key for the Farmer Cooperative Postharvest Management Model

1 Manufacturers of technology can engage cooperative unions or societies to market their technology on commission basis. Furthermore, the technology provider trains cooperative union or cooperative society members on operations of the technology.

2 The extension provider gets information from the technology manufacturer about the available technology. The extension provider subsequently passes information about the available postharvest reducing technologies to leaders of cooperative societies, farmer clubs or groups and smallholder farmers at community level.

3 Training provider gets information from the manufacturer of the technology. Thereafter, the training provider trains leaders of cooperative unions, primary cooperative societies, farmer clubs or groups and smallholder farmers at community level on the available postharvest reducing technologies.

4 On the output market side, the cooperative unions or societies can buy grain from primary cooperative societies which buy the grain from farmer groups. Cooperative unions, cooperative societies, farmer clubs or groups can deposit their grain in certified warehouses.

5 The certified warehouse can sell the grain to millers or export markets.

6 Smallholder farmers can sell their maize to FRA and small/medium - scale grain traders.

7 Small /medium - scale grain traders can sell their maize to grain trading companies and millers.

8 FRA can sell its maize to millers and foreign markets.

9 Commodity trading companies can sell their maize to millers and export market.

5.4 Social-economic Benefits of Postharvest Models

The study found that the CAD-Postharvest Management (CAD-PhM) and Farmer Cooperative Postharvest Management (FCPhM) Models had some social-economic benefits. Table 5.1 provides a summary of the social economic benefits associated with the two models.

Table 5.1: Social-economic benefits of postharvest models. Source: (Author)

Social-economic benefits of the CAD Postharvest Management (CAD-PhM) and Farmer Cooperative Postharvest Management (FCPhM) Models	
Economic benefits	**Social benefits**
a) Serve as a cost reduction approach to input and output markets in various communities. b) Facilitate business contracts between input /technology suppliers and output buyers. c) Exploitation of various value chain business opportunities from input and technology suppliers to output marketing, processing, storage thereby improving cash flows and profits from several business lines. d) Facilitate localisation of incomes thereby improving the livelihoods of farmers at community level. e) The cost of selling the technologies is lower as the cooperatives leverage on the existing channels for reaching out to their members. f) Facilitate payment for technology through the stop order system.	a) Marketing services of inputs, technology and produce can be localized at community levels. b) Various postharvest technologies (hermetic storage, use of pesticides etc.) can be promoted through demonstrations at community level. c) CADs and cooperatives can serve as bulking centres for grain for farmers that wish to participate in the warehouse receipt system. d) In cooperatives farmers jointly own and democratically control business.

Summary

Chapter 5 presented the CAD-Postharvest Management (CADPhM) and Farmer Cooperative Postharvest Management (FCPhM) Models which were developed from the research findings supported by literature. The CAD-Postharvest Management Model involves the manufacturers or suppliers of technology channeling their innovation through the CADs to the smallholder farmers. This model further brings on board training and extension providers. The role of training and extension is to provide additional to support to CADs and the lead farmers on the availability and operations of the postharvest loss reducing technologies.

The Farmer Cooperative Postharvest Management Model (FCPhMM) was developed from the Cooperative Model. Commercial cooperatives were considered ideal because they assist farmers to participate in the mainstream of cash economy and wealth creation. The developed models can find application in enhancing the adoption of postharvest technologies among smallholder farmers in Zambia.

CHAPTER 6: RECOMMENDATIONS FROM THE STUDY

6.1 Introduction

"We can have all the knowledge in the world, but it means nothing without the wisdom to know what to do with it"- Marie Osmond.

The chapter presents some recommendations towards enhancing the adoption of technologies and practices for reducing postharvest food losses. These recommendations include:

i Food security programmes should adopt a production to postharvest approach

Food security programmes implemented in Zambia should have a component of postharvest management. The recommended approach in the design of such projects or programmes should be from production to postharvest (P2Ph). The production to postharvest (P2Ph) approach's major objective is to increase productivity, production, marketing and storage. The P2Ph approach calls for incorporation of postharvest management strategies right from the point of programme design to the postharvest stage. For example, in Zambia it is only the World Food Programme that applies P2Ph approach while other institutions which promote food security projects have mainly laid emphasis on improving crop production/productivity and market linkages.

ii. Linkage of postharvest technologies to the farmer input support programme

The Farmer Input Support Programme (FISP) is a programme under which the Zambia Government has traditionally distributed subsidised agricultural inputs to smallholder producers of the staple food, maize (MACO, 2011). In order to participate in this programme, the smallholders are required to contribute ZMW 400 (US$ 40) while government contribution is in the sum of ZMW 1,610 (US$ 160). During the 2017/2018 agricultural season, the programme targeted one million beneficiaries (National Assembly of Zambia, 2017).

During the 2015/2016 farming season the ministry responsible for agriculture introduced an Electronic Voucher (E- Voucher) initiative whose purpose was to improve the distribution of inputs to smallholder farmers (Musika, 2016; Kasoma, 2018). The E-Voucher System has the potential of diversifying the smallholder sector by allowing farmers a wide range of inputs such as agricultural equipment, veterinary drugs, poultry, grain storage bags, and fish fingerlings. The Farmer Input Support Programme Electronic Voucher initiative is implemented by agrodealers on behalf of government (Musika, 2016; Kasoma, 2018).

The FISP initiative offers an opportunity for the inclusion of postharvest loss reducing technologies such as PICS and super grain bags among products which could be accessed by smallholder farmers. For example, in order to increase food security the Guatemala government implemented a subsidy model for silo production and dissemination (SDC, 2012). This calls for strengthening the capacity of agrodealers in postharvest management to enable them appreciate the importance of reducing postharvest losses and be in a position to explain usage of the relevant technologies to smallholder farmers. An expenditure of approximately US$15 on ten PICS bags would enable a farmer to store one ton of maize which on average is about the quantity needed for household consumption per season. Smallholders reported losing about 50 -100 kgs of grain during storage for household consumption. Since on the average smallholder store approximately one ton of grain for consumption, they incur PHLs in the range of 5 -10%. In absolute figures this works out as 1 - 3 x 50 kg bags per ton of grain stored for home consumption. These results are consistent with findings from World Bank (2011); De Groote (2013); Kaminski and Christiaensen (2014) and Ambler *et al.,* (2017) who report grain losses of 5 -15% during storage for home consumption.

The use of PICS bags would drastically minimise or totally eliminate the 5 -10% grain losses experienced during storage of grain for home consumption. If all the smallholder farmers participating in the FISP were to adopt the use of PICS bags for grain storage, 50, 000 to 150, 000 tons of maize with an approximate value of US$ 1 million to US$ 3 million would be saved per season. The maize saved from PHLs could be sold or stored in order to lengthen the period during which the households remain food secure. According to Kalita and Kumar (2017) the application of scientific storage methods can reduce grain losses to as low as 1- 2%. The results from a trial conducted on use of hermetic storage involving 400 smallholder farmers in Burkina Faso and Uganda showed that approximately 98% of their harvest was retained (WFP, 2014). This programme owed its success to the intensive training on use of hermetic storage prior to introducing improved PHLs technologies (ibid). Ndegwa *et al.,* (2015) found that although hermetic storage was not perfect, it was very effective in reducing grain losses resulting into preserving the quality of stored grain and increasing the period of on-farm storage, hence improving the income and food security of farmers.

It's important to note that low postharvest losses do not essentially indicate effective management techniques or storage but maybe due to selling of the produce early in order to reduce the anticipated losses caused by inadequate storage capacity (Sheahan *et al.,* 2017). If farmers were to effectively store large quantities of their harvest for longer periods, they might realise more revenue as a result of seasonal increase in market prices. Kadjo *et al., (*2015) found that farmers in Benin that anticipated high crop losses in storage were more likely to dispose-off their produce on the market early, suggesting that there was an inverse relationship between revenue losses and quantity of the commodity stored.

Therefore, FISP should go beyond provision of inputs to farmers and include PHL reducing technologies such as PICS and Supergrain bags. For this to happen there is need for political goodwill just like in the case of the Guatemala government which had made a conscious decision to support the fabrication and dissemination of metal silos in order to boost food security.

iii. Strengthening the capacity of Grain Traders in postharvest management

Grain Traders Association of Zambia can be instrumental in increasing the adoption of technologies for reducing postharvest losses. Since the grain traders interface with farmers at village level they could assist with the dissemination of information about the available technologies. During the bags to bulk trainings conducted for members of the Grain Traders Association in 2014-2015, upon graduation, the trainees trained farmers in grain handling with the subsequent increase in the marketing of quality grain by the smallholders (Chikoye *et al.,* 2017). If the farmers were to reduce postharvest losses, then they would have more grain to sell because they would subsequently minimise the grain retained for home consumption. During focus group discussions, farmers reported that due to grain losses, they had to keep more grain for home consumption to compensate for grain destroyed by storage pests. As such when smallholders store grain for domestic consumption, they provide an allowance for pest damage.

vii. **Strengthening postharvest management curricula in agricultural training institutions**

Agricultural training in Zambia is offered at various institutions namely the University of Zambia and Mulungushi University (degree level), Natural Resources Development College, Mpika and Monze Agricultural Colleges (diploma). Other institutions such as Kalulushi, Chapula and Kasaka Farmer Training Institutes, In-Service Training Trust and Farmer Training Centers provide short-term, demand driven courses. Co-operatives education and training is provided at the Co-operative College, Katete Centre of Marketing and Co-operatives and Kabulamwanda Co-operative Training Centre.

The study established that there was no curriculum which addressed postharvest management of non-perishable crops in the School of Plant Science at the University of Zambia and Mulungushi University. Postharvest management of perishable crops was offered at University of Zambia because of the high losses experienced in the fruit and vegetable value chains at national level. Among the colleges which offer diplomas in agriculture, it was only the Natural Resources Development College (NRDC), where postharvest handling and storage of grain was taught. In addition, the curriculum on postharvest management at NRDC had not been revised since the 1992.

First and foremost, there is a need to train students from agricultural training colleges and universities in postharvest management and storage. Curriculum strengthening in postharvest management and storage in agricultural universities and colleges and farmers training centres can enhance the country's capacity to conduct research, and extension activities in postharvest management. According to Kitinoja *et al.,* (2011) postharvest management should be integrated in the agricultural curriculum in developing countries because of the critical need for capacity building in postharvest policy formulation at government, research, extension services and design of appropriate technology levels. Agricultural training institutions in Zambia should consider the introduction of postharvest management and grain storage in their training programmes.

v Integration of Postharvest Management in Agricultural Extension Programmes

When planning the integration of postharvest loss reduction solutions in the agricultural extension programmes, due consideration should be given to lessons learnt from previous extension projects and programmes addressing postharvest losses (McNamara and Tata, 2015). The application of lessons learnt from previous programmes is an evidence - based method to the application of appropriate solutions to postharvest losses.

Post-harvest loss projects which have been implemented in Zambia (See Table 2.8) to provide technical advice to farmers on improved postharvest practices and technologies never got integrated in the agricultural extension service. According to World Bank and FAO (2011), the postharvest agenda should be integrated in national agricultural research and extension services in sub-Saharan African countries. The report further points to the importance of strengthening the research-extension cycle for the purpose of providing extension staff and farmers with updated information on postharvest management and business management skills. The Distance Learning Programme in Grain Management which was implemented in the SADC region in the late 1990s and early 2000 did not only focus on grain handling but included business management skills (Chikoye and Chisala, 2006). The inclusion of business skills in the training helped the grain traders and smallholders to grow their grain trading business with some of them securing large contracts to supply food grains to the World Food Programme.

Due to the large number of smallholders and extension staff that would require to be trained in postharvest management and business skills, the application of open and distance learning would be an ideal approach. Distance learning provides an opportunity for training of smallholders and grain traders as they would learn at their own pace and apply the newly acquired knowledge and skills in their businesses (Chikoye *et al*., 2004).

There are several definitions of open and distance Learning (ODL) or education. This study has adopted the definition used by the Commonwealth of Learning (COL). "Distance education is a mode of teaching and learning characterised by the separation of teacher and learner in time and /or place for most part of the educational transaction, mediated by technology for delivery of learning content with a possibility of face-to-face interaction for learner teacher and learner - learner interaction, provision of two way didactic communication and acceptance of industrial process for division of labour and economies of scale (COL, 2015, p. 2)".

According to Mumba (2002) the potential for distance learning to contribute to socio-economic development of Zambia has been broadly accepted and several institutions are offering ODL programmes. After gaining independence in 1964, the Zambia government adopted open and distance learning as one of the educational strategies for increasing access to both formal and non-formal education and for improving the quality of education (Lungwangwa, 1999; Mumba, 2002). Since then, the government, non-government organizations, and international institutions have invested in ODL to alleviate problems of access, equity, and quality in education provision (Chikoye and Kaonga, 2007). They further point out that the existing capacities of various institutions in Zambia to offer ODL should be matched against necessary human and materials required for running such programmes.

Although Zambia gives priority to agriculture, the sector faces a lot of constraints in trained human resource (MACO, 2004). In spite the availability of several public institutions offering training courses in agriculture, they cannot meet the human resource requirements from their residential programmes (Chikoye and Siaciwena, 2008). They further mention that some of the agricultural institutions have introduced open and distance learning (ODL) programmes as a means of increasing their capacity to train many individuals.

vi. Domestication of international and regional policies

In general terms food loss and waste and postharvest losses are a significant component of global agricultural policies. For example, from a consumer's standpoint, food loss leads to higher prices while for countries which are dependent on agriculture lower PHLs can reduce the need for food imports thereby saving on foreign reserves.

