An evaluation of the factors that influence maize production and the adoption of modern storage technologies in two Districts in Mozambique.

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Declaration

I declare that this dissertation is my own, unaided work. It is being submitted for the Masters of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

(Signature of candidate)

29th day of May 2019 at the University of the Witwatersrand Johannesburg, Science Faculty

Abstract

Over the past few decades, post-harvest management has gained recognition as a possible means towards achieving efficient food security. In Mozambique nearly 400 000 metric tonnes of maize are lost due to poor post-harvest storage conditions which threatens food security. A pilot study conducted by Helvetas, a Non-Government Organization and private companies introduced the hermetic bag and the metal silo in an attempt to reduce the post-harvest food losses experienced by the smallholder farmers in the Mecuburi and the Chiure Districts, in Mozambique. The adoption levels of the technologies have been extremely low and this study explored why this may have been the case. The impact of abiotic factors (soil fertility, rainfall, minimum and maximum temperatures) on maize production in the Districts was evaluated. In addition, the changes in the retail price of maize from 2002 - 2016 was examined to assess the consumption and purchase patterns of farmers. Semi-structured interviews with 22 smallholder farmers from the Mecuburi District and 62 from the Chiure District were conducted to determine the socio-economic factors that have influenced the adoption of the two modern technologies. The results revealed that the Districts have sandy, nutrient poor soils with extremely low phosphorus content, high temperatures and highly variable rainfall which results in very low yields, which in many cases did not meet the food needs of many households. One of the implications was that farmers felt that the existing traditional ways of storing any surplus yield and that modern technologies, which were expensive, were unnecessary. Retail maize prices have fluctuated over the years and are driven by yields in various seasons, along with the variability of the rainfall and the supply and demand for maize. The main driver of adoption of the metal silo in the Mecuburi District is the purchase of the technology on credit which reduces the likelihood of more farmers adopting the technology. In the Chiure District, farmers spend most of their money to purchase additional food, which has reduced the likelihood of more farmers adopting the metal silo. It is recommended that subsidies or credit systems be provided to allow for more farmers to adopt the technology. In addition, farmers could be provided with fertilizer subsidies to improve the soil fertility or perhaps introduce livestock for the manure which may potentially result in an increase in the maize production level.

Key words: maize yield, temperature, rainfall, socio-economic factors, adoption

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Abbreviations

ADRO	Western Regional Rural Development Association
AFAAS	African Forum for Agricultural Advisory Services
APHLIS	African Post-Harvest Loss Information System
AU	African Union
C	Carbon
CAADP	Comprehensive African Agriculture Development Programme
CBA	Cost Benefit Analysis
CEC	Cation Exchange Capacity
CFSR	Climate Forecast System Reanalysis
CGAP	Consultative Group to Assist the Poor
CIPRES	Center for Research Promotion and Rural and Social Development
COMESA	Common Market for Eastern and Southern Africa
CV	Coefficient of Variance
FANRPAN	Food, Agriculture and Natural Resources Policy Analysis Network
FAO	Food and Agricultural Organization
FARA	Forum for Agricultural Research in Africa
FEWSNET	Famine Early Warning System Network
GDP	Gross Domestic Product
HLPE	High Level Panel of Experts on Food Security and Nutrition
IPCC	Intergovernmental Panel on Climate Change
K	Potassium

MDG	Millennium Development Goal
N	Nitrogen
NEPAD	New Partnership for Africa’s Development
NOAA	National Oceanic Atmospheric Administration
P	Phosphorus
PHL	Post- Harvest Loss
PHM	Post-Harvest Management
SDC	Swiss Development Cooperation
SDG	Sustainable Development Goal
SRO	Sub-Regional Organization
SSA	Sub-Saharan Africa

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Chapter 1: Introduction

One of the biggest challenges of this age is the fight against world hunger. About one in nine individuals do not have sufficient food to lead healthy lives, which equates to approximately 795 million people in the world (FAO *et al*., 2018). The vast majority of these individuals are from developing countries, where 12.9% are malnourished (FAO *et al*., 2018). The problem of world hunger does not only affect developing countries, but also affects developed nations and therefore calls for collaborative work, as it involves human lives. This was demonstrated at the Millennium Development Summit in 2000 that established the Millennium Development Goals (MDGs). The aim was to create a universal framework which the global community could implement towards ending world hunger and achieving food security (United Nations, 2007). Building on the MDGs, in 2016, the United Nations World Summit developed the Sustainable Development Goals (SDGs), which replaced the MDGs and also had a focus to improve food and nutritional security.

Part of the solution toward achieving food security is to improve post-harvest management (PHM) which is a field that has gained significant recognition over the past few decades (Aulakh *et al*., 2013). In sub-Saharan Africa (SSA) alone, close to 40% of all food that is produced is lost between the production and consumption stages (FAO, 2011). Cereals account for 20.5% of the losses experienced along the value chain (FAO *et al*, 2018). The African Post-Harvest Loss Information System (APHLIS) estimated a 10 - 12% loss of grain in post-harvest handling and storage for smallholder farmers. These food losses are alarmingly high, as 80% of the agricultural production systems in the region are occupied by smallholder farmers (Livingston *et al*., 2011). These farmers have fields that are 2 hectares at most (Livingston *et al*., 2011). With very limited to no application of inputs (quality seeds and fertilizer), these rain-fed agricultural systems are most likely to suffer the impacts of global climate change (Zingore *et al*., 2008). The increase in temperatures, an increase in the variability of the rainfall patterns as well as an increase in the intensity and frequency of extreme weather events such as floods and droughts are expected to reduce the production levels due to limited human, economic and social capacity to adapt to the changes in the climate (Pereira, 2017).

This poses a challenge to the proposed FAO target to eradicate hunger in SSA by 2050 (FAO and World Bank, 2010). Despite the mitigation plans that are currently being practiced, very few changes in the level of food insecure households are expected within the next few decades (Chegere, 2017). In addition to the disadvantaged socio-economic conditions and very under-developed food value chain systems, smallholder farmers are often left vulnerable and face the risk of experiencing very severe and frequent cases of household food insecurity due to limited access to resource which reduces the farmers' capacity to cope with any shocks to their agricultural activity (Harvey *et al*., 2014). For countries such as Mozambique, 99% of the population live in rural areas and about 80% of that population is dependent on agriculture (Ngare *et al*., 2014).

Unfortunately, the food losses experienced during storage range between 20% and 40%, which partly explains the food insecurity that is experienced in the country (Ngare *et al*., 2014). As a consequence, farmers are forced to sell their produce immediately after harvest at much lower prices due to the high availability of crops which reduces the demand (Ngare *et al*., 2014). This allows farmers to avoid food losses (Chisvo and Jaka, 2017). From the months of October till February the farmers' food reserves are depleted and prices are very high, which then compromises the availability and accessibility of food for households (Tivana *et al.*, 2014). The seasonal variability in the production levels, do not only affect food prices, but also the state of household food security among rural populations (Tivana *et al.*, 2014). The traditional storage technologies that continue to be used by the vast majority of farmers do not prevent contamination by pests and aflatoxins.

1.1. Conceptual framework

The Global Programme for Food Security of the Swiss Agency for Development and Cooperation (SDC) in the Federal Department of Foreign Affairs, initiated a Post-Harvest Management (PHM) project in sub-Saharan Africa (Sikirou *et al.*, 2016). The project was implemented in partnership with; Helvetas Swiss Inter-cooperation, the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN), the African Forum for Agricultural Advisory Services (AFAAS), Agridea, and the Swiss Centre for Agricultural Advisory and Extension Services (Shikou *et al*., 2016). The project targets smallholder farmers in Benin and Mozambique. In Mozambique the pilot project is conducted in the

Mecuburi District located in the Nampula Province and the Chiure District which is located in the Cabo Delgado Province (Shikou *et al.*, 2016). Both Districts are mostly rural, with the population living below the global poverty line of US $1.90 per day (Sikirou *et al.*, 2016). The project was divided into two phases, with the first taking place from April 2013 to May 2017. The overall aim of the project was to improve food security by introducing new handling and storage options for the grains and pulses of the value chain systems that benefit the smallholder farmers (Sikirou *et al.*, 2016). Farmers were also encouraged to adopt good practise options to reduce post-harvest losses, with the intention to disseminate and scale-up those practises throughout the Province and perhaps the entire country (Sikirou *et al.*, 2016). Lastly the project aims to advocate for the implementation of a regulatory framework at the national and regional level in support of improved PHM and to secure the financing required to sustain that structural reform in the agricultural sector (Sikirou *et al.*, 2016). The crops which were focused on for the project were maize, cowpeas and beans. However, for the purposes of this study, maize has been selected as the focus and it is also one of the important staples in the country. The overall project has identified the drying and threshing as crucial stages for reducing post-harvest losses (PHL), which will ultimately allow farmers to gain the benefits in the storage phase (Sikirou *et al.*, 2016). Following the very successful Postcosecha PHM project in Central America, the hermetic bag and metal silo have been introduced to the farmers in the Mecuburi and the Chiure Districts.

This research study uses a systems analysis approach to evaluate the factors that have influenced the adoption levels of these modern storage technologies in the Districts. These factors include the impact of temperature, soil fertility and rainfall on maize production levels and the changes in the market dynamics in response to the changes in maize availability. Furthermore, the household socio-economic dynamics are evaluated. The aim is to identify the feedback loops in the interactions between all these factors and how those relationships may have influenced the farmers' decision on whether or not to adopt the introduced technologies.

1.2. Aim

The aim of the project is to evaluate the factors that influence maize production and the adoption of modern storage technology, for the reduction of post-harvest losses in the

Nampula and Cabo Delgado Provinces and the Mecuburi and the Chiure Districts respectively, in Mozambique.

1.3. Objectives and key questions

1. To analyze the abiotic factors that influence maize production and to review the annual and seasonal retail prices of maize in the Nampula and Cabo Delgado Provinces.

Key questions

i. How have the annual maize yields changed from 2002 - 2016?

ii. What are the soil properties and rainfall and temperature trends from 2002 - 2016 in the Districts?

iii. What trends can be identified from the retail maize price market dynamics in the Provinces, across the years and within the maize growing season?

2. To assess the adoption of the hermetic bag and metal silo in the Mecuburi and the Chiure Districts and their influence on the amount of crop stored.

Key questions

i. Which of the adopted technologies, the hermetic bag or the metal silo has the highest adoption level?
ii. What are the farmers' perceptions on the amount of maize crop stored in the adopted technologies?
iii. How have the technologies influenced the storage and the purchasing patterns of the farmers in the Districts?

3. To review the socio-economic factors that may have influenced the adoption of modern technologies in the Mecuburi and the Chiure Districts.

Key questions

i. What are the farmers' main drivers for adopting the technologies?

ii. What are the household structural dynamics that may have influenced the adoption of the technologies?

iii. How were the technologies introduced to the farmers and promoted in the Districts?

4. To understand the key factors that influence the adoption of the technologies in the Districts using a systems modelling approach.

Key question

i. What are the negative and positive feedback interactions between the factors influencing the adoption of the storage technologies?

Chapter 2: Literature review

The purpose of this chapter aims to firstly define and understand the effects of PHL on food security. Particular attention will be drawn to maize production levels in sub-Saharan Africa (SSA) and how certain abiotic factors affect those levels, mainly because maize is one of the major staples in the region. The review further aims to examine how the changes in the production levels affect the market dynamics as well as the livelihood patterns that have been adopted by the smallholder farmers in the region. Building on that, the socio-economic factors that influence the adoption of modern storage technology, will be examined. This seeks to provide more elaborate understanding of the association between these factors and the level of adoption of modern storage technology in African countries. The last section of the review will examine the extent and impact of food losses in Mozambique, and the adopted livelihood patterns of the farmers in the country as well as the introduction of the hermetic bag and the metal silo as an intervention strategy to food losses. In addition, the literature will evaluate the systems analysis approach as a method that can be used to understand complex systems.