The Malabo Declaration, agreed to by African governments aims to accelerate agricultural growth by at least doubling current agricultural productivity levels, and to "halve the current levels of postharvest losses, by the year 2025" (AUC 2014, p.3). The Sustainable Development Goal 12, aims target 12.3 agreed to by the world leaders, aims to " halve per capita global food waste at retail and consumer levels and reduce food losses along production and supply chains, including postharvest losses" by 2030 (UNGA 2015, p. 22). This goal implies an effort to reduce food losses and waste in the production and consumption of commodities, especially in the food system (ibid). In order to do so, there is a need to understand the magnitude of losses and waste within specific value chains for the purpose of applying the most cost effective solutions.

The interrogation of agricultural policies from Kenya, Uganda, Nigeria, Malawi Mozambique and Zambia revealed that none of these countries have effectively addressed the reduction of PHLs in line with the Malabo declaration and SDG Target 12.3. The only exception is Rwanda which has a directorate responsible for postharvest management. In the absence of policies, strategies and plans for reducing postharvest losses, it might not be possible for most African countries to meet the Malabo Declaration and SDG target 12.3.

There is therefore, a need for Zambia to domesticate the Malabo declaration and SDG Target 12.3 on reducing postharvest losses at national level through the development and implementation of appropriate policies, strategies and plans.

viii. **Adoption of the Farmer Field School approach in promoting postharvest technologies and practices**

The business model behind a lead farmer is to provide training services to the farmers under a training of trainer (TOT) approach. This method helps in maximising delivery of inputs, technologies and innovations to farmers. The lead farmer conducts trainings using the Farmer Field School Model (FFSM). The Farmer Field School (FFS) method is an innovative, participatory and interactive learning approach that emphasizes problem solving and discovery based learning (FAO, 2006). It aims to build the farmers' capacity to analyse their production systems, identify problems, test possible solutions, and eventually encourage the participants to adopt practices most suitable to their farming systems (ibid). The learning process takes place in the field and it combines different types of knowledge and skills (farmer's traditional or indigenous and scientific knowledge) and values both as essential elements towards sustainable farming practices. Farmer field schools consist of groups of 20-30 farmers with a common interest, who get together on a regular basis to study the "how and why" of a particular topic (Waddington *et al*., 2014). The size of 20-30 farmers per school is recommended because this number can comfortably work together with one trainer (Lead Farmer). The farmers can be sub-divided into groups of 4 - 5 persons for better field observations, analysis, discussion and presentations.

ix. **Creation of Africa FLW Champions**

The study recommends the creation of champions for food loss and waste at continental level which should be replicated at national and community levels. Some of the proposed members at national and community levels include:

National level

i. Influential personalities in society;
ii. Representative of supermarkets;
iii. Representative of grain trading companies;
iv. Representative of farmers;
v. Technology manufacturers;
vi. Government officials; and
vii. Representative of academic institutions.

Community level

i. Village headman/woman;
ii. Representative of the cooperatives;
iii. Government extension worker;
iv. Member of community development committee;
v. Representative of women;
vi. Representative of agrodealers; and
vii. Representative of religious organisations.

Such a task force can play a key role in creating awareness and driving forward the food loss and waste including postharvest loss agenda. Currently there is lack of a group of people with passion and commitment to driving forward the issue of reducing food loss and waste including postharvest losses.

Summary

Chapter 6 presented some recommendations towards enhancing the adoption of technologies and practices for reducing postharvest food losses. Some of the proposals are that the design of food security programmes should adopt a production to postharvest (P2Ph) approach. In countries where government provides subsidies in the form of agricultural inputs, postharvest technologies should be part of the package. The thesis is calling for strengthening the capacity of grain traders and smallholder farmers in postharvest management. Furthermore, curricula in agricultural training institutions should include postharvest management. The integration of postharvest management in Agricultural Extension Programmes should be considered. The adoption of the Farmer Field School approach in promoting postharvest technologies and practices is being proposed. The domestication of international and regional policies is cardinal as it will contribute to improving postharvest management.

CHAPTER 7: CONCLUSION AND FURTHER RESEARCH

7.1 Introduction

> ***"People do not like to think. If one thinks, one must reach conclusions. Conclusions are not always pleasant" – Hellen Keller***

Chapter 7 gives the conclusion of the study by providing a summary of the preceding chapters. Furthermore, the chapter links the research findings to the aims and objectives of the study. The research conclusions are presented in 5 sections namely; i) Research problem, goal and objectives, ii) Research methodology, iii) Limitations to the study, iv) Contribution to knowledge and practice, v) Further research work. The first section gives a short narrative on addressing the research problem and accomplishment of the research goal and objectives. Section two debates the research work and its validity. The third section provides limitations of the study. Section four highlights the knowledge and practical contribution of the study to the field of postharvest management. The last section considers the additional research prospects which can contribute to the improvement of postharvest management.

7.2 Research Problem, Goal and Objectives

The research problem of this study was "the low adoption of technologies and practices which reduce postharvest losses of maize incurred by smallholder farmers in sub - Saharan Africa, particularly in Zambia". To address this problem, a study goal was formulated which was to "develop a framework for increasing the adoption of technologies and practices for reducing postharvest maize losses incurred by smallholder farmers in sub - Saharan Africa, principally in Zambia".

The development of the Community Agrodealer Postharvest Management Model (CADPhMM) and Farmer Cooperative Postharvest Management (FCPhM) Models has addressed the research problem and contributed to the achievement of the study goal. The data collected from literature, interviews and focus group discussions with farmers and key informants from three districts helped in the development of the two models. The sub-sections below provide summarised information regarding accomplishment of the study objectives.

Objective 1: To review the supportive policies and technologies which have been developed for reducing postharvest maize losses.

A detailed analysis of literature of supportive policies and technologies for reducing postharvest maize losses is provided in chapter two of this thesis. The literature review covered many aspects of postharvest management. Some of the areas explored were: policies, causes of postharvest food losses, global trends of interventions for reducing food loss and waste, available technologies and factors affecting their adoption.

It was established that there were a number of international and continental protocols supporting the reduction of food losses and waste. Policy consistency is cardinal in addressing postharvest losses because the quantity and quality of food losses which can practically be reduced depends on the cost and benefits. Government policies which have an effect on food prices can alter motivation by producers and consumers to avoid postharvest losses. Therefore, if agricultural policies are badly designed they may cause a disincentive to prevent postharvest losses. As such reducing postharvest losses can be increased through policy reform.

By and large the international and continental protocols were not domesticated at national levels. In addition, it was found that in a number of countries including Zambia, the national agricultural policies did not provide clear direction on addressing postharvest food losses.

Objective 2: To investigate barriers to the adoption of technologies and practices for reducing maize losses among smallholder farmers.

The study identified 6 many barriers faced by smallholder farmers in the adoption of technologies and practices for reducing postharvest losses of maize. Some of these barriers included:

i. The major challenge was the inadequate information and knowledge of the available technologies for reducing postharvest losses of maize. Most smallholder farmers did not relate grain losses to a reduction in revenue. Furthermore, there was lack of clarity about the economic benefits of investing in postharvest loss reducing technologies.

ii. The lack of a clearly articulated national policy to address postharvest losses. The 2016 - 2025 Zambia National Agriculture Policy does not provide adequate information regarding the reduction of postharvest losses. Since the Zambia Agriculture Policy was developed after the Malabo Declaration and Sustainable Development Goal Target 12.3 were endorsed by the continental and world leaders respectively, this document should have provided a clear direction regarding the reduction of postharvest losses.

iii. There was inadequate integration of postharvest management in the agricultural extension services. Notwithstanding the fact that a number of projects on postharvest management implemented in the past had involved the participation of district agricultural staff from the ministry responsible for agriculture, there was lack of continuity of postharvest activities after closure of the projects.

iv. The low numbers of extension workers skilled in postharvest management contributed to the lack of awareness and knowledge of the available technologies among smallholder farmers.

v. The agriculture extension package emphasised increased maize production and productivity at the expense of postharvest management.

vi. As a consequence of inadequate information provided by some agrodealers on chemical control of postharvest pests, some farmers had lost faith in chemical control methods. In addition, the recommendation of fumigants for protection of grain made farmers get more disillusioned when there was re-infestation of grain by storage pests. Therefore, the consequence of poor performance of the chemicals had led to farmers abandoning the chemical control method of storage pests.

***Objective 3:	To identify and analyse opportunities which exist for adopting technologies and practices for reducing postharvest maize losses among smallholder farmers*.**

The study identified ten opportunities for increasing the adoption of postharvest management technologies by smallholder farmers. These opportunities included:

i. The global attention which had been given to the problem of postharvest losses. For example, adoption of the Malabo Declaration by African leaders and Sustainable Development Goals by the world leaders were indicators of the seriousness with which the issue of food loss and waste including postharvest losses was being considered. The Malabo Declaration is a set of agriculture goals aimed at achieving shared prosperity and improved livelihoods (AUC, 2014, p. 1). The declaration includes a commitment "to halve the current levels of post-harvest losses by the year 2025" (AUC, 2014, p 3). The Malabo Declaration focuses on food loss because this is a bigger issue along the production and postharvest value chains in Africa than food waste at the market and consumption levels (ibid). The Sustainable Development Goals also known as the Global Goals, "are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity." (UNGA, 2015). For example, SDG Target 12.3 which calls for "halving per capita global food waste at retail and consumer level, and reduce food losses along production and supply chain chains including postharvest losses by 2030" (UNGA 2015, p. 22) is key to unlocking some of the SDGs. The SDGs which are linked to the reduction of postharvest losses include: SDG 1: No poverty; SDG 2: Zero Hunger; SDG 5: Gender Equity; SDG 6: Clean Water and Sanitation; SDG 7: Affordable and Clean Energy; SDG 8: Decent Work and Economic Health; SDG 12: Responsible Consumption and Production; SDG 13: Climate Action.

ii. The development of hermetic storage such as PICS and Supergrain bags, metal and plastic silos can contribute to the reduction of postharvest maize losses among small grain traders and smallholder farmers in Zambia. Prior to 2016, PICS bags were imported and the World Food Programme was the only organization using these bags for the storage of grain. Since then, PICS bags have become locally produced leading to improved access to the technology by smallholder farmers.

iii. There is an opportunity to use Commercial Farmer Cooperatives and Community Agrodealers to disseminate information on the available technologies for reducing postharvest losses among smallholders.

iv. There is an opportunity to lobby government so that the Farmer Input Support Programme (FISP) can besides provision of seed and fertilizers include PICS bags. Every year the Zambian government provides subsidy in form of production inputs to approximately

1,000,000 farmers. If FISP farmers could adopt the use of PICS or Supergrain bags then other farmers would be influenced to adopt this technology.

v. The impact of climate change had made smallholder farmers more willing to invest in postharvest loss reducing technologies. Since smallholder farmers were no longer certain of producing food in the subsequent farming seasons due to the unreliable weather patterns, they were more willing to invest in the protection of their harvested grain. Therefore, circumstances under which farmers found themselves due to erratic rains could be a good entry point for promoting technologies for reducing postharvest losses.

vi. There was an opportunity for the Zambian government to collaborate with private companies, NGOs, International organisations and donors in increasing the adoption of technologies for reducing postharvest losses.

vii. The introduction of the Warehouse Receipt System (WRS) has attracted individual farmers and farmer groups to use this facility which in turn reduces postharvest losses, while increasing the farmer's revenue from the sales of maize at premium market prices offered when maize stocks are low.

viii. The increase in the number of organisations and individuals (academicians, scientists, traders) interested in postharvest issues could lead to the formation of champions that could subsequently spearhead the promotion of the postharvest agenda in Zambia.

ix. Recognition that food loss and waste had an impact on climate change has increased the number of actors advocating for improved postharvest management. Of the 43.1 gigatonnes of the annual global greenhouse gas emissions, food loss and waste contributes approximately 4.4 gigatonnes (IPCC 2019 and FAO, 2019). The emissions are caused by the energy used in food production, storage, and transportation of food which ends not being consumed by humans (ibid).

x. Change in farmers' attitude and behavior towards grain storage influenced by drought. Prior to the onset of recurring droughts which had resulted in crop failure, maize was traditionally stored in cribs (nkokwe or matala) which were considered as a cultural totem of wealth normally associated with generosity and hospitality. In recent times, farmers preferred to store bagged grain in dwelling houses where it is not exposed to the prying eyes of relatives, neighbors, thieves and NGO staff and/ or government officials conducting food assessments.

Objective 4: To develop a framework or model for increasing the adoption of technologies for reducing postharvest maize losses among smallholder farmers.

The Community Agrodealer (CAD) Postharvest Management (CADPhM) and Farmer Cooperative Postharvest Management (FCPhM) Models or frameworks have been developed from the research findings. The models provide a succinct outlook of their application in the maize grain value chain. The CAD Postharvest Management Model localises agriculture inputs and output marketing services and farmer training. The capacity building activities undertaken involve training of CADs and Lead Farmers and subsequent training of members of farmer groups using the Farmer Field School (FFS) approach where various postharvest technologies can be promoted through demonstrations. Some of the technologies include hermetic storage and use of pesticides for control of storage pests. The warehouses owned by CADs serve as aggregation centres for grain owned by farmers that wish to participate in the Warehouse Receipt System.

Farmer Cooperative Postharvest Management (FCPhM) Model is proposed for members of the cooperatives because such organisations are established by farmers to undertake the supply of inputs, and marketing of produce and facilitate access to technology. Although various types of cooperatives play an important role in promoting rural development, horticulture and dairy cooperatives have special characteristics which make them more suitable for dissemination of technologies for reducing postharvest losses. In comparison with the other proposed models, the cost of selling the technologies would be lower because the cooperatives can leverage on the existing channels for reaching out to their members. Payment for the technology can be done through the stop order system which farmers are already familiar with as it's the method used when paying for dairy inputs and equipment acquired on credit.

7.3 Research Methodology

In this study the interpretive paradigm was used because it helps to "gain full access to the knowledge and meaning of the phenomenon" (Collis and Hussey, 2009, p.65). The inductive research approach was selected because the data collected allowed for the generation of theories and explanation of the phenomena discovered through the research findings. Furthermore, the case study strategy was selected because it has the advantage of enabling a systematic investigation into the issues, the collection of large amounts of data, and easy data analysis. The study was anchored on the Unified Theory of Acceptance and Use of Technology (UTAUT) theoretical framework.

7.4 Reliability and Validity of Findings

This research study took deliberate steps to ensure reliability and validity of the research findings. "Reliability is really the consistency of a measure. Reliability analysis can be used to measure the consistency of a data collection tool" (Field, 2009, p 681). Furthermore, reliability denotes that a measure or data collection tool should consistently mirror the construct that it is assessing (Field, 2009). According to Huck (2007) testing for reliability is cardinal because it signifies the uniformity throughout the evaluating tool. A measuring gauge is considered to have an elevated inner stability consistency if the points of the measure "hang together" and compute the same concept (Huck 2012). Validity explains how well the collected data covers the actual area of investigation (Ghauri and Gronhaug, 2005). Validity basically means "measure what is intended to be measured" (Field, 2009, p 681). According to Ghauri (2005) validity explains the extent to which collected data covers the field under investigation.

Some of the measures taken to ensure reliability and validity of the research findings included the use of the case study approach, adoption of the mixed methods design and application of the techniques used in the grounded theory approach. The case study approach enabled the collection of valuable qualitative and quantitative data. In order to achieve researcher triangulation, data collected from each case location was analysed and compared to other case locations. The accuracy and consistency of the results was achieved through investigator triangulation of data collection and analysis.

Triangulation is the practice of using multiple sources of data or multiple approaches to analyzing data to enhance the credibility or enhance the rigour of a research study (Salkind, 2010). Triangulation can increase the reliability of research results (Stavros and Westberg, 2009) and allow a researcher to overload data (Fusch and Ness, 2015) as reported in Fusch *et al* (2018). Triangulation in a research study is generally considered to promote a more comprehensive understanding of the phenomenon under research (Heale and Forbes, 2013). The significance of triangulation cannot be underrated in ensuring reliability and validity of research results (Fusch *et al.,* 2018). This is possible when data is truthful and accurate and when the assumptions have a high chance for really happening and can be traced back to the conceptual framework of the research (Roe and Just, 2009) as reported in Fusch *et al.,* (2018).

The mixed methods, convergent followed by parallel design allowed for collecting, analyzing and mixing both qualitative and quantitative research and methods in a single study. This assisted in understanding the research problem as supported by Creswell (2011). Tashakkori and Teddlie (2003) explain that multiple methods are useful because they provide better opportunities for a study to address research questions. They further state that methods allow for better evaluation of the degree to which the research results can be trusted. This is consistent with Denzin and Lincoln (2011) who argue that a mixture of several methods, viewpoints and observations in a research is an approach that enhances robustness, coverage and penetration in any investigation. However, no single technique, theory or researcher can capture all that is important or relevant (Denzin, 2012).

During the study Cronbach's Alpha was used because it's an indicator normally cited by researchers to establish that the tests and scales approved for the research are suitable (Taber, 2018). The analysis of data from the study showed (Alpha = 0.681, $P < 0.05$). According to Whitley (2002), Cronbach's Alpha Coefficient is considered as the most suitable measure of reliability particularly when using the Likert Scales. Although there is no clear rule for internal reliability, a coefficient of 0.70 is mostly agreed upon as a minimum (Huck 2012). Wilson (2014) opined that much as reliability was essential for a study, it's inadequate unless when combined with validity.

Therefore, use of the case study approach, adoption of the mixed methods design, triangulation of multiple sources of data and application of techniques used in the grounded theory approach ensured reliability and validity of the research findings.

7.5 Future Research Work

This section provides information about the limitations of this study and makes suggestions on future research work which could be undertaken.

7.5.1 Limitations to the Study

One limitation is the strategy used in sampling of the respondents for data collection. When it became difficult to sample farmers from the register kept at the district agricultural level, the researcher used the register kept by the farmer cooperatives. This register had fewer farmers than the one kept at the district agriculture office. However, the limitation created by using the farmer register kept by the cooperatives was corrected in locations where the village registers were used in sampling of farmers that participated in the study. Furthermore, the quality of data collected may have been affected by the loss of meaning during translation from English to local language at the time of conducting the interviews. There were times during the interviews when explaining the contents of the questionnaires became a challenge particularly with the farmers interviewed by enumerators. Additionally, he respondent's lack of knowledge of available technologies for reducing postharvest losses may further have affected the data collected.

During data analysis the respondents (institutions, and individuals) where empirical data was collected were not revealed. The hiding of names of respondents where the information was collected may have denied readers of the opportunity to make specific assumptions. Nevertheless, such a strict code of ethics was necessary to protect the institutions and identity of respondents that participated in this study. Stake (2010) supports this research practice and asserts that the value of the best research is not likely to out weight the wrong caused to the person revealed.

The sample size in this research is another area where some limitations are revealed. This limitation gives rise to a significant opportunity and direction for further research. There is scope for extending this research by conducting additional case studies for collection of more data which can strengthen the developed models.

7.5. 2 Future research work

There is a need and an opportunity exists for expansion of this study. The research findings can be applied and tested in different locations as well as broadened and enhanced by conducting additional case studies. An expansion of this dissertation would be to test the practicality and limitations of the models developed in this study. This research should be conducted in collaboration with the manufacturers of technology for reducing postharvest losses, commercial farmer cooperatives, community agrodealers and smallholder farmers. The proposed research can enrich the developed models by evaluating their real time validity and consequences.

Further research provides an opportunity to broaden the findings of this study by conducting an additional set of case studies. Yin (1984) and Zucker (2009) argue that replication can be claimed if several case studies support the same theory. Therefore, additional case studies would enhance the investigative generalisations made in this dissertation. These additional case studies could provide more data for triangulation, hence enhancing the validity and scope of this study. This research can be conducted in districts from other provinces of Zambia. The research extensions would strengthen the CAD-Postharvest Management Model and Farmer Cooperative Postharvest Management Model.

Future research work could involve developing a financing strategy for enhanced application of the CAD and Farmer Cooperative Postharvest Management Models in increasing the adoption of postharvest technologies by the smallholder farmers. Financing is an important area for future research particularly that funding to agriculture is still heavily skewed towards crop production at the expense of postharvest management. Another potential area for further research is the financial benefit of reducing postharvest losses of maize. Empirical evidence of financial benefits accruing from reducing postharvest losses can assist smallholder farmers, policy makers and other maize value chain actors in addressing the issue of food loss and waste

7.6 Contribution to Creation of New Knowledge and Practice

One of the driving forces behind this study was to contribute to the creation of new knowledge and practice in the field of postharvest grain management. Therefore, the succeeding sub-sections attempt to provide the contribution of this thesis to creation of new knowledge and practice in the field of postharvest grain management.

7.6.1 Identification of reasons for the low adoption of technologies for reducing postharvest losses among smallholder farmers

One major contribution to knowledge of this thesis was the identification of factors for the low adoption of postharvest reducing technologies among smallholder farmers. Whilst the causes and magnitude of food losses in the food supply chains was well understood, the issues which remain a subject of continued debate includes: the impact and feasibility of the proposed solutions and importance of different causes and the beneficial effects of food loss reduction. The study established that smallholder farmers were not aware of the availability and benefits of technologies for preventing postharvest losses. The lack of visibility of technologies was mainly due to ineffective strategies used in marketing of the technologies by manufacturing companies and inadequate information dissemination by NGOs and private sector promoting agriculture as well as the government extension service. This finding slightly deviates from the commonly held view that smallholder farmers were averse to technology adoption due to financial constraints (Manandhar *et al.,* 2018; and Vos, 2015).

7.6.2 Contribution to practice

During the course of the study, the author participated in the development of the Food Loss and Waste Accounting and Reporting Standard (FLW Standard). This is a global standard which provides requirements and guidance for quantifying and reporting on the weight of food and/or associated inedible parts removed from the food supply chain. It helps countries, companies, cities and other practitioners to quantify food loss and waste; what to measure and how to measure it and encourages consistency and transparency in the reported data.

The standard was developed through a multi-stakeholder partnership convened by the World Resources Institute and initiated at the Global Green Growth Forum (3GF) 2013 Summit. The World Business Council for Sustainable Development (WBCSD), The Consumer Goods Forum (CGF), FAO, and EU funded Fusions project, UNEP, and WRAP were the FLW protocol partners.

The Consumer Group Forum (CGF) member companies such as Tesco, a major UK retailer, Kellogg's and Delhaize America (Robertson, 2016; Charad *et al*., 2019), were already using FLW Standard because they considered it a valuable tool for establishing a baseline and measuring progress. According to literature, studies conducted in 17 countries found that 99% of the 1,200 business entities reported earnings of more than 14 - fold financial return on investment (Hanson and Mitchell, 2017). In addition, 20 leading retailers and brands have pledged to halve food waste by 2030 (ibid).

With Ybema Grain Services of South Africa, the Author participated in the design and delivery of the Bags to Bulk Storage Training Programme which targeted small-scale grain traders in Malawi, Mozambique and Zambia. The objective of the training was to strengthen the capacity of small and medium scale grain traders to reduce postharvest grain losses in storage and improve the profitability and efficiency of their businesses during trading and transition from bag to bulk storage. During training the participants were continuously assessed through theoretical and practical tests. Of the 300 participants enrolled for the trainings, 286 passed the tests and became certified to manage grain handling facilities in the Southern African Development Community (SADC) region.

The post training follow-up conducted 6 months after the trainings, established that each of the trained grain trader was handling an average of 600 tons of maize per season which was adequate to feed approximately 3,330 people. Overall this contributed to the food security of about 1,000,000 people per annum in Malawi, Mozambique and Zambia. Due to improved skills there was an improvement in grain quality and a reduction in losses during grain handling by the small and medium scale grain traders which subsequently increased their revenue.

The study contributed to the enhancement of the database for Centre for Agriculture Bioscience International (CABI) and the Zambia Ministry of Agriculture on the prevalence of the larger grain borer in the country. CABI is an international, inter-governmental, not for profit organization that improves people's lives worldwide by providing information and applying scientific expertise to solve problems in agriculture. Furthermore, the thesis assisted in the identification of the pest (LGB) which was destroying grain in Katete District and linked traders and farmers to specialists that provided advice on the control measures of the storage insect pest. There was enhancement of food and income security of 250 smallholder farmers and 50 youths in Kazungula district through the use of PICS bags provided through application of the Production to Postharvest Management (P2Ph`) approach to implementation of food security projects. This activity which distributed 3,000 PICS bags was done in collaboration with Environment Africa Trust Zambia. Furthermore, the thesis contributed to increasing the food and income security of 5,000 farmers and refugees in Kawambwa and Luwingu districts through the application of the Farmer Cooperative Postharvest Management Model in grain handling through training and distribution of PICS bags. This was a joint activity with an NGO called Action Africa Help Zambia (AAHZ) which works with United Nations High Commission for Refugees (UNHCR) in supporting refugee work in Zambia.

The models developed in this research can find practical application among manufacturers of technology, community agrodealers and farmer cooperatives. Furthermore, the models can serve as a conduit which financial institutions or funding agencies can use in financing of postharvest reducing technologies.

7.7 Participation in International and Local Workshops

The Author presented a paper entitled, "Constraints and Opportunities for Increasing Adoption of Technologies for Preventing Postharvest Maize Losses in Africa", during the First International Congress on Postharvest Loss Prevention held in Rome, Italy in 2015. The Congress provided a forum for various stakeholders to share, learn, and plan to develop action items for reducing postharvest losses. Along with major postharvest loss and reduction issues, this Congress aimed at addressing various challenges and opportunities associated with postharvest losses within the framework of metrics and measurements that may enable development of better tools and interventions to reduce postharvest loss for smallholders in developing countries. This gave the Author an opportunity to interact and share his work with scientists, academicians, researchers, representatives from public and private institutions, philanthropic organizations, producers and others passionate about improving the lives and livelihoods of humankind on the globe through reducing food loss and waste including postharvest losses.

Additionally, the Author further shared with scientists from University of Illinois and Natural Resources Institute, UK about the PhD work that he was undertaking under the University of Bolton. Furthermore, the Author participated in three PhD conferences organised by the University of Bolton in collaboration with the In-Service Training Trust, Zambia.

Summary

Chapter 7 provided conclusion to the study and in the process highlighted the research problem, goal and objectives, research methodology, reliability and validity of findings. The chapter further underscored the proposed further research work, contribution of the study to knowledge and practice, and shed light on the participation of the author in local and international workshops.

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APPENDIX - A: SEMI-STRUCTURED QUESTIONNIRE

University of Bolton
Deane Road
Bolton
BL3 5AB
United Kingdom

Dear Sir/Madam,

REQUEST FOR AN INTERVIEW

I am a PhD student at the University of Bolton and would be very grateful if you could make time out of your busy schedule to grant me an interview relating to post harvest maize losses. I am investigating the constraints and opportunities for preventing postharvest losses of maize in sub Saharan Africa (SSA): A case study of Zambia.

The aim of the study is to develop a framework to increase the adoption of technologies for preventing post-harvest losses of maize along the value chain. It is envisaged that this research will contribute to the discourse on the low adoption of technologies for preventing food postharvest losses.

The interview session is expected to last between fifteen and twenty minutes. I wish to assure you that the University of Bolton complies with the relevant data protection legislation and your responses and personal details will not be divulged to anyone else. No source, individual or institution, will be identified or comment attributed without the permission of the originator and you may withdraw at any time without consequences of any kind.

Thank you for your time. I look forward to meeting up with you.

Daudi M. Chikoye
Research Student
Business and Creative Technologies

University of Bolton

Tel. 0978316952 Email: dmc5mpo@bollton.ac.uk

Do you give consent to participate in this study?