2.1. Food security

Food security in both developed and developing countries is still a major concern and remains a priority on the global agenda. However, the greatest occurrences of food insecurity are experienced in developing countries, especially by the poor and vulnerable (Food FAO, 2016). In response to this, the United Nations has aimed to end hunger by achieving food security, improve nutrition and promote sustainable agriculture in accordance with the Sustainable Development Goals (Food FAO, 2016). The ultimate goal is for all people from around the world to have good quality food to lead healthy lives (Food FAO, 2016).

However, in order to effectively tackle the problem of global food in/security there had to be universal definitions and an understanding of what it is. According to the World Food Summit in 1996, food security is defined as a situation that" *exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"* (Declaration, 1996). This accepted definition is pillared on four main dimensions, which are;

Food availability: which is a measure of the amount of food that is available in preferred quantities, which can either, be supplied through domestic production or imports, including food aid (Napoli, 2011).

Food access: is the extent to which consumers are able to gain access to the available food, which is strongly linked to the socio-economic state of an individual or a household that enables access to appropriate food for a nutritious diet (Napoli, 2011).

Utilization: refers to the manner in which an individual makes use of the food and the nutrients it provides. This ensures that the physiological needs of an individual are met which will allow them to active nutritional well-being (Napoli, 2011).

Stability: is achieved when both the food availability and access dimensions are maintained. Food stability aims to ensure that consumers have access to sufficient food at all times and do not deal with the risk of losing access to food due to external shocks such as the economy or the weather.

The state of food in/security, in accordance with the four dimensions, varies across countries. Therefore, the prioritization of these dimensions to improve food security will vary by country (Ziervogel and Ericksen, 2010). Burchi and colleagues (2011) presents a graphical representation of the connection between food availability, accessibility, utilization and stability (Figure 1).

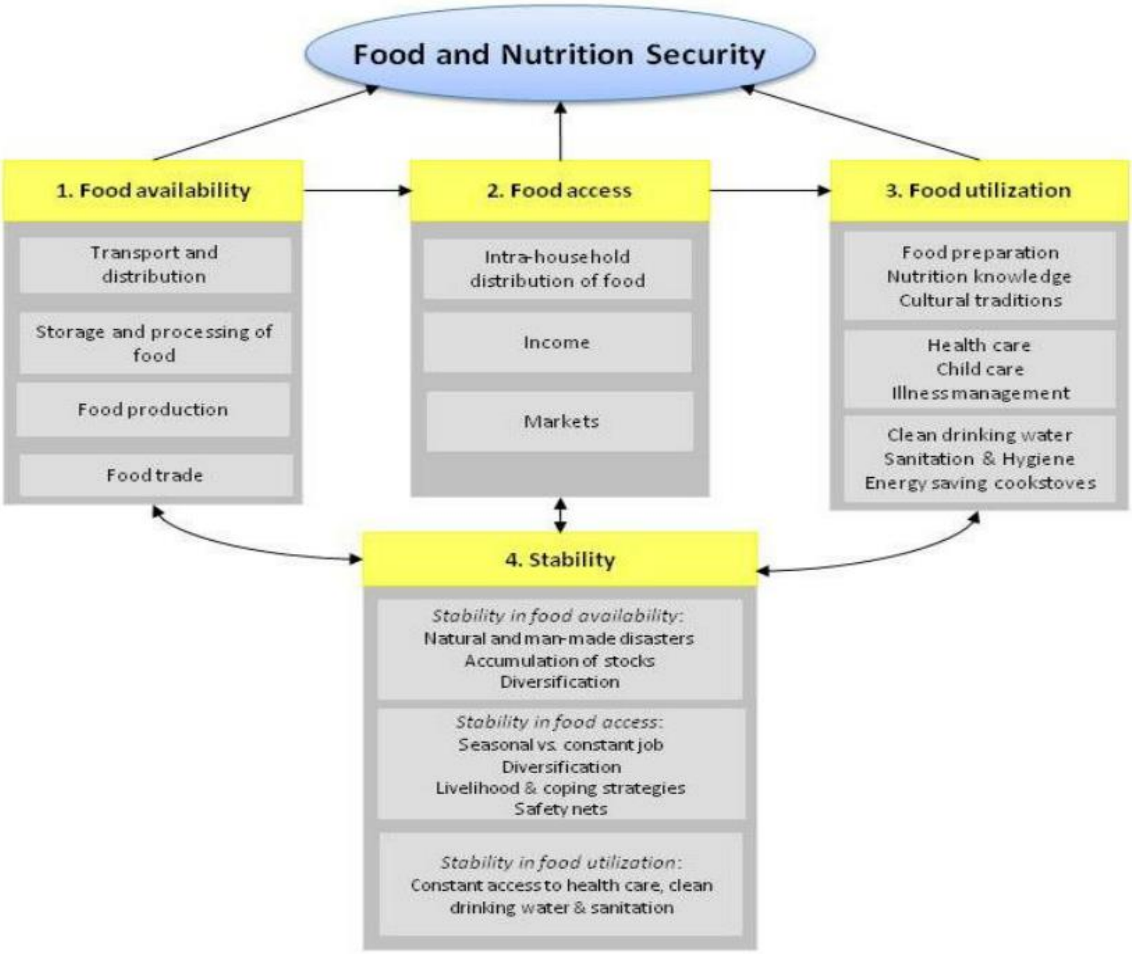


Figure 1. The four dimensions of food security (Burchi *et al*., 2011).

2.1.2. Food security and post-harvest management (PHM)

For three decades, food security research has focused on increased production as a way to reduce the level of food insecurity (95%) in the world, and only 5% has been directed toward reducing food losses as a possible means to achieve the same goal (Aulakh *et al.*, 2013). In light of the four pillars of food security, a reduction in food losses will increase the amount of food made available for consumers. Under normal circumstances, an increase in available food will decrease food prices and the value of the farmer's products, which in turn, may allow more consumers to gain access to food (Sheahan and Barret, 2017). Still aligned with the four pillars of food security, a reduction in post-harvest losses in the form of improved food quality will enhance the third pillar of the food security dimension; utilization. When consumers have good quality food that has not deteriorated due to poor processing or post-harvest handling, they are more likely to gain the necessary nutrients and vitamins that are required to live healthy lifestyles, which is also fundamental in achieving nutrition security. For smallholder farmers who are consumers of their produce, when grains are stored for long periods of time, they may potentially be able to sell excess crops during the lean season when food prices are much higher. As a consequence, this may increase the stability of agricultural systems within a given area and thus contribute toward the overall state of food security (Sheahan and Barret, 2017).

Post-harvest management has gained recognition and is now viewed as an important contributor toward reducing hunger. About 1.3 billion tons of food are lost or wasted per year globally in the post-harvest phase, this is equivalent to about one third of the food that is produced globally (Gustavsson *et al*.,2011). About 40% of the food losses experienced in developing countries occur postharvest particularly during the processing phase (Gustavsson *et al*.,2011). Food waste per capita is approximately 222 million tons per year, which is almost as high as the total net food production in sub-Saharan (230 million ton) (Gustavsson *et al*.,2011). Therefore, a reduction in post-harvest losses and waste will make a significant contribution toward ensuring food security in all nations. The difference in food waste and food losses is clearly understood when comparing the food value chain systems between developed and developing countries (Gustavsson *et al*.,2011). For instance, food waste is a problem that is mostly encountered in developed countries where food is lost at the retail and consumption stages of the food supply chain, this often relates to retail or consumer behaviour (Gustavsson *et al*.,2011). Food losses, on the other hand are a decrease in edible food mass throughout the entire food supply chain system and these losses may be experienced in the production, process and post-harvest stages of the food supply chain (Gustavsson *et al*.,2011).

To further illustrate this, the annual food waste per capita in Europe and North America, which are developed regions, is estimated to be 95-115 kg/year, while in sub-Saharan Africa and South and South East Asia it is 6-11 kg/year (FAO, 2011). To a very large extent, developed countries waste large amounts of food by merely throwing it away even when it's still suitable for human consumption (FAO, 2011). The food losses are lowest in the middle stages of the supply chain due to advanced technology and highly mechanized systems that almost guarantee high agricultural outputs. In contrast, the food losses experienced in developing countries occur throughout the broad supply chain due to poorly developed value chain systems (FAO, 2011). These losses are mainly caused by the lack of infrastructure, processing facilities, inadequate market facilities and poor storage technology (FAO, 2011).

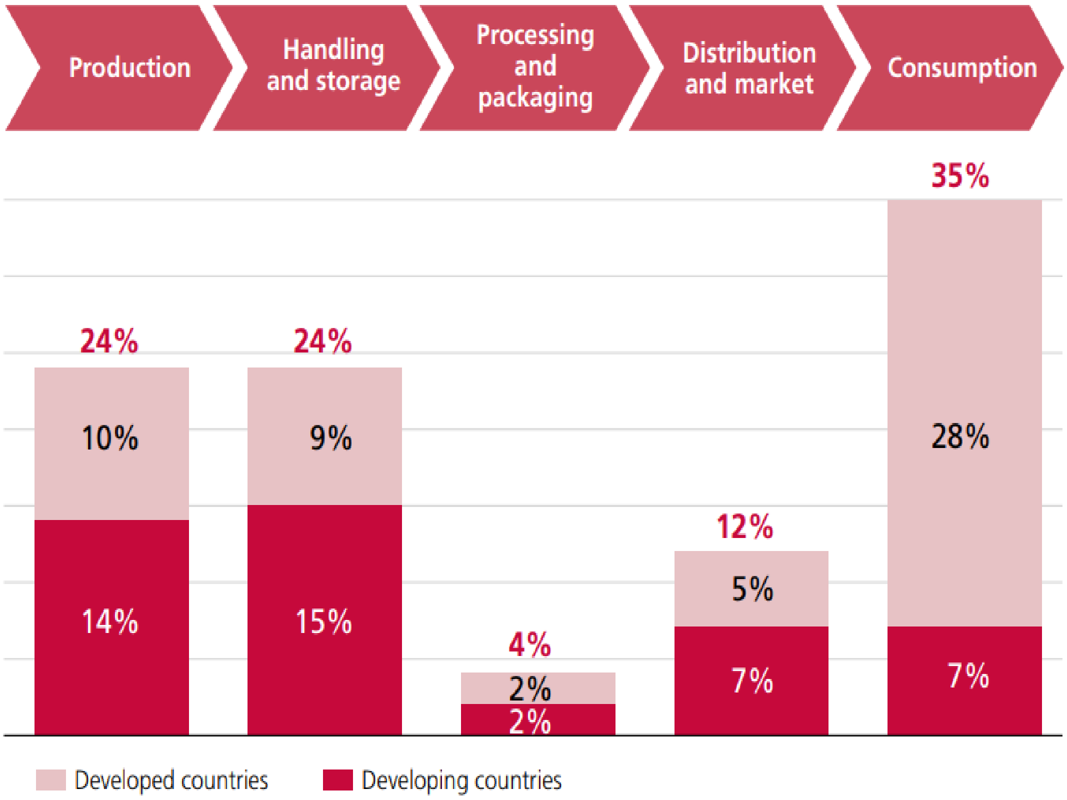


Figure 2. Distribution of food losses and waste along the food value chain (Laub *et al*., 2018)

The food losses that occur along the value chain systems exacerbate food insecurity. In developing countries these losses are intensified by the impact of global climate change. For smallholder farmers who are solely dependent on the environment and the resources and services it provides, they are often left more vulnerable due to the impact of the changing weather patterns. Many of these changes form in such a way that other factors limit the production levels (soil infertility). In addition, the socio-economic conditions of these developing nations further limit the farmers' production output as they may not be able to invest or improve their agricultural systems to combat or mitigate the impact of the external shocks.