☐ Yes

☐ No

Section A: Biographical Data

1. (a) District code district | | (b) District name:_______________

2. (a) Cooperative/group code | | (b) Coop/group name:___________

3. (a) Village name: ________________ (b) Chiefdom: _________________________

4. (a) Is the household head the main respondent?

   ☐ No

   ☐ Yes

   (b) If no, what is the relationship of respondent to household head? (Use the codes below)? Please choose from one of the 11 options listed below:

   ☐ Self ☐ Nephew/Niece

   ☐ Spouse ☐ Son/daughter in-law

   ☐ Own child ☐ Grandchild

   ☐ Step child ☐ Other

   ☐ Parent ☐ Unrelated

   ☐ Brother/Sister

5. What is your gender?

   ☐ Male

   ☐ Female

6. What is your level of education?

   ☐ University ☐ College

   ☐ Secondary ☐ Primary ☐ Not been to school.

7. What is your age (in years)

   ☐ 20 – 30 ☐ 31 – 40 ☐ 41 – 50 ☐ 51 – 60 ☐ Above 61

Section B: Crop Production Questions

1 (a) Which of the following types of maize do you grow?

   ☐ Hybrid

   ☐ Local maize

☐ Both

If your answer to question 1 (a) is both, please continue with question 1b and 1c below. However, if your answer is hybrid, only address question 1 (c). And if your answer to question 1 (a) is local maize, continue to address question 1 (b).

(b) For local maize, how many bags of maize do you produce per season?

☐ 1-200 bags

☐ 201 - 300 bags

☐ 301 - 400 bags

☐ 401 - 500 bags

☐ Other (please specify the number) _____________

(c) For hybrid maize, how many bags of maize do you produce per season?

☐ 1- 200 bags

☐ 201- 300 bags

☐ 301- 400 bags

☐ 401- 500 bags

☐ Other (please specify the number) ____

2. How would you describe: harvesting methods, lead time, and your target market?

____

____

3. How would you describe your maize storage structures?

____

____

4. (a) In which form do you store the maize kept for consumption?

☐ Shelled ☐. Cob ☐ Both

(b) Why is the maize stored in this form?

____

____

5. (a) Does your maize get attacked by storage pests?

☐ Yes ☐ No

(b) If the response to question 5a is Yes, name the pests which attack your stored maize?

____

____

. (c) Do you protect your stored shelled/unshelled maize against storage insect pests?

☐ Yes ☐ No

(d) If the response to the above question is Yes, what do you use for protection? If no, proceed to question 6.

____

____

6. (a) How many bags of maize do you sell within 3 months after harvest? ________________

(b) How many bags of maize do you sell 3 months after harvest? _____________________

7. How many family members are involved in postharvest activities? _____________________

8. How many workers do you hire during harvesting to selling of maize? __________________

9. (a) Which gender spends more time on activities involving harvesting to selling of maize?

☐ Men ☐ Women ☐ Both

(b). Please give reasons for your response

____

____

10. Rank postharvest losses of maize by putting a cross in the options listed below (1 being extremely very low and 9 being extremely very high)

Likert Scale	1	2	3	4	5	6	7	8	9
During harvesting									
Transportation from field to homestead									
During drying									
Shelling/Threshing									
During storage before marketing									
During storage for home consumption									
During transportation to the market									

During Marketing									
Other									

11 (a). Have you ever been trained in postharvest loss management/technology?

☐ Yes ☐ No

(b). If the response Yes, tick in the table below how the training was conducted and if No proceed to question 12

#	Training method	Tick (as relevant)
i	Exchange visit	
ii	Demonstration	
iii	Meeting	
iv	Workshop	
v	Others (specify)	

©. Who was the training provider?

#	Name of training provider	Tick (as relevant)
1	Government extension officer	
2	NGO (specify)	
3	Private sector (specify)	
4	Training institution (specify)	
5	Other (specify)	

d. Has the training assisted you in reducing postharvest losses?

☐ Yes ☐ No

e. If Yes give reasons for your response and if No proceed to question 12

____

____

12. Rank the technologies and practices for preventing grain losses you have used. (Rank 1 as very low and 7 being very high.)

Likert Scale	1	2	3	4	5	6	7

Application of chemicals to grain in storage							
Application of traditional plants							
Use of recommended grain bags							
Improved brick or cement storage bins							
Metal silos							
Growing varieties tolerant to storage pests							
Other (specify)							

____

13. Why have you not adopted recommended technologies for preventing maize losses? (Rank 1 as very low and 7 being very high)

Likert Scale	1	2	3	4	5	6	7
Lack of awareness about the available technologies							
Lack of knowledge about the benefits of preventing losses							
Technology not available							
Prohibitive cost of technology							
Not considered as profitable investment							
Technology is too complicated to operate							
Other (specify)							

____

14 (a). Do you consider postharvest losses as a loss in revenue?

☐ Yes ☐ No

(b) If Yes, give reasons and if No proceed to question

____

____

15 (a). Are you willing to pay for technology which can reduce maize losses?

☐ Yes ☐ No

(b). Give reasons for your response

____

16. If you gave a response of Yes to question 15a, how much money are you willing to invest in PHL technology? Tick the relevant box.

☐ Below K100 ☐ K 100 - K499 ☐ K 500 - K999 ☐ K1000 - K5000 ☐ above K5000

Section C: The Unified Theory of Acceptance and Use of Technology Assessment: (UTAUT Model)

1. Please complete the questionnaire below by ticking an option from 1-5 on the rating scale (5 being strongly agree/ 1 being strongly disagree), in response to the following statements

Scale				1	2	3	4	5
Variables	Construct	Definitions	Items					
Knowledge Expectancy	Perceived understanding	The degree to which an individual perceives that they have understood how a particular technology works	1. I understand the benefits of using PHL technologies to reduce maize losses					
			2. It's easy for me to remember how to perform the tasks using PHL technologies					
			3. My interaction with PHL technologies is easy for me to understand					
Effort Expectancy	Perceived ease of use	The degree to which an individual believes that using a particular system would be free of physical and mental effort	1. Learning to operate some of the PHL technologies was easy for me					
			2. I rarely become confused when I use the PHL technologies					
			3. I rarely make errors when using PHL technologies					
			4. I rarely get frustrated when					

			using PHL technologies					
			5. Overall, I find PHL technologies easy to use					
Performance Expectancy	Perceived usefulness	The degree to which an individual believes that using a particular system would enhance his or her productivity	1.Using PHL technologies gives me greater control over my work					
			2. PHL technologies enable me accomplish tasks quicker					
			3.Using PHL technologies reduces the amount of time I spend on unproductive activities					
			4.Some of the PHL technologies are rigid and inflexible to interact with					
			5.Using PHL technologies saves me time					
Attitude towards using the technology	Attitude toward behaviour	Technology characteristics could directly influence the attitude of the person toward using the technology, without the need by the person to form a belief about the technology	1. All things being equal, my using of technology on my farm is good.					
			2. All things being equal, my using of PHL technologies on my farm is wise.					
			3.All things being equal, my using of PHL technologies on my farm is favourable					
			4.All things being equal, my using of PHL technologies on my farm is positive					

Facilitating Conditions	Perceived behavioural control	Given a system which was perceived useful, a person may form a strong behavioral intention to use the system without forming any attitude	1. I am able to confidently use some of the PHL technologies.					
			2 .I have the knowledge to use some of the PHL technologies.					
			3. I have the resources to acquire some of the PHL technologies.					
			4. I have the ability to use some of the PHL technologies					
			5. I have control over some of the PHL technologies					
Social Influence	Subjective norms	Person's perception that people who are important to him think he should or should not perform	1. People who influence my behavior think I should use PHL technologies.					
			2. People who are important to me think I should adopt PHL technologies					
			3. My close friends think I should adopt PHL technologies					
			4. My peers think I should adopt PHL technologies.					
			5. People whose opinions I value prefer that I use PHL technologies.					

2. Do you have any comments to make about post-harvest losses of maize? If you have, kindly write them below

____

____

____

3. (a) Are you interested to participate in any future research in this field?

☐ Yes ☐ No

(b) If yes, kindly provide your phone number and address:____________________________

____

Thank you for completing this questionnaire

APPENDIX -- B: SELECTED JOURNAL PAPERS

BAGS TO BULK STORAGE APPROACH FOR REDUCING MAIZE POSTHARVEST LOSSES IN MALAWI, MOZAMBIQUE AND ZAMBIA.

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ABSTRACT

The main challenge for agriculture is the feeding of the estimated 9 billion people by 2050. Besides increasing food production, attention should be directed towards reducing food loss and waste. It is estimated that 1.3 billion tons of food produced globally is lost or wasted. Sub Saharan Africa, Eastern and Southern Africa lose food valued at about US$ 4 billion and US$ 1.6 billion per annum respectively. This food can meet the annual food requirements of at least 48 million of the 220 million undernourished people in Africa. Malawi, Mozambique and Zambia experience annual maize post-harvest losses of 20% - 30%. Despite the availability of technologies for reducing postharvest food losses worldwide, their adoption remains low in Africa. Therefore, identification and elimination of constraints to the adoption of existing technologies for reducing postharvest losses should be considered. To improve the flow of information on the available technologies a capacity building programme which targeted 300 smallholder farmers and grain traders was developed in Southern Africa. The results of the post training showed an insignificant adoption of the 30 ton metal silos due to inappropriateness of the technology, cost and weak support infrastructure.

Key words: postharvest losses, bulk storage, food waste, technology.

1.0 INTRODUCTION

The problem of global food loss and waste is real (FAO, 2011; Lipinski *et al.,* 2013; and HLPE, 2016). Nearly one third of the food produced globally every year eventually goes uneaten (FAO, 2011; The Consumer Goods Forum, 2015, Bahadur, 2016; IPFRI 2016). Nearly 800 million people globally suffer from hunger on a daily basis and 160 million of these are children and about quarter of the undernourished people live in sub-Saharan Africa.

Although there are many agricultural commodities in sub - Saharan Africa (SSA) which experience postharvest losses, this study focused on maize because it is the most important cereal and staple food for about 1.2 billion people in the region (IITA, 2009, FEWSNET, 2016). Most countries in Southern Africa, particularly Malawi, Mozambique, Zambia are concerned about the food security situation and the future outlook because of low agricultural productivity and the impact of climate change. Another factor contributing to food insecurity are postharvest losses which occur along the value chain and are estimated to range from 20% - 30%. With regard to cereals, it's estimated that at least 14 billion tons of food valued at US$ 4 billion is lost in sub Saharan Africa annually (World Bank, 2011). These estimates are exclusive of postharvest losses (PHL) in the form of reduced revenues arising from quality and market opportunity losses. Much as there is a lot of knowledge about PHL, there is lack of accurate figures on the actual level of losses in sub - Saharan Africa (Parfitt *et al.,* 2010 and Sheahana *et al*., 2016).

There are competing definitions of food loss and waste. Although food waste is mainly defined at retailing and consumption stages where agricultural products are predominately meant for human consumption, waste takes place at different stages of the food supply chain (Lipinski *et al.,* 2013)). According to FAO (2013) food losses are "a decrease in mass (dry matter) or nutritional value (quality) of food that was originally intended for human consumption". In reinforcing the debate of food losses, Lipinski *et al.,* (2013) asserted that food loss is the absence or decrease in food quality caused by spillage and spoilage because of poor food handling and transportation. Food losses take place at production, postharvest and processing stages in the supply chain (Parfitt *et al.,* 2010).

Post-harvest losses are caused by several factors which include inappropriate handling or bio-deterioration by micro-organisms, insects, rodents or birds (Kumar and Kalita, 2017;Grolleaud 1997; Boxall, 2002). In the developed world, large quantities of food produced is wasted for reasons such as it has passed expiry date and includes that which remains on the plate after meals (Hodges *et al.,* 2010, WRAP, 2007). Food losses and waste in developing countries are caused by financial, managerial, and technical constraints in harvesting methods, handling, storage, cold chain infrastructure, packaging and marketing systems (ibid).

In a bid to reduce food insecurity in the sub Saharan Africa region, intervention in post-harvest food loss reduction is seen as an important intervention (World Bank 2011; FAO, 2010). Other reasons for reducing food loss and waste include social, economic gains and environmental sustainability (Kader 2003; Gustavsson *et al.,* 2011, Parfitt, 2010)). One of the constraints to reducing food loss and waste is that some of the institutions that have the capacity to address the problem, such as governments and private sector are not very clear about where to start from due to inadequate empirical data to guide them during policy formulation (Sheahana *et al.,* 2016).

In the aftermath of the food crises of 2006/2008 and the anticipated food shortages in future, investment in reducing postharvest losses are considered to be potentially more cost effective and environmentally sustainable possibility to boost food security of particularly more vulnerable populations (IFPRI, 2011). Owing to the fact that food loss and waste reduces net food supply available for human consumption, it's envisaged that the reduction of food losses and waste would contribute to increasing net food supply, which subsequently could lower food prices locally and globally (FAO, 2011; Lipinski *et al.,* 2013, Lundqvist, de Fraiture and Moulden, 2008).

The dearth of infrastructure and poor production and harvesting techniques in many third world countries are bound to remain key factors in the creation of food waste. Although the reduction of postharvest losses is acknowledged as a cardinal element of improved food and nutrition security (Nellemann et al 2009), less than 5 percent of the funding for agricultural research is apportioned to postharvest systems (Kader, 2003).

While there may be other technologies for preventing PHLs in existence or under research, most discussion in literature is skewed towards the hermetic storage structures. The experimentation on use of acoustics to detect pest outbreaks in storage indicates that further innovations for PHL reduction is on the way (Sheahana *et al.,* 2016). They further say that arising from the compounding effect of crop deterioration accrued from the field, consideration should be given to interventions which reduce PHLs prior to harvesting of the crop.

There are opportunities for reducing postharvest losses through application of availability technology, arising from renewed world interest in addressing postharvest losses in response to the food crisis experienced during 2006-2008. For example, a variety of technologies are available for reducing PHLs, including crop protectants and storage containers such as hermetically sealed bags (PICS) and metal silos.

Despite the availability of knowledge and technologies for reducing PHL, there is poor flow of information to the ultimate users; the smallholder farmers and other value chain actors (Nellemann et al. 2009 and Shiferaw *et al.,* 2012). In addition, the factors which determine the adoption of technologies for reducing postharvest losses by value chain actors are not clearly known (Mwangi *et al.,* 2015).

Therefore, the use of technology to mitigate postharvest maize losses is one of the promising strategies that could be used to address food insecurity in Malawi, Mozambique, Zambia and other sub-Saharan African countries (FAO 2010; Nellemann *et al.,* 2009; Parfitt, 2010). It's against this background that a series of training workshops in grain handling and storage management was developed in Southern Africa.

2.0 MATERIALS AND METHODS

Between 2014 and 2015, the Southern Africa Trade Hub under the Feed the Future Programme supported 12 training workshops attended by 300 participants from Malawi, Mozambique and Zambia. The objective of the training workshops was to strengthen the capacity of smallholder farmers and grain traders to reduce post-harvest losses of maize during handling and marketing and to transition from bags to bulk storage. The training was targeted at smallholder farmers and traders dealing with cereal grains of at least 300 - 1,000 tons annually.

3.0 PLANNING OF THE TRAINING WORKSHOPS

The SierkYbema Grain Services of South Africa collaborated with Zambian Centre for Lifelong Learning Limited (ZL3 Ltd), ACE Ltd in Malawi and Unilurio University in Mozambique in running the training workshops. Planning for the workshops involved a series of meetings with trainers, suppliers of post-harvest equipment and commercial grain trading companies that buy grain from small scale grain aggregators. Some of the significant outcomes of the planning meetings included agreement on the workshop content, delivery methods, criteria for selection of participants and post training activities.

The expected outcomes of the training were:

- Shared understanding of the concepts and practices of grain handling;
- Increased knowledge and skills in grain handling;
- Increased skills in the use of grain handling equipment such as, moisture testers, sample dividers, sieving equipment;
- Exposure to pesticides used in preventing PHL caused by insects and rodents; and
- Increased adoption of 30 ton metal silos.

4.0 IMPLEMENTATION OF THE TRAINING WORKSHOPS

The training employed participatory learning and action methods. This approach used learner centered training styles aimed at developing skills and abilities of adult learners to diagnose and solve their own problems. The training delivery further employed a process of competence building and self-discovery for learners, whose needs, experiences and goals were the focus of the workshops. The practical sessions gave the participants an opportunity to exchange views on the opportunities, challenges and problem solving approaches in grain handling and trading.

The training workshops in the three countries included theory practicals and demonstration of various postharvest storage technologies. With regard to hermetic storage environments, the participants were shown the operations of 30 ton metal silos. These metal silos were robust units made from galvanized iron and capable of storing a wide range of grain crops. Since metal silos are hermetic and water resistant, they provide long term storage of grain which contributes to a reduction in postharvest grain losses and enhancing food and income security of the farmers. The metal silos used during the trainings were under promotion by the manufacturers that had even established a credit facility for traders interested in acquisition of this technology for storage of grains.

The other grain storage technologies demonstrated included Super Grain Gags, Zero Fly Bags and the GrainSafes. Although these bags can protect grain from moisture, insect pests and fungus, they are susceptible to damage by rodents.

5.0 TRAINING EVALUATION

In order to access the participant's level of knowledge on grain handling, they wrote a pretest at the start of the training workshops. The participants were continuously assessed through theoretical and practical tests administered at the end of each training session. The final evaluation of understanding of learning materials involved participants writing theory and practical tests. Of the 300 participants enrolled for the trainings, the 286 that passed the tests became certified to manage grain handling facilities in the Southern African Development Community (SADC) region.

The assessment indicated that participants were satisfied with the learning materials, practical exercises and the delivery of training. The participants further expressed the view that much as metal silos provided more versatile protection of grain than grain bags, the 30 ton capacity metal silos which were demonstrated during the training were not appropriate for their needs. The participants preferred that the credit facility for the purchase of the metal silos could have been made available for buying of grain as this would have increased their volume of business.

At the end of the training participants developed plans for the application of the knowledge and skills acquired from the training.

6.0 POST TRAINING FOLLOW - UP

Six months after the training, a post training follow - up was conducted. The objectives of the follow-up study were to:

i. Determine the challenges faced by participants in applying the knowledge and skills acquired from the training;

ii. Evaluate the number of 30 ton metal silos bought by the trained grain traders; and

iii. Identify the technologies used by traders to reduce postharvest grain losses in their businesses.

7.0 DATA COLLECTION AND ANALYSIS

7.1 Data Collection Methods

The data collection tools included questionnaires for structured interviews directed at the respondents and a checklist used in focus group discussions (FGDs). The information from focus group discussions assisted to triangulate and qualify data collected from interviews and in making the recommendations on remedial measures to be undertaken. Other tools included observations. Key informants comprised maize processors and manufacturers of agro storage equipment. Data analysis was done using SPSS and content analysis.

7.2 Sampling

Purposive sampling was used because it helped to answer the study questions (Kumar 2011). Purposive sampling is virtually synonymous with qualitative research (Palys, 2008), also known as judgmental, selective or subjective sampling is a type of a non-probability sampling technique. The main goal of purposive sampling is to focus on particular characteristics of a population that are of interest, which best provide answers to research questions.

The grain traders interviewed were those that had attended the training workshops in the three countries. The 150 farmers (75 per district) will be randomly selected using RANDBETWEEN Excel function. The 60 sampled traders were at the standard error of the mean ≥ 0.05 (i.e. n/N= 0.05). Therefore this sample size was within the 95% confidence interval and 5% margin of error.

8.0 RESULTS AND DISCUSSION

The results from post training follow up showed a reduction in the grain rejected by the market on account of low quality. Grain losses incurred by the traders reduced due to improved handling methods. The study further established that the grain losses incurred by the traders reduced and this subsequently increased the volume of grain traded. Table 1 shows that methods such as cleaning, grading and application of pesticides to grain contributed to improved quality and reduction in postharvest losses. These results confirmed that capacity strengthening of actors along the food supply chain can contribute to the reduction of postharvest losses. In the absence of information about postharvest loss management, it is no wonder that there is a low uptake of innovations and technologies for preventing postharvest food losses among the actors in the food supply chain in Malawi, Mozambique and Zambia and other SADC member states.

With regard to adoption of metal silos, table 2 shows that 12 percent of the trained traders had bought the metal silos despite the availability of a credit facility to support the purchase of the technology. The few silos were bought by the large grain marketing companies on recommendation from employees that had attended the training. Reasons for the poor adoption were inappropriateness of the technology to the target group, high cost, lack of power for loading and offloading of grain and trucks for bulk transportation.

Table1 : Technology application

		Frequency	Percent	Valid Percent	Cumulative Percent
Va	Pesticides to control pests	5	8.3	8.3	8.3

Valid combination of pesticides cleaning and grading	54	90.0	90.0	98.3
No response	1	1.7	1.7	100.0
Total	60	100.0	100.0	

Source: Field survey data: 2016

Table 2: Purchases of metal silos

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	7	11.7	11.7	11.7
	No	51	85.0	85.0	96.7
	No response	2	3.3	3.3	100.0
	Total	60	100.0	100.0	

Source: Field survey data: 2016

The low adoption of the metal silos can be explained by the Technology Acceptance Model (TAM) which is widely used to predict and explain user acceptance of technologies (Davis, 1989, Venkatesh, 1996). TAM suggests that user acceptance and usage of a technology is determined by perceived usefulness (PU) and perceived ease of use (PEU).

According to the Technology Acceptance Model (TAM) the two theories which determine an individual's behavioral intention to adopt a technology are perceived usefulness (PU) and perceived ease of use (PEU). Perceived usefulness is defined as "the degree to which an individual believes that using a particular system would enhance his or her productivity" while perceived ease of use is defined as "the degree an individual believes that using a particular system would free of effort" (Davis,1989). Of the two theories, perceived ease of use has a direct effect on both perceived on both perceived usefulness and technology usage (Adams et al,. 1992; Davis, 1989). Saga and Zmud (1994) found that an individual may adopt a technology if it is perceived suitable, beneficial and socially desirable even if they do not like using the technology.

Although several approaches and technologies for reducing postharvest losses in developing countries have been developed there are challenges in adopting these technologies in the rural areas (Rosegrant *et al.,* 2015). Shiferaw et al (2012) report that technologies face adoption challenges because of their inappropriateness for smallholder farmers, unavailability at the right time and right price. Although literature reports of several studies conducted on innovation and uptake of agricultural technology and its impact of smallholder farmer in developing countries, its adoption is slow and certain features of adoption are not yet properly understood although they are a critical creation of prosperity in developing countries (Bandiera and Rasul; 2011).

9.0 LESSONS LEARNED

Some of the key lessons learned were that:

i. Metal silos have an important role to play in reducing postharvest losses because they offer long term storage of grains. The suitability of metal silos to the needs of grain traders is an important factor in the adoption of this storage technology. The stallholder farmers and traders preferred metal silos of 1-2 ton capacity because they were appropriate for storage of maize grain retained for consumption. Since the grain for the market does not get stored for more than 3 months it did not make any business sense to invest in a 30 ton metal silo for temporary storage.

ii. The 30 ton capacity metal silos which were on promotion during trainings were poorly adopted by the target market which preferred smaller capacity metal silos. Even the availability of credit to purchase the US$ 18, 000 metal silos was not attractive enough to make the grain traders invest into the metal silo technology.

iii. Although grain bags are not as versatile as metal bins in providing long term storage of grain, farmers and grain traders are likely to continue using this technology because of its suitability to the circumstances of the users.

iv. Poor adoption of the metal silo technology was due to inappropriateness of the technology to the circumstances of the target group.

v. The absence of adequate information about postharvest loss management, contributes to the low uptake of innovations and technologies for preventing postharvest food losses among the actors in the food supply chain in the target countries.

vi. Residential training was not suitable for traders as at times they had to leave the training venue in order to attend to their businesses. The use of open and distance learning (ODL) would have been a better option because it does not remove traders from their businesses.

vii. Small grain traders could not afford the cost of grain grading equipment such as moisture testers, sample dividers and sieves

viii. The concept of bags to bulk was not feasible due to lack of support infrastructure such as appropriate metal silos, trucks for transportation of bulk grain and electrical power for driving the equipment used in loading and off-loading of grain.

ix. After training there was an improvement in the quality of grain delivered by the trained traders to grain trading and milling companies.

x. Arising from the application of improved grain handling methods, there was a reported reduction in the quantity of grain lost along the supply chain.

7.0 CONCLUSION

Most countries in Southern Africa, particularly Malawi, Mozambique, Zambia are concerned about the food security situation because of low agricultural productivity and the impact of climate change. Food insecurity is further exacerbated by postharvest losses which occur along the value chain.

Despite the availability of technologies for reducing postharvest food losses worldwide, their adoption remains low in Africa. Therefore, identification and elimination of constraints to the adoption of existing technologies for reducing post-harvested losses should be considered. Grain storage is a critical stage in the supply chain where losses should be minimized and appropriate technology to achieve this is required. The common storage systems used by small and medium producer includes granaries, plastic containers storehouses, plastic or jute bags.

The results of the post training evaluation showed an improvement in the quantity and quality of grain marketed by traders that had received training in grain handling. The adoption of the 30 ton metal silo, however, was insignificant because of the cost and inappropriateness of the technology to the operating environment of the target group.

The strategy to use bulk storage for preventing post-harvest grain losses through replacement of bags for packaging and transportation of maize is not yet feasible in Malawi, Mozambique and Zambia. This is due to lack of support infrastructure such as technology for on farm bulk storage, trucks for bulk transportation of grain and power for operating the equipment for bulk loading and off-loading of grain.

One of the limitations with this study was its focus on the 30 ton bulk storage bin. The study can be broadened and enhanced through the inclusion of other bulk storage technologies such as the 2 ton metal bin storage, GrainSafes and Purdue Improved Storage (PICS) bags. This technology is more suitable to the circumstances of smallholder farmers and grain traders because of its low cost and adaptability.

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APPLICATION OF UTAUT IN UNDERSTANDING THE ADOPTION OF TECHNOLOGIES FOR REDUCING POSTHARVEST MAIZE LOSSES IN ZAMBIA

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Abstract

The purpose of this paper is to contribute to the discourse on factors which influence the adoption of technologies for preventing postharvest losses of maize among smallholder farmers in Zambia. In this study, the Unified Theory of Acceptance and Use of Technology (UTAUT) was used to understand the farmers' behavioral intention to adopt technologies.

Unless the current strategies employed to reduce world hunger are changed, it may be difficult to feed the world's population which is expected to be 9.6 billion by 2050. World food supply can be increased by either embarking on more production or saving the food already produced.

Eastern and Southern Africa experiences annual food loses valued at US$ 1.6 billion. The estimates of annual maize losses for Zambia are between 15-20%, valued at US$ 150 million.

Despite the availability of technologies for reducing postharvest food losses worldwide, their adoption remains low in Zambia. Therefore, identification and elimination of constraints to the adoption of existing postharvest technologies should be explored.

The results showed that farmers considered the use of technology as beneficial. They, however, needed more information on the available technologies and that social influence was important in technology adoption.

Key words: Postharvest losses, technology, adoption, UTAUT.