2.2. The impact of extreme weather patterns in sub-Saharan Africa

2.2.1. The impact of temperature on maize production in sub-Saharan Africa

Among the several staple crops that are produced in SSA, maize is one of the most important and largely consumed crops. It accounts for 30% of the area cultivated under cereal production in the entire region (Cairns *et al*., 2013). Maize together with rice and wheat, provide over 30% of the total calories and proteins that are consumed, however, production levels remain low and insufficient (Shiferaw *et al*., 2011). The maize produced in SSA is mainly grown by smallholder farmers, who depend on rainfall and apply very little inputs to their agricultural systems (Cooper *et al*., 2008 and Zingore *et al.*, 2008). The low yields experienced in the region are largely attributed to drought, low soil fertility, pests, weeds, low input availability, low input use, and inappropriate seeds (Cairns *et al*., 2013). This, in addition to the highly variable seasons and the decline in soil fertility due to nutrient mining, increases the vulnerability of the smallholder farmers in SSA, as these changes fall outside of the scope of the farmers' previous experiences (Cairns *et al*., 2013).

The Intergovernmental Panel on Climate Change (IPCC) scenario models for SSA predict an increase in seasonal and extreme temperatures (Solomon *et al*., 2007). The intensity of drought conditions, particularly in the interior parts of the region, are expected to rise (Solomon *et al*., 2007, Cairns *et al*., 2013). The highest increase in temperature is anticipated for the maximum temperatures; however, both the minimum and maximum temperatures are expected to rise. Temperature is predicted to rise by 2.7 °C in the dry lowlands and 2.8 °C in the dry mid-latitude regions, which is where the Nampula and the Cabo Delgado Provinces, are located (Cairns *et al*., 2013). High maximum temperatures, over long periods of time, have an extremely negative impact on the development of maize. One of the most temperature sensitive parts of the crop is in the male reproductive tissue. The pollen produced in the tassel (location of the male reproductive tissue) is positioned at the apex of the plant, and thus receives maximum exposure to heat stress (Cairns *et al*., 2012). As a result, this reduces the viability and quantity of the pollen produced, which in turn reduces the chances of the ovules being fertilized. Not only will the prolonged days of heat stress, due to increased temperatures, affect the male reproductive tissue, but it also affects the early developmental phase of the female reproductive tissue. The increase in temperature delays the emergence of silks (female reproductive parts) which reduces fertilization (Cicchino *et al*., 2010). The microscopic impact of heat stress (temperatures above 30 °C) in maize damages cell division and the replication of amyloplasts, which are the plastids that produce and store starch (Cicchinino *et al*., 2010). As a consequence, this reduces the size of the grain and ultimately the yields produced by the smallholder farmers (Hatfield and Prueger, 2015, Cairns *et al*., 2013). Without adaptation strategies such as the adoption of drought resistant seed technology, smallholder farmers in SSA are more likely to experience more food losses and consequently severe cases of food and nutritional insecurity.

2.2.2. The impact of soil infertility on maize production

The extensive farming activity in SSA has progressively degraded the soil fertility over the years as agriculture is practised continuously, which is essential for the maintenance of livelihoods in the region (Droppelmann *et al*., 2017). Deterioration in soil quality has become a severe problem and more widespread across the region, and has thus restricted the production levels quite significantly (Droppelmann *et al*., 2017). One of the long-term soil resource regeneration strategies that have been applied in past years is that of natural bush fallows around agricultural fields; however, this practise has long been neglected due to the demand for land, which is limited for smallholder farmers (Vissoh *et al*., 1998). Natural bush fallow is an agricultural land use practise based on land use rotation. Farmers can either leave land uncropped or they can cultivate dissimilar type of crops which require certain nutrients more than others, which in turn increases the soil fertility (Gordon *et al*., 2013). Despite the inherently poor soil fertility in SSA, stakeholders within the agricultural sectors have sought to promote intensified agricultural practises by providing famers with subsidized access to fertilizers and improved seed technology. One of the most restraining limitations of maize production in SSA is low soil nutrient status, and smallholder farmers need to invest in fertilizers. Vanlauwe and colleagues (2011) indicate that the combined use of organic and inorganic fertilizer will not only improve the soils fertility immediately, but will sustain the fertility in the long-term. If this were applied in the SSA, it may potentially result in a significant rise in the quality and quantity of maize production throughout the region (Vanlauwe *et al*., 2011). The nutrient poor soils are as a result of insufficient nitrogen (N), phosphorus (P) and potassium (K), which are also indicative of low carbon content in the soils (Vanlauwe *et al*., 2011).

The combined impact of more severe drought conditions and low rainfall, as predicted by the IPCC scenario models, will intensify the poor soil fertility throughout SSA as fertilizers become less effective in dryer conditions. Drought conditions will have a negative impact on the function, structure and productivity of soil ecosystems (Geng *et al*.,2014).

2.2.3. The impact of rainfall variability on maize crop production

Given the IPCC prediction models, the combined impact of population growth and changes in the weather patterns is expected to cause serious water stress and shortages across several countries around the world by 2050, including SSA (Cooper *et al*., 2008). The rain-fed agricultural systems in the region experience highly variable seasonal rainfall that is, to a limited degree, reflected by the variable production levels. However, it is also understood that the amount of maize produced in SSA is not only influenced by factors such as, poor soil fertility and temperature stress as outlined previously, but policy and institutional failure to implement market led innovation models to transform these agricultural systems is also a limiting factor in the production levels (Cooper *et al*., 2008). For example, when weather conditions are highly variable during the drying phase, crops exposed to rainfall become damp and can be spoiled (Hodges *et al.*, 2011). The poor drying practices and storage technologies that have been adopted by smallholder farmers in SSA lead to the growth of mycotoxin-producing moulds that produce aflatoxins (Udomkun *et al*., 2002) resulting in detrimental impacts on human health.

The decline in yields has greatly influenced the farmers' livelihood and has altered the coping strategies of rural populations (Cooper *et al*., 2008). Due to uncertainties in the changed weather patterns, farmers have not learned to mitigate the negative impacts of the rapidly changing weather patterns, but have failed to maximize production on the opportunities presented by the good wet season (Cooper *et al*., 2008). In Madagascar, very few farmers report to have made any changes to their farming methods to reduce their vulnerability to the extreme weather events that occurred in the country, such as droughts and flooding events (Harvey *et al*., 2014). This suggests that the majority of the smallholder farmers in Madagascar had not changed their farming methods to adapt to the weather variability. Some of those practices included better water management, new and variety crop farming and soil conservation, all of which were aimed at creating more sustainable agricultural systems (Harvey *et al*., 2014). The rise in temperature is expected to not only to alter the rainfall patterns, but the soil processes and properties which are essential for food security (Brevik, 2013). An increase in the maximum temperatures will result in an increase in the potential evaporation and transpiration (Várallyay, 2010). When the water stored in the soil is low due to heat stress, crop production will suffer severe water shortages as soils serve as the main source of water supply (Várallyay, 2010).

2.3. Adopted livelihood in response to the climate change

2.3.1. The impact of climatic shocks on smallholder farmers' livelihoods

Research has tried to understand the impact of climate change on crop production, and equally so the implications that this will have on the livelihoods of smallholder farmers. In SSA, agriculture plays a crucial role in structuring the way individuals live their lives, whether socio-economically, environmentally or culturally. The sector forms the basis for constant food supply and income generation. Therefore, the experienced climatic shocks coupled with poor agronomic practises such as nutrient mining, have continually forced smallholder farmers to adopt livelihood patterns that are outside of agriculture, to sustain their livelihoods (Yamba *et al*., 2017). Despite the large majority of the rural population involved in the agricultural sector, households attempt to minimize the environmental shocks from extreme weather events by diversifying their income generation strategies. This may include the use of credit facilities and the participation in non-agricultural activities such as trading, basic household needs, charcoal production or firewood (Yamba *et al*., 2017).

In a study conducted in Ethiopia, it was found that farmers engage in non-agricultural activities whenever they experience decreased or highly variable rainfall (Demeke and Zeller, 2012). This strategy has helped the farmers to mitigate the weather shocks which would have potentially reduce crop yields, ultimately affecting their livelihoods (Demeke and Zeller, 2012). In Mozambique, the three main income generating activities that smallholder farmers are engaged in are; agricultural production, casual labour (often related to agriculture) and off-farm activities where farmers receive wages, remittances and they manage small businesses, which is an effort to diversify household income generation strategies (Anderson and Ahmed, 2016). In addition, smallholder farmers consume large proportions of their produce due to low productivity, which indicates a heavy reliance on agriculture as a food and perhaps income source (Donavan and Tostão, 2010). As a consequence, farmers often do not have excess crop to sell to generate income. However, farmers who do manage to generate income from their produce, experience more volatile income from those sales compared to other income generating activities (Anderson and Ahmed, 2016). The farmers' participation in other income generating activities, besides farming, have allowed for relatively more stable household income (Anderson and Ahmed, 2016). In addition to the very disadvantaged socio-economic conditions, the less commercialized households, which make up the majority in SSA, experience production related-shocks as outlined in Figure 3, such as droughts, pest infestation and bad weather. The lack of institutional support such as affordable insurance for poor smallholder farmers as well as credit facilities, traps the farmers into low returns from their produce and thus perpetuates the cycle of poverty in these agrarian households (Dercon and Christiaensen, 2011, Barrett and Carter, 2013). To remain food secure, households are not only required to increase production levels but also store their produce to cover their own family consumption.

The more commercialized households that, among other things, either have large agricultural fields or have adopted modern storage technology, are able to maximize on their production levels and thus have sufficient crop for consumption and sale. This group of farmers experience shocks related to the markets, such as fluctuating crop prices which in turn may result negatively on household income (Anderson and Ahmed, 2016). When rural financial structures are well developed, farmers can gain financial access to resources such as credit, insurance and savings which enables them to invest in their agricultural systems and thus maintain high levels of production, including post-harvest loss remediation strategies (Sheahan and Barrett, 2017). From a broader perspective, part of the remediation may include improvements in the transport infrastructure, which will change the agricultural supply chain system, ultimately resulting in reduced food losses and better food security (Sheahan and Barrett, 2017). The domestic orientated agricultural sector in SSA needs to undergo structural transformation that will bring the growth and development of the value chain systems to cater for not only rural households, but also urban settlements through trade (Barret *et al*., 2017). With higher agricultural availability, the region may be able to supply neighbouring countries with food demands that are currently being met by other continents outside of Africa (Brenton, 2012, Barret *et al*., 2017).

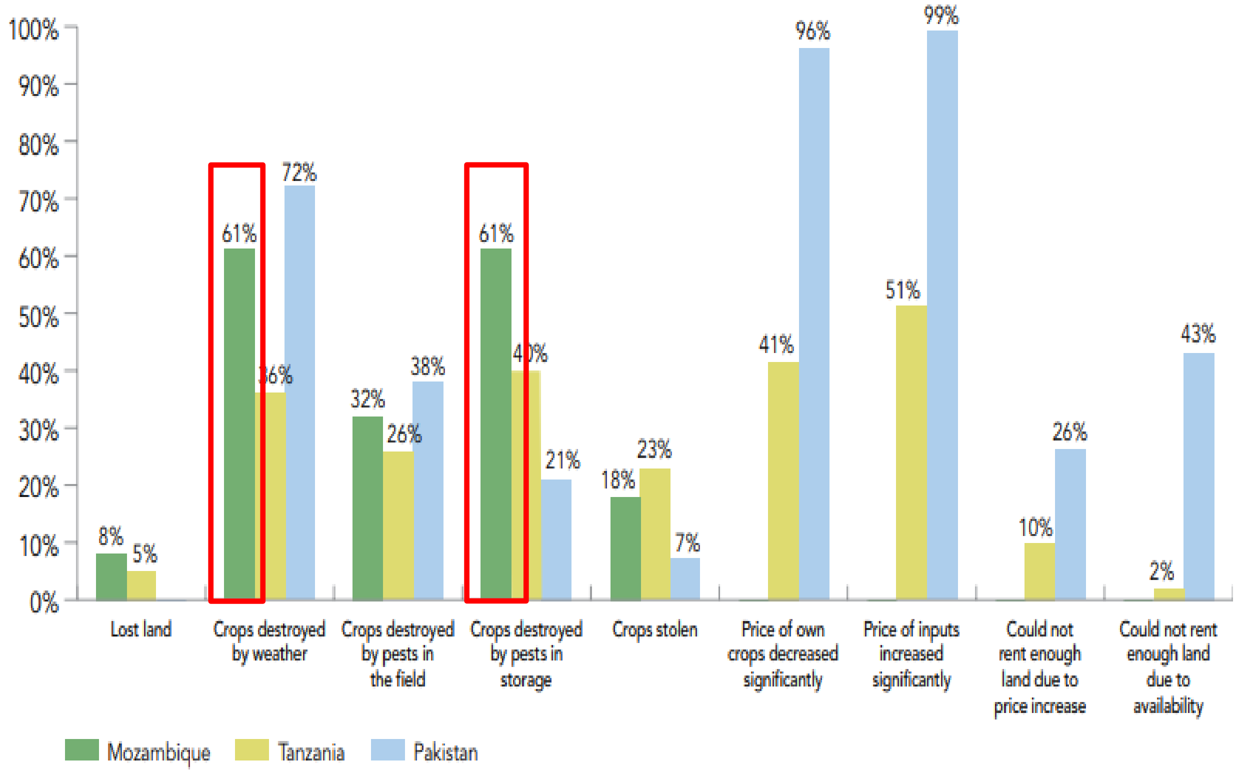


Figure 3. Households that experienced selected agricultural shocks at least once in the past five years, July 2015 (Percentage) (Anderson and Ahmed, 2016).

2.4. What causes post-harvest losses in sub-Saharan Africa?

2.4.1. Causes of post-harvest food losses

The global food crisis in 2008 which resulted in the rise in food prices, called for a re-evaluation of global food security and post-harvest food losses around the world (Gerlatch, 2015). As expected, developing countries experienced the greatest shock during this period; and these countries are characterized by large populations of smallholder farmers who depend on agriculture (Gerlatch, 2015). These farmers produce enough food for household consumption and in very few cases produce a surplus amount of grain for sale, in order to generate income (Hodges *et al*., 2011). In addition to the food losses that occur in the production phase due to the exacerbated impact of extreme weather events, one of the main drivers of post-harvest food losses is primarily due to biological spoilage (Hodges *et al*., 2011). The decay of cereals in the fields, such as maize, is caused by the contamination of pesticide residue that is used during production and storage (Kimatu *et* *al*., 2012). Although this is not a frequently applied agricultural practice by farmers in the region due to socio-economic constraints, the other major crop contaminant is aflatoxins which occur before and post-harvest due to poor handling and processing practices (Kimatu *et al.,* 2012). *Aspergillus flavus* Link: Fr, *A. parasiticus* Speare and *A. nomius* Kurtzman *et al,* are the three largest fungal species that are responsible for the contamination of grains in SSA (Atehnkeng, 2014). Some crops are destroyed by pests while in the field, and the insects responsible for the greatest damage of cereal grains are the Larger Grain Borer, *Prostephanus truncates,* and the Maize Weevil, *Sitophilus zeamais* (Tivana *et al*., 2014). In Mozambique 90% of the smallholder farms account for the domestic food supply (Botta *et al*., 2017). Despite the very large participation in agriculture, SSA has among the largest food losses in the world. According to the World Bank, total food losses are approximately worth $4 billion per year, which is sufficient to feed about 48 million people (Zorya *et al*., 2011, FAO, 2013). It comes as no surprise that the region suffers the highest number of cases of malnourished. The food systems in developing countries experience the largest post-harvest food losses on the farm (Hodges *et al*., 2011); therefore, interventions should be made at this level to reduce these losses. Kaminski and Christiaensen (2014) conducted a study in Malawi, Uganda and Tanzania. They discovered that the largest losses occurred during the handling and storage phases, due to pests and extreme weather events that occurred during different seasons (Kaminski and Christiaensen, 2014). They also identified food losses at the farm level; which coincides with the losses that occur throughout the broader SSA region. The African Post-Harvest Loss Information System (APHLIS), a large data source, aims to provide large scale estimates of the areas in which post-harvest cereal losses occurred throughout the value chain in SSA. The system provides estimates for most sub-Saharan African countries, which aids for identification of specific areas with large losses and thus assists in the development of target specific evidence based intervention startegies (Rambold *et al*., 2011).

2.4.2. Intervention strategies

The intervention strategies that have been adopted in the reduction of post-harvest food losses across developing countries, were intended to become sustainable through a multi-stakeholder approach. An example of this approach was illustrated in the Postcosecha project which was initiated in Central America from 1983 - 2003.

The project targeted smallholder farmers in four countries, namely; Honduras, Guatemala, Nicaragua and El Salvador, and it was coordinated by the Swiss Development Cooperation (SDC). Approximately a total of 415 000 metal silos were distributed to farmers in rural regions of these countries (Tefera *et al.*, 2011). The key stakeholder who participated in the project was each country's national government, which was involved in coordinating and creating an enabling environment for the spread of the technology across the countries. The project was sponsored by the SDC. However, in 2003 the financial support from SDC was ceased, other organizations such as the Center for Research Promotion and Rural and Social Development (CIPRES) in Nicaragua and the Western Regional Rural Development Association (ADRO) in Honduras, pioneered the promotion of the technology from 2004-2009. In Guatemala, the government led programmes which provided subsidies for the production and distribution of the metal silo to promote food security in the country, which increased the adoption of the technology (Fischler, 2011). Other key role players, in the four countries, were the self-employed tinsmiths together with the farmers, who also contributed significantly to the success of the project (Tefera *et al*., 2011, Bebbington and Thiele, 2005). The Postcosecha project is an example of an effective method to tackle the issues pertaining poor PHM, in developing countries.

In Africa the projects that have been initiated focused on on-farm losses, because that was the phase with the highest losses along the value chain (Sheahan *et al.*, 2017). However, compared to the Postcosecha project in Central America, the governments in African countries have not been able to invest in these initiatives, due to poor institutional support, limited funding, political instability and various other reasons. In view of this, the introduction of modern storage technologies would play an important role in the reduction of post-harvest food losses experienced by smallholder farmers in SSA (Sheahan *et al.*, 2017). Some of the modern storage technologies that have gained recognition in the region are the hermetic bag and the metal silo. The hermetic bag is the most frequently reported technology that has been introduced, promoted and adopted by farmers throughout Africa, and to a lesser degree the metal silo (Sheahan *et al.*, 2017). The introduction of these technologies aims to reduce the contamination of crops in storage with the ultimate purpose to reduce household post-harvest food losses. A successful dissemination programme such as the one in Central America, would call for the participation of multiple stakeholders from participants in the agricultural sectors within the different countries in SSA.

Considering the socio-economic conditions of the countries in the region, appropriate measures should be pursued to reduce food losses and develop stronger food systems.

2.4.3. The hermetic bag and metal silo

The greatest advantage that can be gained from using modern storage technologies i.e. hermetic bag and metal silo, is the ability for the technologies to create anaerobic conditions which prevent oxygen from entering or leaving the storage container (Kimatu *et al*., 2012). These conditions create pest free storage environments which result in reduced losses irrespective of the duration of the storage (Costa, 2014). The absence of oxygen prevents the spread of aflatoxins as well as pest populations from increasing while grains are stored in the container (Coffi *et al*., 2013). Despite the introduction of these technologies in SSA, many farmers continue to use traditional technologies such as mud silos and granaries made from wood, due to confounding socio-economic constraints. The biggest concern with the continued use of these storage technologies is that they do not provide the anaerobic conditions that would protect the stored grains (Coffi *et al*., 2013). Instead the technologies may be the very reason for the proliferation of mould contamination and pest populations. Traditional storage technologies are made from local materials which makes the technology inexpensive to construct (Costa, 2014).

However, the disadvantage to this is that pests may be hibernating in the materials used to construct the technologies; due to the aerobic conditions, the stored pests and aflatoxins will consume or contaminate large proportions of the stored grains, if not the entire batch (Coffi *et al*., 2013). Costa (2014) proved the effectiveness of modern technologies compared to the traditional technologies, in a study conducted in Uganda and Burkino Faso. The study presents different food losses between traditional and modern technologies in Figure 4.

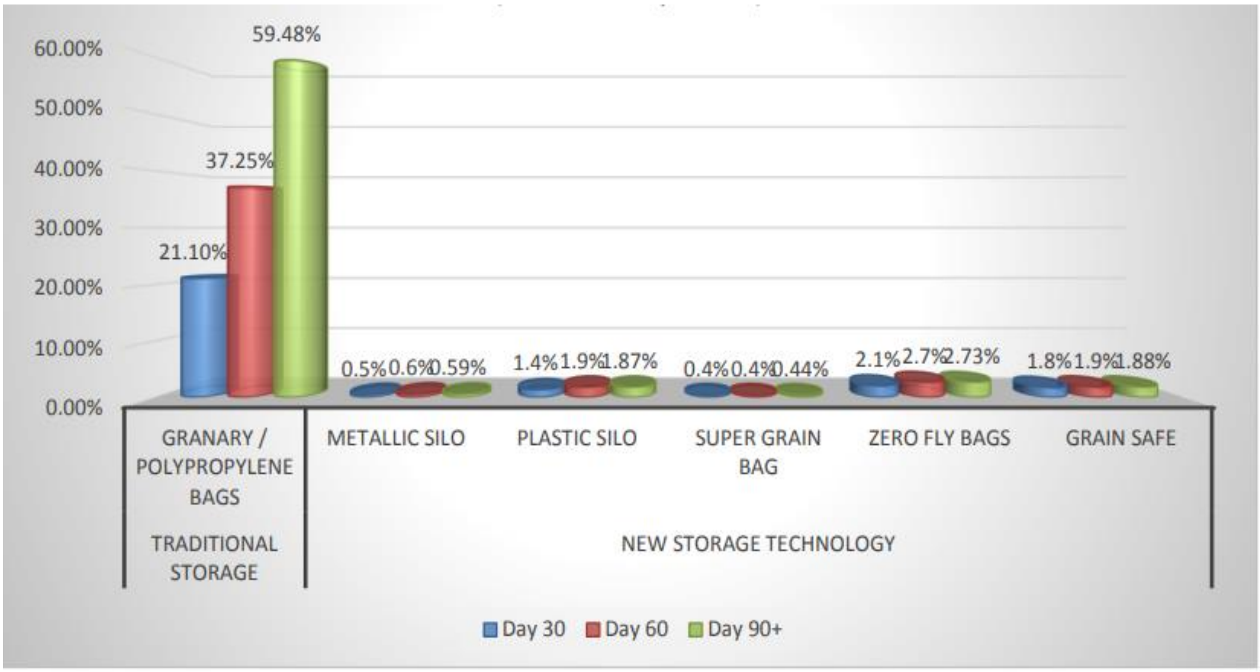


Figure 4. Average recorded losses (Maize) Uganda (December 2013-April 2014) (Costa, 2014).