1.0 INTRODUCTION

Unless the current strategies employed to reduce world hunger are changed, it may be difficult to feed the world's population which is expected to be 9.3 billion by 2050 (Godfray et, al. 2010; FAO, 2010; Buzby *et. al.,* 2015; Winkworth-Smith *et el.,* 2015; Kumar and Kalita, 2017). The world food supply can be increased by either embarking on more production and / or saving most of the food already produced (Kiaya, 2014). It is estimated that 1.3 billion tons of food produced globally is lost or wasted between the time that it is harvested and consumed (FAO, 2011; The Consumer Goods Forum, 2015, Bahadur, 2016; IPFRI 2016). Food losses and waste at world level are estimated to be 30% for cereals, 40 to 50 % for fruits and vegetables and root crops, 30% for fish and 20 % for oil seeds, meat and dairy (Rutten, 2013).

Sub Saharan Africa, Eastern and Southern Africa lose food valued at about US$ 4 billion and US$ 1.6 billion per annum respectively (FAO, World Bank: "Missing Food", 2011). This food is adequate to feed at least 48 million of the 220 million undernourished people in Africa. In a bid to reduce food insecurity in the sub Saharan Africa region, intervention in post-harvest food loss reduction is important (World Bank 2011; FAO, 2010). Food losses take place at production, postharvest and processing stages in the supply chain (Parfitt et al., 2010). Although, there is a lot of knowledge about PHL, there is a lack of accurate figures on the actual losses in sub - Saharan Africa (Parfitt *et al.,* 2010 and Sheahana *et al.,* 2016). Post-harvest losses are caused by several factors which include inappropriate handling or bio-deterioration by micro-organisms, insects, rodents or birds (Kumar and Kalita, 2017; Grolleaud 1997; Boxall, 2002).

Although there are many agricultural commodities in Southern Africa (SSA) which experience postharvest losses, this study focused on maize. This crop has been selected because it is the most important cereal and staple food for about 1.2 billion people (IITA, 2009, FEWS NET, 2016). According to USAID (2010), maize is the second most important food crop after cassava in Africa. It provides nutrients for humans and animals and also serves as a basic raw material for the production of starch, oil and protein, alcoholic beverages.

In Southern Africa, agricultural policies of many member countries reflect and emphasise the importance of maize in the national economies. For example, Malawi and Zambia channeled the majority of producer and consumer subsidies into maize at the expense of other crops (Tschirley *et al.,* 2006). The report by Zambia Parliamentary Committee on Agriculture revealed that during the 2006/2007 agricultural season, the Food Reserve Agency (FRA) lost 5,776 tons of maize from main depots and 2,800 tons from sheds (National Assembly of Zambia, (2011).

Maize is an important crop in Zambia because it is the main staple food for human and a source of raw materials for the livestock industry (FAO, 2009, FSRP, 2011). Zambia is one of the major producers of maize in sub -Saharan Africa with annual production in recent years averaging 3 million metric tons (IAPRI, 2016, Chapoto *et al.,* 2015). The problem of postharvest maize losses in Zambia is significant because it has an implication on national food security as maize is the staple food (USAID SATH, 2012; Hays *et al.,* 2014). Any shortfall in supply can lead to high consumer prices and might call for food imports. It is estimated that every year Zambia loses up to 30% of the harvested food grains through wastage resulting from poor handling, poor storage, and inadequate capacity among the value chain actors, lack of good facilities and delayed collection of maize from the depots (USAID SATH, 2012). According to Indaba Agricultural Research Institute (2013) Zambia loses thousands of bags of maize through crop waste resulting from poor storage, lack of good facilities and delayed collection of grain from storage depots. This costs the country a lot of money and is a huge drain on the resources which could be channeled to boost food security and increase export earnings. The estimates of grain losses quoted by APHLIS for Zambia are between 15-20%, which is less than what is found in most publications (APHLIS, 2011).

All these losses happen in the midst of available information and technologies for reducing PHL worldwide due to low adoption and poor flow of information to the ultimate users such as the smallholder farmers and other value chain actors (*Nellemann et al.,* 2009 and Shifeeraw *et al.,* 2012). In addition, the factors which determine the adoption of technologies for reducing postharvest losses by value chain actors are not clearly known (Mwangi & Kariuki, 2015).

Therefore, the use of technology to mitigate postharvest losses is one of the promising strategies that could be used to address food insecurity in sub-Saharan African countries (FAO 2010; Nellemann *et al.,* 2009; Parfitt, 2010). Some of the technologies available for reducing PHLs, include crop protectants and storage containers such as hermetically sealed bags, plastic drums and metal silos (Chikoye, 2017).

Smallholder farmers in developing countries face many pre-and post-production challenges, hence they must be a primary target for Agricultural technology solutions (Loevinsohn *et al.,* 2013). Although literature reports of several studies conducted on innovation and uptake of agricultural technology and its impact on smallholder farmers in developing countries, their adoption is slow and certain features of adoption are not yet properly understood (Bandiera and Rasul; 2011).

The identification and elimination of the constraints, such as lack of finances, knowledge and trained personnel; political and cultural issues (Kiaya, 2014); and the application of existing technologies for reducing post-harvest food losses should be given due attention (Kitinoja *et al.,* 2010).

There are several methods used to analyse product, system or technology acceptance. Davis (1985) proposed that what motivated the user of a system or technology could be supported by three factors, perceived ease of use (PEU), perceived usefulness (PU) and attitude towards using a system or technology. According to Davis (1985), Davis et al., (1989), Venkatesh and Davis, (1996), and Venkatesh and Bala (2008), perceived ease of use (PEU) is defined as “the degree to which a person believes that using a particular system would be free of effort” and perceived usefulness (PU) as “the degree to which a person believes that using a particular system would enhance his or her job performance”. The attitude of the user toward a system or technology was a major determinant of whether the user actually uses or rejects the system or technology (Davis 1985). The attitude of the use in turn was considered to be influenced by two major beliefs, perceived usefulness (PU) and Perceived Ease of Use (PEU) with the latter having a direct influence on PU. Between the two theories, perceived ease of use has a direct effect on both perceived usefulness and technology usage (Adams *et al.,* 1992; Davis, 1989).

The Technology Acceptance Model (TAM) (Davis, Bagozzi and Warshaw, 1989) is the most commonly known and is mostly used in research focusing on users (Venkatesh and Davis, (1996). The consumers' acceptance of new technologies and their intention to use has been explained by several theories (Venkatesh and Bala (2008) including, but not limited to: Theory of Diffusion Innovation (DIT) (Rogers, 2002), which began in 1960; Theory of Reasonable Action (Fishbein and Ajzen, 1975); the Theory of Task-technology Fit (TTF) (Goodhue, and Thompson, 1995);Theory of Planned Behavior (TPB) (Ajzen, 1985, 1991); Decomposed Theory of Planned Behaviour (Taylor and Todd, 1995); Final version of Technology Acceptance Model (Venkatesh and Davis, 1996); and Unified Theory of Acceptance and Usage of Technology (UTAUT) (Venkatesh, Morris, Davis and Davis, 2003) and TAM 3 (Venkatesh and Bala 2008).

The most prominent of these is the Unified Theory of Acceptance and Use of Technology (UTAUT) (Lescevica *et al.,* 2013). See figure 1. This model was created from studies done on eight major models in adoption research. Empirical studies conducted have demonstrated that the UTAUT model outperformed the other eight models inclusive of the popular TAM (ibid). While the UTAUT model versatile model, it has raised some issues among researchers (Mohavvemi *et al., 2012*). When prospective users are deciding on technology adoption, intentions are formed before behavior although the link between them is rather complicated and might require more inquiry (Krueger, 2007) as reported by Mohavvemi *et al., 2012*. Venkatesh *et al.,* (2008) found that performance of behavior is not affected by behavioral intention because the latter lacks the necessary external factors. They further found that behavioral intention does not have a strong predictive and explanatory ability between the time of formation of intention and when behavior is put into action (Ibid). Finally, behavioral intention lacks strength in its capacity to foretell behaviors which are not fully within an individual's power to choose (Mohavvemi *et al., 2013*). According to Sheeran (2002), the gap between intention and behavior is called the 'intention- behavior gap'.

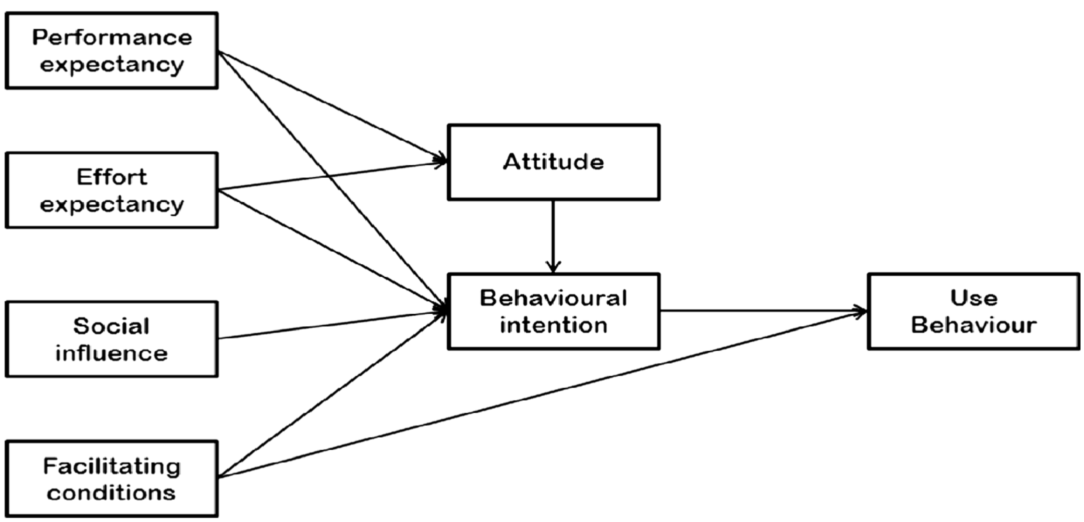

Fig 1: UTAUT Model (Source: Adapted from Venkatesh *et al.,* 2003)

The central constructs or endogenous variables of the UTAUT Model are; Performance Expectancy (PE), Effort Expectancy (EE), Attitude towards using the technology (ATUT). Social Influence (SI), Facilitating Conditions (FC) towards adoption of postharvest loss technology. Gender, age and education are categorized as key moderators or important moderating influences on behavioral intention and use behavior (exogenous variables) (Venkatesh *et al.,* 2003, Niehaves and Plattfaut 2010).

Behavioral intention describes, “an individual’s readiness to display a certain behavior, i.e., use a given technology to accomplish certain tasks” (Veronikis *et al.,* 2011). Behavioral intention (BI) is defined as a persons’ perceived likelihood or “subjective probability that he or she will engage in a given behavior” (Committee on Communication for Behaviour Change in the 21st Century).

According to Veronikis *et al.,* 2011, Use behavior, describes, “ the extent to which an individual really uses a given technology”.

Table 1 provides additional information on constructs or endogenous variables used in the model.

Table 1: Definition for constructs used in the model

Construct	Definition
Knowledge Expectancy (KE)	The degree to which an individual perceives that they have understood how a particular technology works (Venkatesh *et, al*., 2003).
Effort Expectancy (EE)	The degree to which an individual believes that using a particular system would be free of physical and mental effort (Venkatesh *et, al.,* 2003).
Performance Expectancy (PE)	The degree to which an individual believes that using a particular system would enhance his or her productivity (Venkatesh *et, al.,* 2003).
Attitude towards using the technology	Technology characteristics could directly influence the attitude of the person toward using the technology, without the need by the person to form a belief about the technology (Davis et., 1989; Fishbein and Ajzen, 1975; Taylor and Todd 1995 a, b).
Facilitating Conditions (FC)	Given a system which was perceived useful, a person may form a strong behavioral intention to use the system without forming any attitude (Venkatesh *et, al.,* 2003).
Social Influence (SI)	Person’s perception that people who are important to him think he should or should not perform (Venkatesh *et, al.,* 2003).

According to Lescevica *et al.,* (2013), UTAUT has been applied, integrated and extended by researchers when studying distinct technology acceptance and use across an array of scenarios such as different types of technologies, different periods and places. They further proposed that technology users can be grouped into consumers, citizens, workers. For instance, Hong et al., (2011) used a sample of workers at organizational level while Zhou, Lu, and Brown (2010) used a sample of service users such as consumers. UTAUT has further been used in studies investigating technology acceptance in settings which are not in western countries, such as Korea (Im, Hong and Kang, 2011), India (Gupta *et al.,* 2008), China (Venkatesh and Zhang, 2010). Furthermore, UTAUT can be used to study different types of tasks such as those which focus on technology supports which include idea initiation, and decision formulation in technology design (Brown *et al.,* 2010).

Additional research has concentrated on particular economic factors like food services (Yoo, Han and Huang, 2012), public sector (Dasgupta and Gupta, 2011) and education (Chiu and Wang, 2008).

To all intents and purposes, research has established beyond any reasonable doubt that UTAUT is a versatile model (Lescevica *et al.,* 2013). Nevertheless studies have not thoroughly investigated the moderating influences of factors such as experience, age and gender. Most investigations have merely tested the key effects (Chang *et al.,* 2007); while other researchers have studied the subclass of the moderation effects (Gupta *et al.,* 2008). Generally, numerous research findings back the generalizability of UTAUT, although only in terms of its principal effects (Lescevica *et al.,* 2013).

2.0 OBJECTIVES OF THE STUDY

The objective of this study was to identify factors which contribute to the adoption of technologies for reducing postharvest maize losses among smallholder farmers in Zambia.

3.0 DATA COLLECTION METHODS

3.1 Data Collection

A bibliographic review of both published and grey literature was conducted. Data from this study were collected from respondents using a pre-tested semi structured questionnaire. In addition, discussions were held with informants and focus group discussions to access detailed information which was used to qualitatively support the study result and characterize the constraints. The key informants (KI) comprised, agro-dealers, heads of departments of agricultural universities and colleges, government officials at national and district levels and policy makers. Furthermore, millers, manufacturers of agro storage equipment, and managers of warehouses provided information that assisted in triangulating and assessing qualify of data collected from interviews. Focus group discussion outcomes assisted in qualifying the recommendations on remedial measures to be undertaken.