2.4.4 Factors that influence the adoption of storage technologies

In a recent study, Elemasho and colleagues identified a few socio-economic factors that influenced the adoption of modern storage technologies (Elemasho *et al.*, 2017). The study targeted smallholder farmers from River State Nigeria. A few of the household structural dynamics that influenced the farmers decision on whether or not to adopt modern technologies were the age, gender, marital status, household size, education level and farming experience (Elemasho *et al.*, 2017). These are factors of influence that are also common in other African countries such as Sierra Leone, Nigeria and Ethiopia (Conteh *et al.*, 2017, Okoedo-Okojie and Onemolease, 2009, Admassie and Ayele, 2010). For example, some of the most common cases that have been identified in African countries are that younger farmers, farmers with large agricultural fields and those with an education are more likely to adopt modern storage technologies than older farmers (Uaiene *et al.*, 2009, Melesse, 2018). In contrast, farmers who are older, with small fields and with a low education level are often more resistant to change, due to uncertainties they have regarding the adoption of the modern technology. As a result, they would much rather continue to use traditional storage technologies.

Considering the highly patriarchal societal construct in many African countries, male farmers are the household heads and they make the decisions which pertain to anything that occurs in the household, this may include the adoption of modern technology (Tanellari *et al*., 2013). Another factor of influence in the adoption of modern technology is the work of extension services (Altalb *et al*., 2015). Masere (2015) illustrated how the low adoption levels of modern technology in Zimbabwe were strongly influenced by poor extension services offered to smallholder farmers. He further highlighted that there was no single approach to the type of service that could be offered to farmers, as circumstances were different across different communities. Therefore, context specific methods of approach should be considered when new technologies are being promoted in new community (Masere, 2015). Capacity building, skills development and in-service training are some mechanisms that could be used to equip the personnel and to ensure quality transfer of information from research and government institutions to farmers (Agunga and Manda, 2014). Extension services personnel need to be skilled to persuade the famers to adopt modern technology in order to accelerate the rate of adoption (Masere, 2015). Farmers who do not get an opportunity to engage with extension services personnel are most likely to show little interest in the modern technology because they do not have sufficient information about the technology. In River State, Nigeria, farmers were not introduced to the modern technology from extension services, but from other farmers in the area, and this resulted in low adoption levels (Elemasho *et al*., 2017).

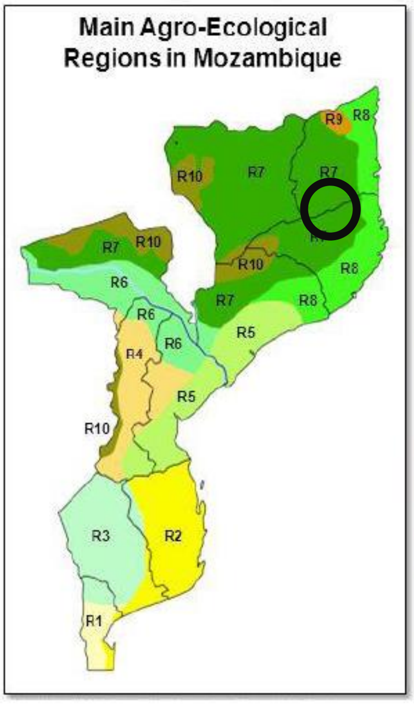
Still in line with the adoption of modern storage technology, smallholder farmers in the Guruvi and Gokwe District in Zimbabwe, experienced significant improvement in the quantity and quality of grain which was stored in their adopted modern storage technologies (Burns and Suji, 2007). This included improved granaries and metal silo tanks (Burns and Suji, 2007). However, these farmers were given the technologies as part of the project experiment and did not have to purchase them which then raises questions of whether the farmers would still adopt the technology if they had to purchase them. Chegere (2017) cautions and advises that projects conduct a cost-benefit analysis before introducing modern technology in any given community, especially in Africa given the disadvantaged socio-economic environments (Chegere, 2017). As expected, the study conducted by Chegere (2017) revealed that the more affordable the technology, the higher the adoption level and the greater the benefits.

2.5. Food security in Mozambique

2.5.1. Agriculture in Mozambique

Mozambique is a country heavily dependent on agriculture, with approximately 3 million smallholder farmers who account for the domestic supply of food in the country (Chisvo and Jaka, 2017). The food losses range from 20-40% depending on the geographical location and the associated environmental conditions, as well as the crop produced (Chisvo and Jaka, 2017). Close to 400 000 metric tonnes of maize are lost due to poor storage facilities (Chisvo and Jaka, 2017). The harvested maize grains are usually stored for three months before farmers are forced to sell their produce at lower prices, due to high availability and low demand, to avoid spoilage (Chisvo and Jaka, 2017). This may come as a result of continued use of traditional storage technology, which has been proven to be a contributor to the losses the farmers' experience (Chisvo and Jaka, 2017). Mozambique is divided into three agricultural production areas due to varying agro-ecological conditions; the north, central, and the south (Baez and Olinto, 2016). The central region produces the largest amount of maize (50%) followed by the north (40%), which is where the Nampula and the Cabo Delgado Provinces are located (Region 7 in Figure 5 below), and lastly the south (10%) (Baez and Olinto, 2016). Due to very poor infrastructure, the southern parts of Mozambique import maize from South Africa; this is cheaper than if it were to be transferred from central and northern Mozambique (Tivana *et al*., 2014).

The PHM project in Mozambique is run by the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN), the African Forum for Agricultural Advisory Services (AFAAS) and Agridea (Sikirou *et al*., 2016). The organizations have active regional operations in Mozambique which are linked to the continental processes and frameworks that are aimed towards improving food security. This includes NEPAD/CAADP, the African Union (AU), Regional Economic Communities (COMESA), and the Forum for Agricultural Research in Africa (FARA) and Sub-regional Organizations (SRO) (Sikirou *et al*., 2016). The collaborative work between these institutions, together with the local government agricultural departments, aims to increase food security for the smallholder farmers through reduced post-harvest losses at community and farm level" (Sikirou *et al*., 2016).



Region	Part of Mozambique	Ag. Commodities Produced
R1	Inland Maputo and south Gaza	Maize, cowpea, groundnut, cassava, sweet potato, banana
R2	Coastal region south of the Sabi (Save) River	Maize, sugar, cowpea, sweet potato, groundnut, cassava
R3	Center and north of Gaza, and west Inhambane	Cattle, goats, rice
R4	Medium altitudes of central Maputo	Maize, sorghum, cassava, cowpea
R5	Low altitudes of Sofala and Zambezia	Rice, cotton, cashew
R6	Semi-arid region of Zambezi Valley and Southern Tete	Sorghum, millet, sugar, rice
R7	Medium altitudes of Zambezia, Nampula, Tete, Niassa, and Cabo Delgado	Maize, soybean, sorghum, cassava, cowpeas, groundnuts, rice, sesame
R8	Coastal litoral of Zambezia, Niassa, and Manica	Banana, cassava, millet, rice, cashew
R9	North interior of Cabo Delgado	Maize, sorghum, cowpeas, cassava, sesame
R10	High altitudes of Zambezia, Niassa, and Manica	Soybean, maize, common beans, potatoes, rice

Figure 5. Agro-ecological zones in Mozambique (Ministério da Agricultura e Segurança Alimentar, 2012-2014). The Mecuburi and Chiure districts are located in the R7 agro-ecological zone.

The study areas selected for the pilot project are the Mecuburi District, located in the Nampula Province and the Chiure District which is located the Cabo Delgado Province (outlined by the black circle on the map). Both Districts are mostly rural and extremely poor (Sikirou *et al.*, 2016). The use of poor storage technologies in the Districts has resulted in major post-harvest food losses.

2.5.2. Introduction of modern technology in the Mecuburi and Chiure Districts

As part of the PHM project, a cost benefit analysis (CBA) report on the adoption of the hermetic bag and the metal silo was compiled. The report provided estimates of the potential economic risks and benefits associated with the adoption of either of the two technologies (Chisvo and Jaka, 2017). The farmers in Mozambique are extremely poor and are highly vulnerable to the risk of increased post-harvest food losses, mainly because a large majority of them use traditional storage facilities (Chisvo and Jaka, 2017). The traditional technologies that are most commonly used are the *celeiro* and *thethera*. Both technologies are constructed from mud, straw and wood, which are natural resources that are freely available to the farmers. The *celeiro* is a "house-like" storage structure that is elevated on a wooden platform. It has an opening in the front and back which is covered with small wooden doors, the top is covered with straw in a "roof-like" design (Figure 6). Once grains have been dried sufficiently, they are stored in raffia bags which are made from polypropylene. The bags are then placed inside the *celeiro* for storage. Grains that have been stored for a longer period of time are located closer to the front opening, while newly stored maize is located toward the back of the *celeiro*. This helps farmers to track with the duration of stored maize. The *silo thethera*, which is commonly referred to as the *thethera*, is like the metal silo tank, however, it is purely constructed from mud, with an opening at the top to insert the dried grain; and at the bottom front which is used to extract the maize (Figure 6). The front opening is covered with a round wooden piece that seals the container. The *thethera* is also placed onto a platform high above the ground to protect the stored grain against rats. It is placed under a shelter to protect it from harsh environmental conditions such as rainfall (Figure 6). However, these technologies do not create hermetic conditions as the modern technologies do (Chisvo and Jaka, 2017).

The one disadvantage in the adoption of the hermetic bag is that it is expensive for the farmers in Mozambique, mainly due to the 37% import duty fee that is charged to purchase the materials used to make the technology (Tivana *et al*., 2014). In the case of the metal silo, farmers cannot afford to buy the silo with cash; however, credit systems have been created to allow them to purchase the silos on credit (Tivana *et al*., 2014). The risk associated with the credit system is that the farmers, very often, fail to pay back the money due to low agricultural production levels (Chisvo and Jaka, 2017). Given that Mozambique mainly consists of rain-fed agricultural systems with very limited inputs, the highly variable weather conditions negatively affect the post-harvest handling and processing practices. The adoption of the hermetic bag and metal silo technologies is low in the northern regions of Mozambique due to the high cost of purchase. Based on the estimates predicted in the CBA report the use of a 500 kg metal silo will result in an estimated 15% reduction in food losses (Chisvo and Jaka, 2017). The silo can be used for up to 20 years before it should be replaced while the hermetic bag can be used for two years at most. However, to use the bag for that long, it is recommended that farmers use the Super-bag plastic together with the raffia bags which provide better resistance against pests (Chisvo and Jaka, 2017). The Super-bag plastic is the stored grains under airtight conditions. The plastic is then placed inside of a polystyrene sack known as the raffia.

Figure 6. Image of the *celeiro* (left) and the silo *thethera* (right)

2.5.3. Economic contribution of agriculture in Mozambique

The agricultural sector in Mozambique contributes 25% toward the Gross Domestic Product (GDP) and employs 75% of the population.. Between 2008 and 2012, the annual growth of the agricultural sector fell from 7% to 2%. However, the country has a large agro-ecological potential that remains untapped, where potential gains will be most available to the poorest and most rural Provinces in the country (Baez and Olinto, 2016). The low production outputs constrain the growth of the sector, for instance, the maize yields in Mozambique averaged 1 ton per hectare in 2013, which was the lowest amongst the other countries in SSA (Figure 6).

	Maize	Rice	Pulses	Wheat	Millet	Sorghum	Roots and tubers
				Yields in 2013 (Ton/Ha)			
Mozambique	1.0	1.2	0.6	1.7	0.5	0.3	7.2
Malawi	2.2	1.9	-	1.4	0.9	1.1	-
South Africa	3.8	2.6	0-	3.6	0.5	2.8	-
Zambia	2.5	1.2	0.5	6.5	0.8	0.7	-
Zimbabwe	0.9	2.3	0.9	2.5	0.3	0.3	10.0
				Average annual yield growth 2000-2013 (%)			
Mozambique	0.2	1.4	1.4	4.0	-1	-4	2.8
Malawi	1.7	1.2	-	4.5	5	12	-
South Africa	2.3	-0.9	-	2.6	0	0	-
Zambia	2.8	0.2	0.9	0.4	4	7	-
Zimbabwe	-3.9	0.9	2.8	-5.8	18	3	3.3

Figure 7. There are large productivity gaps with respect to other countries in the region (FAOSTATS, 2015).

The agricultural sector in Mozambique suffered a severe drought due to the El-Nino in 2016. As a result, the GDP contribution of the agricultural sector decreased from 3.1% in 2015 to 2.5% in 2016. It further contributed to a negative growth in the economy in the first quarter of 2017 (World Bank, 2017). According to the Jobs Diagnostic for Mozambique, the number of formal jobs in the private sector has tripled from 4% to 12% between 1996 -2015 and may potentially grow through the establishment of more businesses (Baez *et al*., 2016). Despite the growth, informal economic activities, including smallholder agriculture, will remain important, especially for the bottom 40% of the income distribution (Baeze *et al*., 2016).

2.5.4. Systems analysis

In a user reference guide, Kim describes systems thinking as a framework to better articulate the complex interconnectedness of several components that contribute towards the functioning of a particular system, which in this regard is the PHM food system in Mozambique (Kim, 1995). The four dimensions of food security are the framework from which the complex issue of food insecurity is understood. These dimensions are components of the issue that provide better understanding of the system in any given context. This study uses a systems analysis approach, which looks into multiple disciplines of knowledge, to understand the abiotic and socio-economic factors that influenced production levels, as well as farmers in the adoption of modern storage technology. In a study by Di Marcantonio and colleagues (2014), a systems' approach was used to examine the relationship between policy, market access, country governance and food production in African countries (Di Marcantonio, 2014). This aided in gaining a holistic understanding of the issue, which therefore effect an impactful change.

Chapter 3: Materials and methods

3.1. Study area

The study was conducted in the Mecuburi and the Chiure Districts which are both located in the north eastern parts of Mozambique. The Mecuburi District is located in the Nampula Province. The Chiure District is located in the Cabo Delgado Province and forms part of the southern region of the Province.

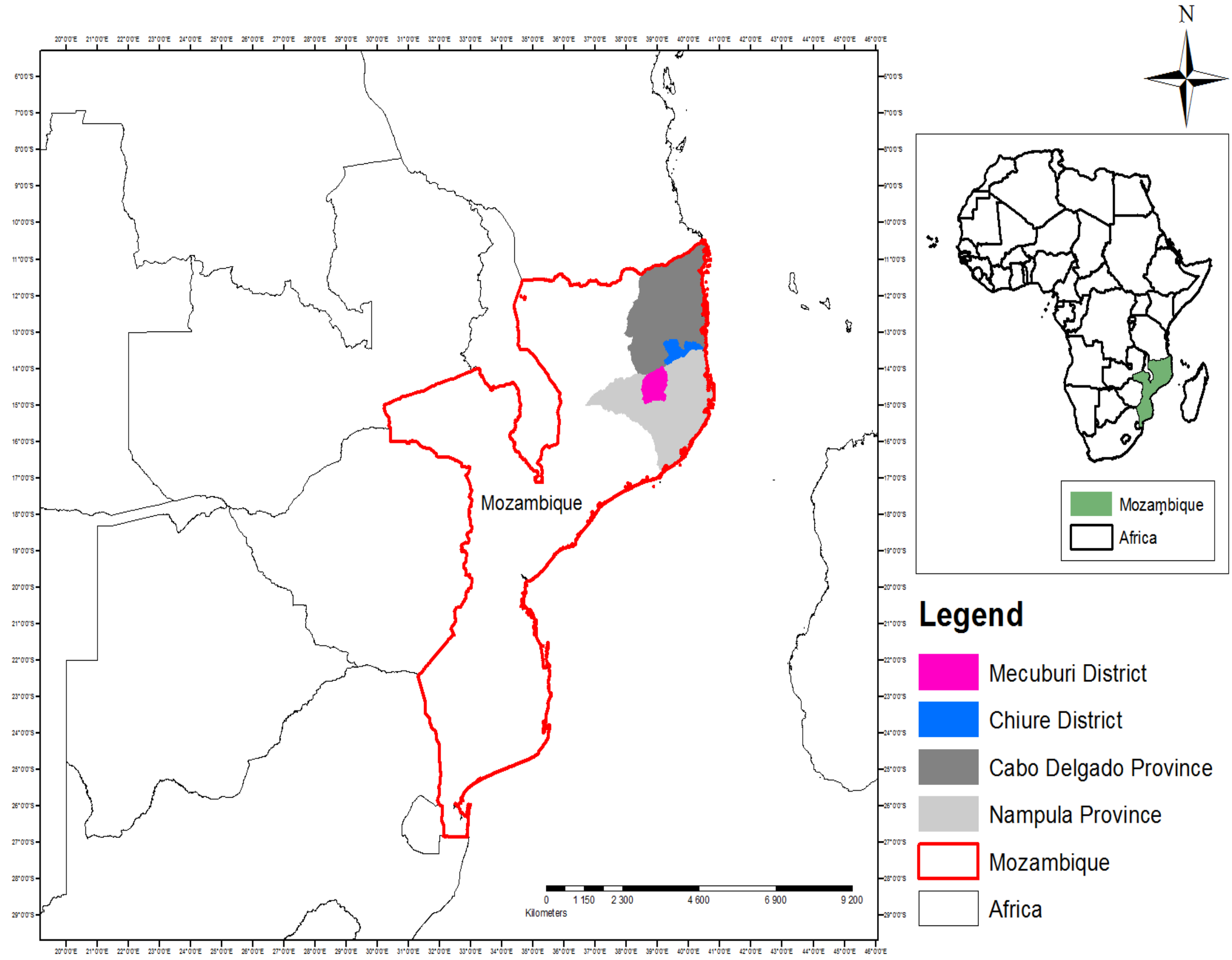


Figure 8. Map of the Chiure District in the Cabo Delgado Province and the Mecuburi District in the Nampula Province, Mozambique.

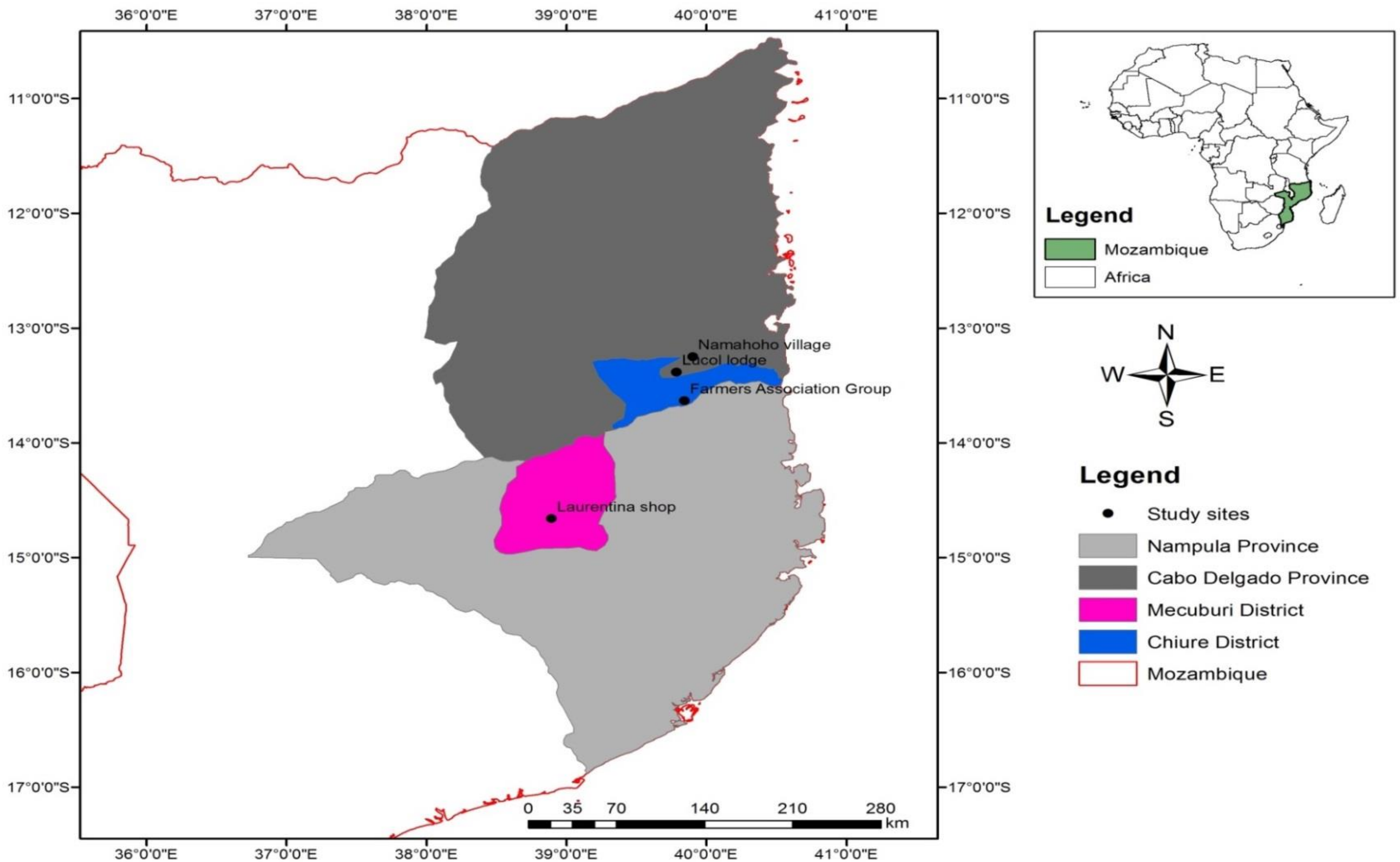


Figure 9. Location map of the study sites in the Mecuburi (pink coloured area) and the Chiure District (blue coloured area). The four study sites are the Laurentina Shop (Mecuburi District), Farmers Association Group, Lucol Lodge and Namahoho Village (Chiure District).

3.1.1. Mecuburi District (Nampula Province)

The Mecubúri District is predominantly rural, with most of the population dependent on agriculture (Ministério da Administração Estatal, 2014). The main agricultural production systems that are largely practiced throughout the District are; firstly the production of cassava (*Manihot esculenta*), maize (*Zea mays*) and Boer beans (*Schotia brachypetala* Sond. (Caesalpinaceae)). Cassava remains one of the most important staple crops in the District and is often intercropped with peanuts (*Arachis hypogaea*) and beans (*Phaseolus vulgaris*) (Ministério da Administração Estatal, 2014). Cowpeas (*Vigna unguiculata*) are also a largely produced crop; and they are also intercropped peanuts (*Arachis hypogaea*) and millet (*Pennisetum glaucum*) (Ministério da Administração Estatal, 2014). Cotton is another widely produced commercial crop that creates employment for farmers in surrounding villages. New agricultural investment aims to enhance the production of cashew and livestock, particularly goats and cattle (Ministério da Administração Estatal, 2014). The District has 37 000 smallholder farms which are approximately 1.4 ha in size. The poverty level in the District was recorded at 53% in 1997 and at 52% in 2007 (Ministério da Administração Estatal, 2014). The district has been severely affected by natural disasters, such a flooding from monsoonal rains and droughts that have led to low agricultural production and food insecurity, particularly in female headed households and the elderly (Ministério da Administração Estatal, 2014). During times of low production, the inhabitants harvest wild berries, sell charcoal, firewood, reeds and beverages such as home brewed alcohol and hunting (Ministério da Administração Estatal, 2014).

The District covers a surface area of 7 216 km^2 with a population density of about 24.4 habitants/km^2. The estimated population is 176 000, 89 000 are females, who account for 12% of the single-parent headed households. The illiteracy rate in the female population is 84% and 49% in the male population. More males have completed primary education (22%) with only nine percent of the females having completed primary school. The average temperature ranges from 20 ºC - 25 ºC; however, during the crop growth season, other regions within the District experience temperatures that exceed 25 ºC. This may be attributed to the presence of valleys and rivers in the District, such as the Lúrio River, which has an effect on the area's micro climate.