3.2 Sampling

Purposive sampling was used. Purposive sampling is virtually synonymous with qualitative research (Palys, 2008), also known as judgmental, selective or subjective sampling, is a type of a non-probability sampling technique. The main goal of purposive sampling is to focus on particular characteristics of a population that are of interest, which best provide answers to research questions (Kumar 2014).

One hundred smallholder farmers (from Choma, Katete and Kalomo districts of Zambia) were randomly selected using RANDBETWEEN Excel function. The 100 sampled respondents were at the standard error of the mean ≥ 0.05 (i.e. n/N= 0.05). Therefore this sample size was within the 95% confidence interval and 5% margin of error.

3.3 Data Analysis

Data analysis was done with the aid of SPSS version 20. The qualitative data collected using key informant interviews, field observations, focus group discussions and oral histories were analysed using narrative explanation and argument. Quantitative data were analysed using different descriptive and inferential statistical tools, specifically means, standard deviation, percentages, frequency distribution and test statistics.

The statements in the section of questionnaire assessing technology acceptance were based on previous studies relating to adoption and use of technology. The variables were measured on a 5 point scale as in the original UTAUT, where 1 was equivalent to the negative end (fully disagree) and 5 for the positive end of the scale (fully agree).

4.0 FINDINGS AND DISCUSSION

In this study, the Unified Theory of Acceptance and Use of Technology (UTAUT) was used to understand the farmers' behavioral intention to adopt technologies. The study used six constructs to assess the farmers' behavioral intentions to adopt and or use technologies for reducing postharvest losses. These constructs were; knowledge expectancy, effort expectancy, performance expectancy, attitude towards using the technology, facilitating conditions and social influence.

The statements in the questionnaire were based on previous studies relating to adoption and use of technology. The variables were measured on a 5 point scale as in the original UTAUT, where 1 was equivalent to the negative end (fully disagree) and 7 for the positive end of the scale (fully agree).

4.1 Respondent's Profile

The questionnaire was administered to 100 farmers located in three high maize production districts of the country. Table 2 presents the gender profiles of the respondents. Nearly 60% of the respondents were male.

Table 2: Gender of respondents

Gender		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	59	59.0	59.0	59.0
	Female	41	41.0	41.0	100.0
	Total	100	100.0	100.0	

With regard to age, 50 % of the respondents were below the age of 51 years. This shows an even distribution of age groups engaged in farming. Table 3 illustrates the age distribution of the respondents.

Table 3: Age of respondents

Age		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-30 yrs.	16	16.0	16.0	16.0
	31-40 yrs.	17	17.0	17.0	33.0
	41-50 yrs.	17	17.0	17.0	50.0
	51-60 yrs.	13	13.0	13.0	63.0
	Above 61 yrs.	21	21.0	21.0	84.0
	Not response	16	16.0	16.0	100.0
	Total	100	100.0	100.0	100.0

Nearly half of the respondents had only attended primary school education and /or had never been to school. Sixty one percent of the respondents with primary school education and those that had not attended school were female. Table 4 shows the educational levels of the respondents by gender.

Table 4: Education level of respondents

Level of education	Frequency	Percent	Valid Percent	Gender		Cumulative Percent
				M	F	
University	1	1.0	1.0	1	0	1.0
College	12	12.0	12.0	10	2	13.0
Secondary school	31	31.0	31.0	25	6	44.0
Primary School	42	42.0	42.0	17	25	86.0
Not been to school	12	12.0	12.0	4	8	98.0
No response	2	2.0	2.0	0	2	100.0
Total	100	100.0	100.0	59	41	100.0

4.2 Reliability

In this study, Cronbach's Alpha reliability test method was applied. A higher value of Cronbach's Alpha is a better value for reliability. The analysis shows that Alpha is at 0.681 which is close to 0.7. Thus we can conclude that the results were reliable. See Cronbach's Alpha for each item in Table 5 below.

Table 5a. Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.681	.698	6

Table 5b. Cronbach's Alpha results

UTAUT Constructs	Cronbach's Alpha
Knowledge expectancy	0.656
Effort expectancy	0.501
performance Expectancy	0.782
Attitude towards using the technology	0.650
Facilitating Conditions	0.598
Social Influence	0.580

4.3 Correlation Analysis

The Spearman's correlation is based on ranked values for each variable rather than raw data. Spearman's correlation is usually used to evaluate relationships involving ordinal variables. The results in Table 6 show that there was strong significant correlation between knowledge expectancy and performance expectancy ($p=0.05$). Other variables that showed significant relationships were gender and education; attitude towards technology and facilitation expectancy; knowledge and effort expectancy; attitudes, facilitation, social influence and knowledge expectancy, respectively ($p\leq0.05$). Attitude towards technology, social facilitation, social influence and performance expectancy, respectively were insignificant ($p>0.05$).

Table 6: Spearman's Correlation (n=100)

	Age	Gender	Education	KE	EE	PE	AT	FC	SI
Age	1.000								
Gender	-.068	1.000							
	.502								
Education	-.181	.370	1.000						
	.072	.000							
KE	-.003	.184	-.020	1.000					
	.974	.067	.843						
EE	-.002	-.010	-.092	.463	1.000				
	.985	.922	.362	.000					
PE	.105	.101	.007	-.197	.014	1.000			
	.298	.317	.945	.050	.890				
AT	-.163	.007	.135	.477	.451	-.015	1.000		
	.105	.948	.180	.000	.000	.879			

FC	-.070	.133	-.150	.301	.598	.071	.227	1.000	
	.491	.187	.136	.002	.000	.484	.023		
SI	.093	-.010	-.162	.480	.737	-.047	.301	.413	1.000
	.356	.923	.108	.000	.000	.639	.002	.000	

Correlation is significant at the 0.05 level (2-tailed)

4.4 Descriptive Analysis

This section attempts to provide a better understanding of reasons behind the farmers' adoption or low adoption of technologies for reducing PHL. All the items under the study had 5 interval scores, with 1 being the lowest score while the highest score was 5.

Knowledge Expectancy

As indicated in Table 7 most of the respondents gave a 4 and 5 score for Knowledge Expectancy, and that their interaction with PHL technologies is easy to understand.

Table 7: Knowledge Expectancy (KE)

Variable	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
KE1: I understand the benefits of using PHL technologies to reduce maize losses	2 2.00%	1 1.00%	8 8.00%	49 49.00%	40 40.00%
KE2: It's easy for me to remember how to perform the tasks using PHL technologies	2 2.00%	9 9.00%	22 22.00%	49 49.00%	18 18.00%
KE3: My interaction with PHL technologies is easy for me to understand	3 3.00%	11 11.00%	27 27.00%	42 42.00%	17 17.00%

Figure 2 shows that about half of the respondents agreed that they understood the benefits of using PHL technologies to reduce maize losses, and that it was easy for them to remember how to perform the technology related tasks.

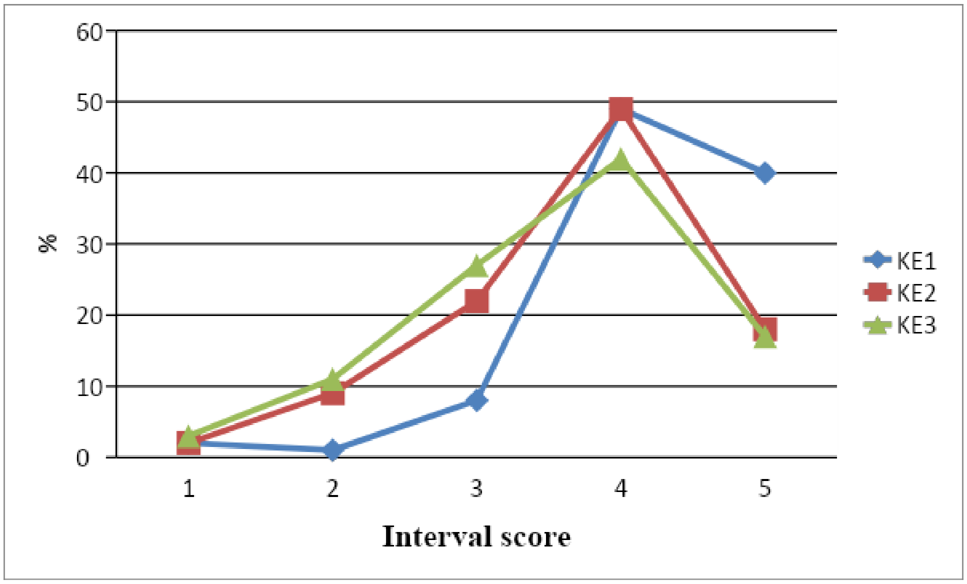

Fig 1: Performance Expectancy Scaling Results.

Effort Expectancy

The results in Table 8 show the insight of respondents on Effort Expectancy. They agree that, learning to operate some of the PHL technologies was easy and that they find PHL technologies easy to use.

Table 8: Effort Expectancy (EE)

Effort expectancy	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
EE1:Learning to operate some of the PHL technologies was easy for me	2 2.00%	13 13.00%	31 31.00%	41 41.00%	13 13.00%
EE2: I rarely become confused when I use the PHL technologies	1 1.00%	22 22.00%	26 26.00%	41 41.00%	10 10.00%
EE3: I rarely make errors when using PHL technologies	5 5.00%	27 27.00%	32 32.00%	28 28.00%	8 8.00%
EE4: I rarely get frustrated when using PHL technologies	3 3.00%	20 20.00%	32 32.00%	34 34.00%	11 11.00%

EE5: Overall, I find PHL technologies easy to use	2 2.00%	3 3.00%	22 22.00%	62 62.00%	11 11.00%

As shown in Figure 2 nearly 60% of the respondents generally, find PHL technologies easy to use. This suggests that farmers would find knew PHL technologies easy to use.

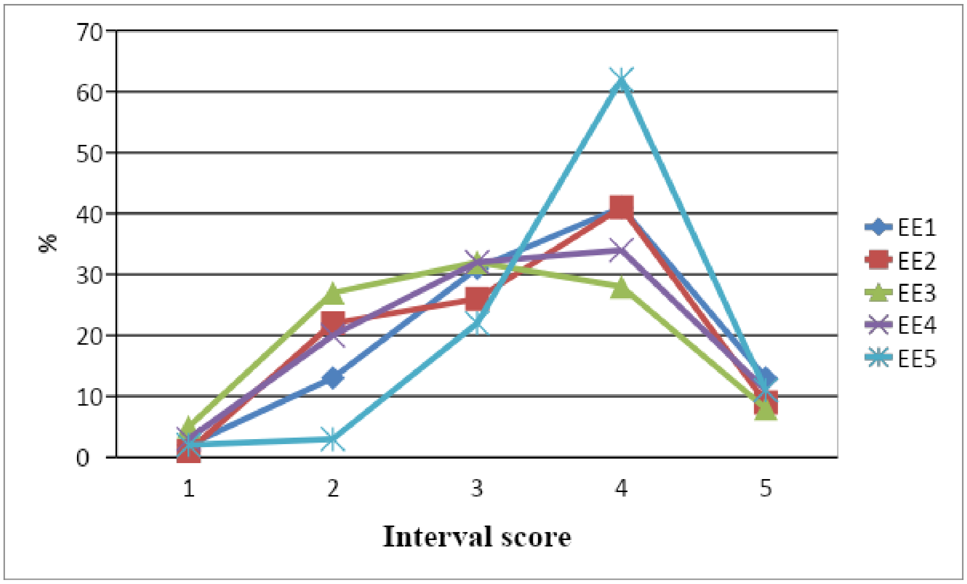

Fig 2: Effort Expectancy Scaling Results

Performance Expectancy

Most of the respondents gave a score of five on this construct. Generally the respondents agreed that PHL technologies would make them more productive through quicker accomplishment of tasks and thereby having greater control over their work

Table 9: Performance Expectancy (PE)

Performance Expectancy	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
PE1: Using PHL technologies gives me greater control over my work	2 2.00%	3 3.00%	14 14.00%	56 56.00%	25 25.00%
PE2: PHL technologies enable me accomplish tasks quicker	0	1	7	65	27

	0.00%	1.00%	7.00%	65.00%	27.00%
PE3: Using PHL technologies reduces the amount of time I spend on unproductive activities	2 2.00%	4 4.00%	9 9.00%	52 52.00%	33 33.00%
PE4: Some of the PHL technologies are rigid and inflexible to interact with	8 8.00%	5 5.00%	5 5.00%	37 37.00%	45 45.00%
PE5: Using PHL technologies saves me time	0 0.00%	3 3.00%	3 3.00%	48 48.00%	44 44.00%

PHL technologies such as cement bins (Ferrumbus) and large capacity metal bins which could not be moved in the event of a farmer relocating to a new place were considered rigid and inflexible to interact with, thereby making their adoption rather difficult.