The climate falls within the semi-arid and dry sub-humid categories, with annual rainfall that ranges from 800 mm to 1200 mm (Ministério da Administração Estatal 2014). The District has four main non-perennial rivers; Lúrio River, Mecubúri River, Monapo River and Muite River that flow into the Indian Ocean in an easterly direction (Ministério da Administração Estatal, 2014). The altitudes range between 200 m to 500 m with an undulating terrain (Ministério da Administração Estatal, 2014). The river valleys are dominated by alluvial soils that are moderately to poorly drained and subject to frequent flooding. The upper slopes are dominated by Rhodic Ferralsols, Chromic Luvisols and Haplic Ferralsols, which are medium to heavy textured soils that are moderately to well drained (Ministério da Administração Estatal, 2014).

3.1.2. Chiure District (Cabo Delgado Province)

The Chiure District comprises of agricultural systems that are identical to those in the Mecuburi District. The District used to consist of forest cover with tree species *Acacia melanoxylon* R.Br, *Millettia stuhlmannii* and *Afzelia quanzensis* Welw., all of which are largely used by the local community members for firewood, furniture, and charcoal (Ministério da Administração Estatal, 2014). As a result, the District has experienced extensive deforestation due to very limited regulatory measures against such activities (Ministério da Administração Estatal, 2014). The people in the Chiure District are also involved in subsistence fishing, commonly practised by males and children who live near the Lúrio, Muatage, Megaruma and Luco Rivers (Ministério da Administração Estatal, 2014). The District covers an area of 5 393 km^2 with a population density of 44.22 habitants/km^2 based on the 2012 census. The population largely consists of the youth, with 46% of the inhabitants under the age of 15 years (Ministério da Administração Estatal, 2014). The District also lies within the semi-arid and dry sub-humid climates with an annual rainfall that ranges between 800 mm to1200 mm between the months of November to April/May (Ministério da Administração Estatal, 2014). The average temperature during the growing season is approximately 25 ºC (Agrarian statistics, 2012 - 2014). The Chiure District has non-perennial rivers that flow over the escarpment into the Indian Ocean (Ministério da Administração Estatal, 2014). The higher slopes are covered with sandy, loamy soils (Ministério da Administração Estatal, 2014). The main soils types in the Chiure District are dominated by Luvissolos, Cambisols and Arenosols. The soils are poorly drained which make the region prone to flooding (Ministério da Administração Estatal, 2014). The District is also strongly dependent on agriculture to sustain household livelihoods (Ministério da Administração Estatal, 2014).

3.2. Sampling design

The data were collected using two approaches:

1) Firstly, for each District, the annual maize yields, soil properties and climate in the Nampula and Cabo Delgado Provinces were extracted from regional databases.

2) Secondly, data on the adoption level of the post-harvest technologies were acquired from Helvetas, the NGO responsible for implementing the project. Data on the adoption level of the technologies was also collected from the interviews with farmers from each District, using a questionnaire.

3.2.1. Adoption level data

The data provided by Helvetas are an absolute number of hermetic bags and metal silos that have been adopted by the farmers from 2015 to 2017, in the Mecuburi and the Chiure Districts. The farmer interviews also provide data on the different technologies that have been adopted by the farmers in 2017. The two introduced modern technologies in the Mecuburi and the Chiure Districts are the hermetic bag and metal silo. The technologies are termed modern because they are different from the original technologies found in the Districts and because they are manufactured from plastic and metal (Coffi *et al*., 2013). The hermetic bag is made from a sealable plastic that creates anaerobic conditions that prevents pest infestation in the stored crop (Coffi *et al*., 2013). The metal silo is made from steel or aluminium and it is also designed to lower the oxygen content of the storage facility, making condition unfavourable for pests. (Coffi *et al*.,2013).

Modern storage technologies introduced in the districts

Figure 10. Images of the hermetic bag (left) and the metal silo (right).

The hermetic bag (left) is made from an outer polypropylene sac, which is also known as the raffia bag. The inside comprises of a thick plastic bag which stores the grain. The hermetic bags can store 50 to 100 kg of grain. The plastic creates anaerobic conditions required to preserve the stored grain for approximately eight months. The farmers are advised to place the bags inside their homes and suspended the bag under the roof to protect against pests. The grain stored in the bag should be threshed and dried for at least three days before storage. The bag can be used for two years before it needs to be replaced. Households often adopt more than one hermetic bag in order to increase maize availability.

The metal silo tank (right) is a cylindrical structure that is made from a thin steel sheet, 0.5 mm thick and covered with tin to make it hermetic. There are several sized metal silo tanks, 250 kg, 300 kg, 500 kg, 700 kg, 1200 kg and 1500 kg. The technology can be used for 20 years before it needs to be replaced. Grains stored in the metal silo will stay preserved for at least 12 months. There are three pesticide treatments that need to be applied before storing grains in the metal silo tank. Farmers who use Actalm powder, must insert the powder before inserting the grains in the container. The other option is to use the Phostoxin tablet, which should be inserted into the metal silo with the grains. Lastly farmers can use Actellic, an insecticide that should be mixed with the grains before inserting it into the silo tank. The metal silo has an opening at the top, to insert the grain, and the side to take grain. The openings are both sealed with rubber bands. The tank should be placed on a wooden platform 15 cm above the ground, preferably in the house away from the outside rainfall and sunlight.

The traditional storage technologies

The improved traditional storage technologies are the *celeiro melhorado* and the *silo thethera* (Fig 11). These technologies are produced from raw materials such as wood, mud and reeds (Chisvo and Jaka, 2017). Farmers often construct the technologies themselves, and they are not required to purchase the materials for manufacture.

Figure 11. Images of the *silo thethera* (left) and the the *celeiro melhorado* (right).

The *silo thethera* looks like the metal silo tank; instead it is purely constructed from mud. It has an opening at the top, and the side, just like the metal silo tank. The openings are covered with wood piece. The *celeiro melhorado* is the other commonly used traditional storage technology that has a “house-like” structure appearance. It has two openings, one in the front and the other at the back. The openings are covered with small wooden doors. The *celeiro* is made from mud and reeds, which is used to cover the top of the structure. It is also placed on a wooden platform that elevates it above the ground. Farmers often construct these technologies outside their homes, under a covering near their homes. The farmers exact grains from the front opening. Grains that have recently been stored inside the container are located toward the opening at the back of the *celeiro*.

3.2.2. Farmer interviews

The questionnaire used to interview the farmers was developed in line with the objectives of the study (Appendix 1). It was designed to collect information on the farmers' experience with the various technologies, the financing used to acquire the technology, the household demographics and their interaction with the extension services personnel (Appendix 1). The study was targeted at smallholder farmers who are part of the Farmers Association Group, an organization present in both Districts. The official language in Mozambique is Portuguese; the questionnaire was therefore translated from English to Portuguese to aid in the interviews (Appendix 1). The interviews took place from the 6th till the 10th of November 2017. A total of 85 farmers were interviewed, 22 were from the Mecuburi District and 63 from the Chiure District.

3.3. Experimental protocol

3.3.1. Crop yield data acquisition for the Nampula and Cabo Delgado Provinces

The maize crop yield data (tons/ha) were obtained from the Mozambique Department of Agriculture. The data provides the annual maize crop yields, from 2002 - 2016 for the Nampula and the Cabo Delgado Provinces. There was no data available at the District level. Although the data could not be provided for the Mecuburi and the Chiure District specifically, the annual yields for the two Provinces may provide insight on the annual maize yields experienced at the District level. The data were collected from national surveys conducted by the Ministry of Agriculture within the aforementioned time period and in the respective Provinces. The data collected by the Government Department accounts for medium to small-scale annual yields in the Provinces.

3.3.2. Soils data acquisition for the Mecuburi and the Chiure Districts

The soil properties data for each District were obtained from GeoServer, which is a global spatial data source that produces maps using defined parameters. The data, specific for each of the two study locations, were the; percentage sand (%), silt (%), clay (%) and coarse fragment percentage (%), the cation exchange capacity (CEC) (cmol/kg), bulk density (g/cm^3), volumetric moisture content at field capacity ((v%) the ratio of water volume to the soil volume), water filled pore space ((v%) the ratio of volumetric soil water content to total soil porosity), pH, total percentage of Nitrogen (N), total Carbon (C) and the available Potassium (K) and Phosphorus (P). Units for each of these properties were acquired by using the coordinate points of the locations where the interviews with the farmers were conducted in each district. The data were one point in time data acquisition.

3.3.3. Climate data acquisition for the Mecuburi and Chiure Districts

The climate data were acquired from weather stations located in and closest to the Mecuburi and the Chiure Districts. The data were acquired from the National Centres for Environmental Predictions Climate Forecast System Reanalysis (CFSR), and the National Oceanic and Atmospheric Administration (NOAA). The data provides the annual rainfall, the average annual minimum and maximum temperature from 1987-2017 for each district. The two sources of data are scientific agencies from the United States of America that provide data bases on the atmospheric-ocean-land surface conditions around the world. These sources were needed as the data bases available in Mozambique from the local climatic and weather services were impossible to access.

3.3.4. Market dynamics data acquisition for the Nampula and Cabo Delgado Provinces

The data on the retail price of white maize were acquired from the Food and Agricultural Organization (FAO) database from 2006 - 2018 for the Nampula and the Cabo Delgado Provinces. The retail price of maize is in Metical/kg (R1= Mt 4.42 and US$ 1 = Mt 63.63) for each District. The regional Departments of Agriculture could not provide the data required for the Mecuburi and the Chiure Districts.

3.3.5. Modern technology adoption level data acquisition for the Mecuburi and Chiure Districts.

The data on the adoption level of the hermetic bag and the metal silo were acquired from Helvetas. The data provided was the adoption level of the modern technologies from 2015 to 2017 for both Districts.

3.3.6. Interviews with the farmers

The data were collected through semi-structured interviews. The random systematic technique was used in the selection of the farmers, where participants were characterised into those who have adopted the hermetic bag, or the metal silo or the traditional *celeiro* or *thethera*. Although the official language in the Districts is Portuguese, the majority of farmers speak Macua, which is a local language spoken mostly in northern Mozambique. As a consequence, two interpreters were required for the interviews. The one interpreter spoke English and Portuguese, and the other spoke Portuguese and Macua. For every question the farmers were asked, the interpreters would communicate it to the farmers and back to the interviewer. The interviewer was present to provide clarity if there was any confusion during the interview process, as well as to receive clarity from the participants' response. Due to time constraints, the farmers were interviewed in groups of three to five. To maintain anonymity, the farmers were not required to provide any official identity documents; however, they were allocated a number and the district, to assist in the data analysis. The farmers who agreed to participate in the interview signed a consent form (Appendix 1). The agreement notified the farmers of their rights to refuse to participate in the interview if they no longer wished to do so, or answer questions they were not comfortable answering (Appendix 1).

3.4. Data analysis

The data were captured and sorted for analysis on Microsoft Excel 2013 and SPSS for Windows version 22 (SPSS Inc., Chicago, Illinois). Descriptive statistics, the logistic regression model and the Levene's homogeneity test of variance were the methods which were used in the analysis of the different data.

3.4.1. Crop yields and climate data analyses

The annual maize crop yields in the Nampula and the Cabo Delgado Provinces from 2002 - 2016 were analysed through the linear regression model using Microsoft Excel 2013. The Pearson's Correlation statistical test was used to test for correlation between variables. The annual average minimum and maximum temperature were calculated for the Mecuburi and the Chiure Districts. The annual rainfall for each District was determined from the daily rainfall. The linear regression model was also used to analyse the temperature and rainfall data in the Districts from 1987 - 2017. The Coefficient Variance (CV %) and the Levene's homogeneity test of variance were the statistical tests that were used in the analysis of these data.