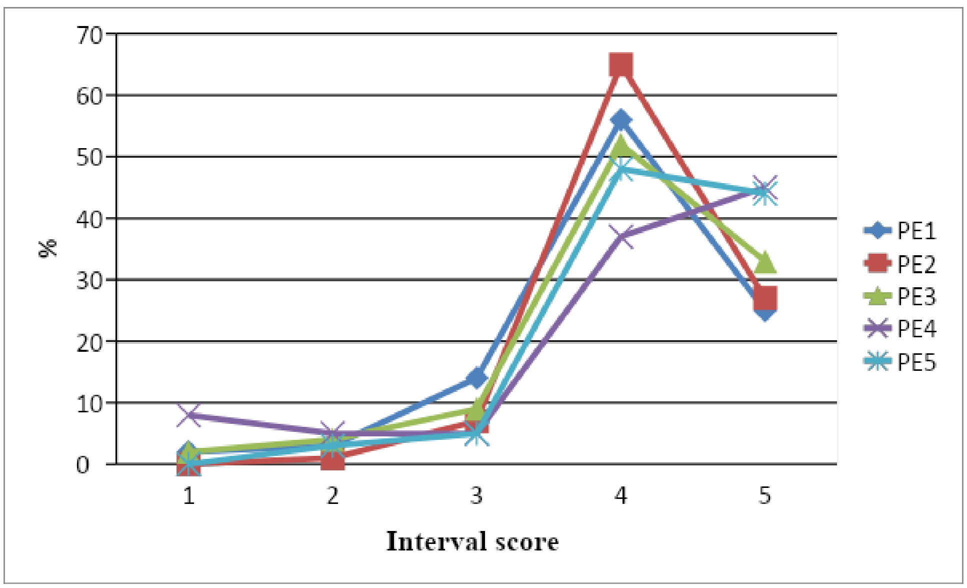

Fig 3. Performance Expectancy Scaling Results.

Attitude Towards Using Technology (ATT)

Table 10 indicates the views of respondents on attitude towards using PHL technologies. Majority of the respondents were of the opinion that using postharvest loss reducing technologies was a great idea.

Table10: Attitude towards using technology

Attitude towards using technology	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
ATT1: All things being equal, my using of technology on my farm is good	0 0.00%	3 3.00%	8 8.00%	56 56.00%	33 33.00%
ATT2: All things being equal, my using of PHL technologies on my farm is wise	0 0.00%	1 1.00%	7 7.00%	56 56.00%	36 36.00%
ATT3: All things being equal, my using of PHL technologies on my farm is favorable	1 1.00%	2 2.00%	13 13.00%	59 59.00%	25 25.00%
ATT4: All things being equal, my using of PHL technologies on my farm is positive	1 1.00%	1 1.00%	7 7.00%	55 55.00%	36 36.0 0%

As indicated in Fig 5, respondents further considered using PHL technologies as being satisfactory on their farms.

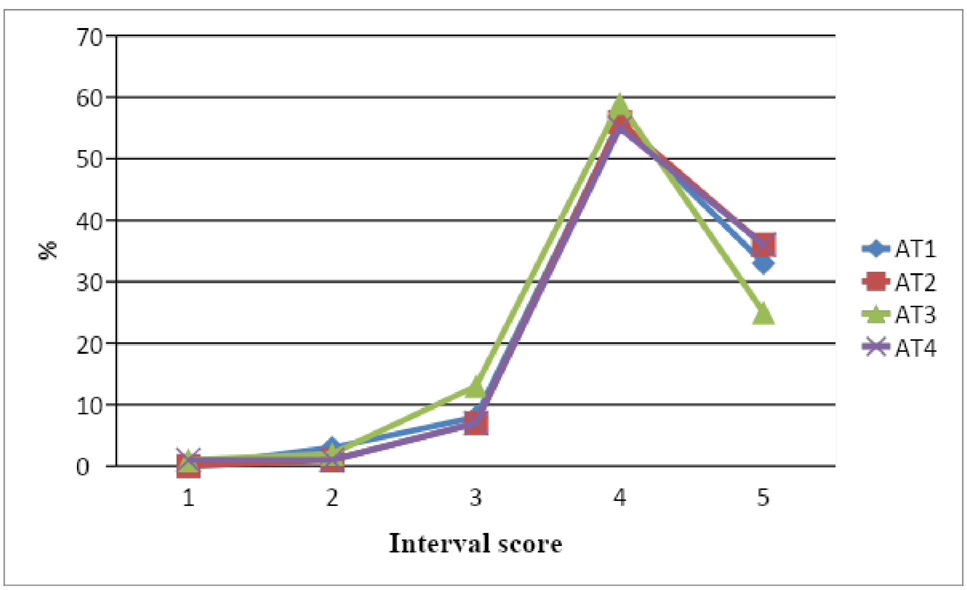

Fig 5: Attitude Towards Using Technology Scaling Results

Facilitating Conditions (FC)

Table 11 provides a general perception of respondents towards usage, investment and control over some of the PHL technologies.

Table 11: Facilitating Conditions

Facilitating Conditions	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
FC1: I am able to confidently use some of the PHL technologies	1 1.00%	5 5.00%	27 27.00%	53 53.00%	14 14.00%
FC2: I have the knowledge to use some of the PHL technologies	2 2.00%	2 2.00%	23 23.00%	59 59.00%	14 14.00%
FC3: I have the resources to acquire some of the PHL technologies	1 1.00%	2 2.00%	6 6.00%	69 69.00%	22 22.00%
FC4: I have the ability to use some of the PHL technologies	1 1.00%	5 5.00%	20 20.00%	57 57.00%	17 17.00%
FC5: I have control over some of the PHL technologies	4 4.00%	9 9.00%	23 23.00%	52 52.00%	12 12.00%

Nearly all the respondents believed that they had the resources to invest into procuring some of the PHL technologies. They further thought that they had the capacity to use some of the PHL technologies (See Fig.6).

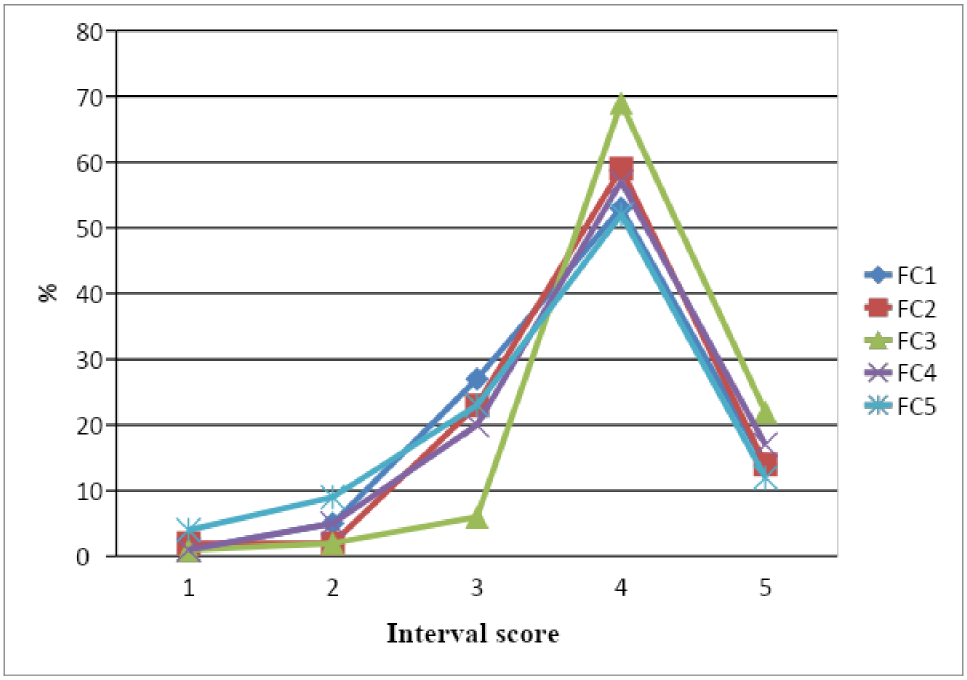

Fig 6. Facilitating Conditions Scaling Results

Social Influence

Table 12 provides a summary of respondent perception of social influence on using PHL technologies. The respondents were of the view that their intention to adopt PHL technologies is influenced by close friends, peers, and influential people and opinion leaders in the community.

Table 12: Social Influence

Social Influence	Strongly disagree 1	Disagree 2	Neither agree or disagree 3	Agree 4	Strongly agree 5
SI1: People who influence my behavior think I should use PHL technologies	4 4.00%	2 2.00%	21 21.00%	50 50.00%	23 23.00%
SI2: People who are important to me think I should adopt PHL technologies	1 1.00%	1 1.00%	15 15.00%	61 61.00%	22 22.00%
SI3: My close friends think I should adopt PHL technologies	2 2.00%	1 1.00%	9 9.00%	31 31.00%	57 57.00%

SI4: My peers think I should adopt PHL technologies	1 1.00%	5 5.00%	22 22.00%	52 52.00%	20 20.00%
SI5: People whose opinions I value prefer that I use PHL technologies	2 2.00%	1 1.00%	11 11.00%	59 59.00%	27 27.00%

As indicated in Fig. 7 close friends, opinion leaders and important people in society exercise the greatest influence on the adoption of postharvest technologies.

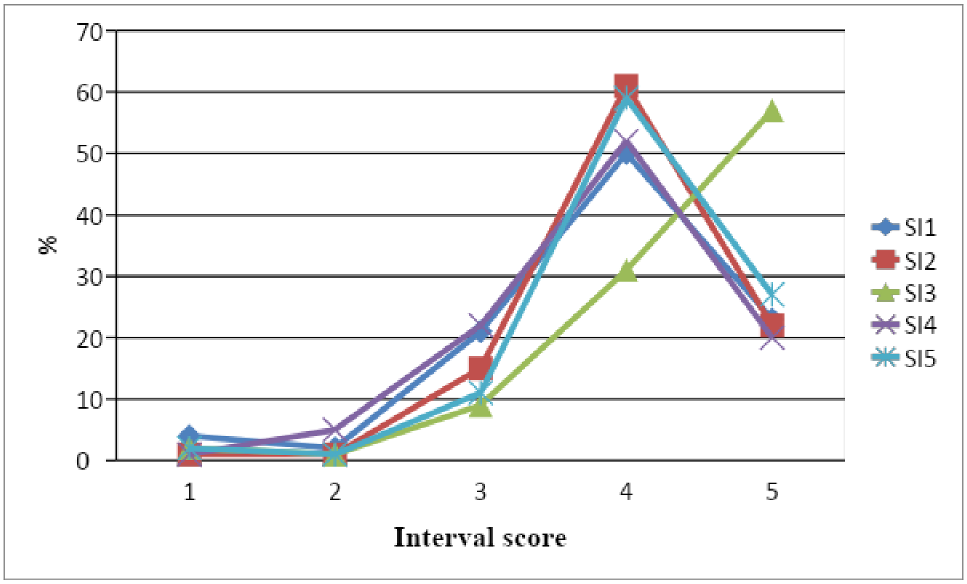

Fig 7: Social Influence Scaling Results

5.0 CONCLUSION

The study attempted to provide a clear understanding of the perception of smallholder farmers towards the adoption of technologies for reducing PHLs. The Unified Theory of Acceptance and Use of Technology (UTAUT) was chosen as the most suitable model for assessing the acceptance and usage of PHL technologies. According to Lescevica et al., (2013), UTAUT has been applied, integrated and extended by researchers when studying distinct technology acceptance and use across an array of scenarios such as different types of technologies, different periods and places. The effect of six constructs namely; Knowledge Expectancy (KE); Performance Expectancy (PE), Effort Expectancy (EE), Attitude Towards Using Technology (ATT), Facilitating Conditions (FC), and Social Influence on behavioral intention and use of PHL technologies was studied.

The gender distribution of respondents was 59% male and 41% female. According to Doss and Morris (2001); Tanellari *et al.,* (2014) the adoption of improved technologies by women tends to be at a lower rate in comparison to men. They further found that technology adoption by women that lived in male headed households was higher than their counterparts in female households. With regard to education nearly half of the respondents had only attended primary school education and /or had never been to school. Sixty one percent of the respondents with primary school education and those that had not attended school were female. According to literature adoption of technology is positively correlated with the education of farmers (Doss and Morris, 2001; Kumar and Hossain, 1996; Simtowe *et al*. 2002). The ability to acquire information about available options and expectations from their decision making is enhanced by education levels of farmers (ibid).

The study demonstrated that most of the respondents were of the opinion that they understood the benefits of using PHL technology to reduce maize losses. Some of these benefits were that technology facilitated quicker accomplishment of tasks, reduced the amount of time spent on unproductive activities and were money and time saving. The time saved would be used for dry season vegetable production, visiting relatives and participating in traditional ceremonies. According to Kitinoja (2013); WFP (2014) the adoption of low cost innovative technologies contribute to enhanced food security and increased incomes for smallholder farmers. The amount of time and energy farmers spend on watering crops compromises the time that could be used for family and community obligations (Alvarez, 2012). Generally the respondents agreed that PHL technologies would make them more productive through quicker accomplishment of tasks and thereby having greater control over their work. For example, the distribution of the mechanized threshers or shellers can reduce drudgery of farming, especially among women who constitute the large percentage of farmers in Africa (AGRA, 2016).

However, some of the PHL technologies such as cement and brick bins and those which require high levels of investment; and electricity for operation were considered rigid and inflexible to interact with, thereby making their adoption rather difficult.

Majority of the respondents were of the opinion that using postharvest loss reducing technologies was a great idea. Nearly all the respondents reported that they had the resources to invest into procuring some of the PHL technologies. Generally, smallholder farmers do not have money to invest in postharvest technologies because of liquidity problems and limited capacity to access finance when they need it (Mendoza, 2016). They further thought that they had the capacity to use PHL technologies such as motorised shellers, grain storage chemicals and hermetic storage like plastic drums and bags. According to AGRA (2016), fifty per cent of the postharvest losses can be reduced by scaling up of low cost and simple technologies such a hermetic storage bags which can contribute to increased farmer income (AGRA, 2016).

The statistical analysis using Cronbach's Alpha showed that the results obtained were reliable. The correlation analysis indicated that some parameters had a more significant relationship. There was strong significant correlation between knowledge expectancy and performance expectancy ($p=0.05$). Other variables that showed significant relationships were gender and education; attitude towards technology and facilitation expectancy; knowledge and effort expectancy; attitudes, facilitation, social influence and knowledge expectancy, respectively ($p \leq 0.05$). This is supported by Saga and Znud (1994) who found out that an individual may adopt a technology if it is perceived appropriate, useful and socially desirable even if they do not enjoy using the technology.

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