3.4.2. Soil analysis

The soil properties which were collected for the Districts were compared to those found in other regions with similar soil properties. The comparisons were drawn from the literature, based on those findings; the soil quality in the Districts could be speculated.

3.4.3. Market dynamics data analysis

Descriptive statistics were used to analyse the change in the retail price of white maize from 2006 - 2018 in the Nampula and the Cabo Delgado Provinces. This included the average, minimum and maximum retail price of maize in the Provinces. The price volatility throughout the years was determined from calculating the standard deviation.

3.4.4. Farmer questionnaire analysis

The interviews with the farmers provided qualitative descriptive data. The answers to the questionnaires were coded onto Microsoft Excel 2013 and SPSS, e.g. "yes" = 1 and "no" = 0. The data were grouped into the Mecuburi and the Chiure Districts and were firstly recorded as frequency counts and then into percentages for the different variables. The logistic regression model was used to assess the relationship between the adoption level and the socio-economic factors of influence, as outlined in the questionnaire (Appendix 1). The model measures the probability of the farmers adopting either of the two modern technologies, through predictor variables which are the socio-economic factors in each District (Appendix 1). This analysis was conducted on SPSS.

3.5. Ethics Clearance

Part of this research project involved the participation of farmers in the Mecuburi and the Chiure Districts. Therefore, it was important to conduct the interviews with the participants with sensitivity. The questionnaire and the proposed methods of data collection were reviewed and validated by the non-medical Human Research Ethics Committee at the University of the Witwatersrand. The committee granted ethics clearance for the study (Appendix 2).

Chapter 4: Results

The results are divided into two main sections. The first section presents the annual maize crop yields, soil conditions, rainfall, temperature and the retail price changes in the study areas, allowing for correlations between these factors and yield. The second section provides the number and types of technologies, the hermetic bag, metal silo and the traditional technologies i.e. *celeiro* or *thethera*, that have been adopted by the farmers in the districts. These technologies are used to store grain once they have been harvested. This section of the results will further identify the main factors that have influenced the adoption of the modern technologies by the farmers. This data set is an analysis of farmers' responses to the questionnaire used in the interviews with the farmers in each district. The last section is a systems analysis of the interactions between the adoption of the two modern technologies and the several factors of influence that can be identified from the data sets.

4.1. The maize crop yields in the Nampula and Cabo Delgado Provinces

The annual maize crop yield data were accessed for the Nampula and the Cabo Delgado Provinces, from 2002 - 2016, from the Ministry of Agriculture in Mozambique. The yields are measured in tonnes per hectare (tons/ha) and account for the maize output produced by the smallholder farmers in the Provinces. The annual yield data were not available at the District level, as there was no data collected. The study therefore assumes that the trend in the annual maize crop yields which were experienced at the Provincial level, are similar to the trends which were experienced at the District level. Although this analysis does not allow for a direct correlation between the annual yields and the soil conditions together with the climate, it does provide some insight into the patterns which may potentially be important in the Districts. The two Districts are also located within the same agro-ecological zone and may potentially display the same characteristics in the annual maize crop yields over time.

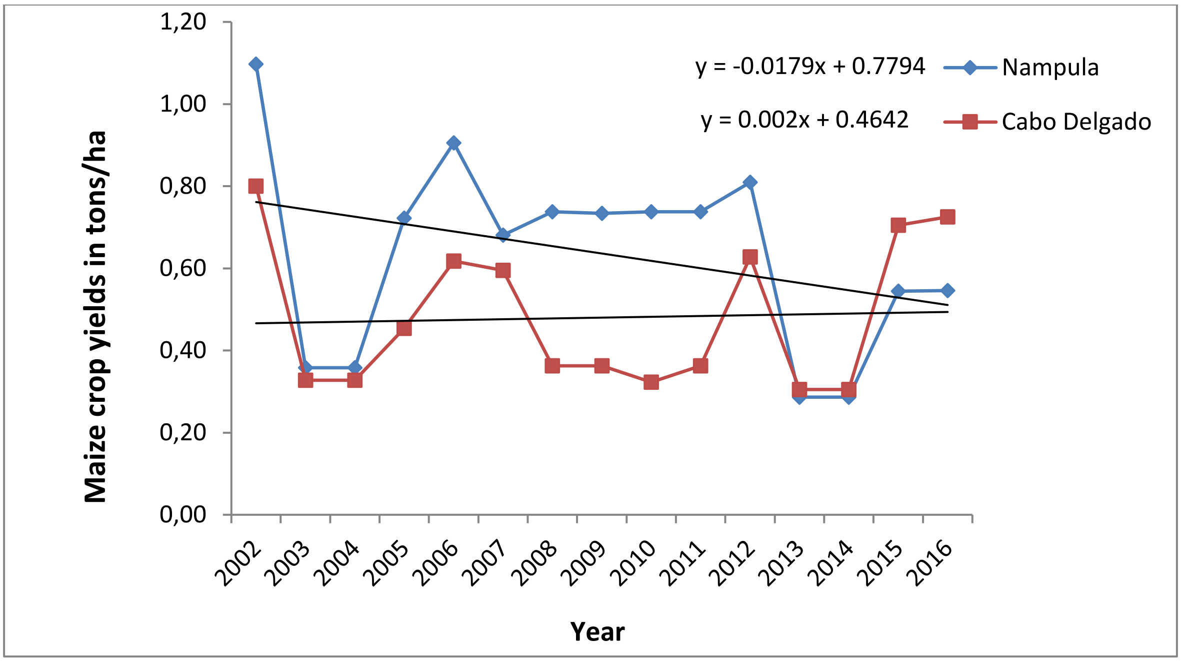


Figure 6. The annual maize crop yields from 2002 - 2016 in the Nampula and the Cabo Delgado Provinces, Mozambique.

The annual crop yields from 2002 – 2016 in the Nampula Province decreased by a rate 0.02 metric tons per hectare for the time period specified above, however, it was not significant (R^2 = 0.11). In the Cabo Delgado Province there was an increase in the annual yields by 0.002 metric tons per hectare, however, it was also not significant (R^2 = 0.003). The farmers in the Nampula Province experienced higher average maize crop yields throughout the 14 years (mean = 0.64 tons/ha; SD = 0.23) compared to the Cabo Delgado Province (mean = 0.48 tons/ha; SD = 0.17). Yet the variability in those maize crop yields was essentially the same in both the Provinces (Nampula CV = 36%; Cabo Delgado CV = 35%).

The highest annual yields were experienced in 2002 in the Provinces, but in 2003 and 2004 they decreased significantly. In the following year both the Nampula and Cabo Delgado Provinces experienced an increase in yields, and peaked in 2006 in the Nampula Province with rainfall ranging from 980 - 1023 mm. However, in 2013 and 2014 both Provinces experienced the lowest crop yields compared to the previous years, more so in the Nampula Province. Following the two years of low agricultural output, there was an increase in the maize yields in both Provinces, in which the Cabo Delgado Province showed higher yields. The Provinces showed no significant difference in the annual maize crop yields from 2002 - 2016 (p-value = 0.213).

4.1.2. The soil properties in the Mecuburi and Chiure Districts

The soil properties, at different depths, outlined in Table 1 are provided for the Mecuburi and the Chiure Districts. The data are single sample points acquired for each District.

Table 1. Soil properties for the Mecuburi and the Chiure Districts.

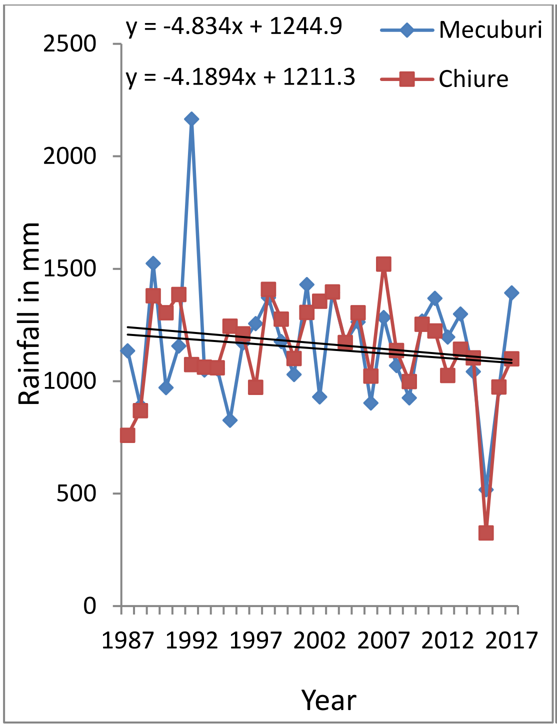
Soil Parameter	Depth	Mecuburi District	Chiure District
Sand %	0-5cm	78.0	74.0
	15cm	84.0	72.0
	30cm	69.0	69.3
Silt %	0-5cm	9.5	7.5
	15cm	7.0	7.0
	30cm	7.0	8.0
Clay %	0-5cm	11.5	20.2
	15cm	17.0	20.7
	30cm	14.0	24.7
Coarse fragments %	0-5cm	1.0	1.2
	15cm	3.0	1.7
	30cm	5.0	1.7
Cation Exchange Capacity (CEC) cmol/kg	0-5cm	6.5	8.0
	15cm	6.0	9.3
	30cm	5.0	7.7
Bulk density g /cm^3	0-5cm	1.4	1.4
	15cm	1.4	1.4
	30cm	1.5	1.5
Volumetric moisture content at field capacity v%	0cm-30cm	7.0	9.0
Water filled pore space v%	0cm-30cm	38.0	41.3
Available K mg/1kg	0cm-30cm	1.022	1.293
Available P mg/1kg	0cm-30cm	0.008	0.009
N (%) by mass	0cm-30cm	0.07	0.10
C (%) by mass	0-5cm	0.6	0.7
	15cm	0.9	1.0
	30cm	0.1	0.4
pH (in H_2O)	0-5cm	6.0	6.1
	15cm	6.1	6.1
	30cm	5.9	6.0

The Districts fall within an agro-ecological zone that mainly consists of Ferralsols, Luvisols and Lixisols, which cover a large region in northern Mozambique (Anuário de Estatísticas Agrárias 2012 - 2014). The Districts are dominated by sandy soils with the content of the coarse fragment in both Districts not exceeding 5% (Table 1). The bulk density ranges from 1.4 g /cm^3 - 1.5 g /cm^3 in the districts, which is a range common to other tropical soils (Bernoux *et al.*, 1998).

The cation exchange capacity (CEC) is higher in the Chiure District compared with the Mecuburi District, which is linked to the differences in clay content in the soils (Aprile and Lorandi, 2012). The CEC ranges from 5 cmol/kg - 9.3 cmol/kg and it is classified as very low to low and characteristic of tropical soils, especially those with low clay content (Aprile *et al.*, 2012). The Districts have soils with very low nutrient contents, which is a limitation for sustainable yields (Vlek *et al.*, 1997). The pH level is acidic in the Mecuburi District and slightly acidic in the Chiure District which is a property common and expected for tropical soils (Aprile and Lorandi, 2012). The volumetric moisture content at field capacity is higher in the Chiure District, indicating that the soil has a higher capacity to retain water compared to the Mecuburi District, however the field capacity values are extremely low, due to the high sand content and these factors will severely limit crop yield (Table 1). Considering properties analysed in the table above, the Chiure District has marginally better soil conditions compared to the Mecuburi District. However, these soil conditions are not very different from each other, when the soils conditions in the districts are compared to other tropical soils, they are characterized as sandy, nutrient poor soils.

4.1.3. Rainfall and temperature in the Mecuburi and Chiure Districts

The rainfall and temperature data were collected for the Mecuburi and the Chiure Districts from 1987 - 2017 and these data are represented from Figure 12 to Figure 15. Figures 12 and 13 provide the annual rainfall for each District but for different time periods. The minimum and maximum temperatures are also provided for the same 30-year period (1987 - 2017), and they are represented in Figure 14 and Figure 15 respectively.



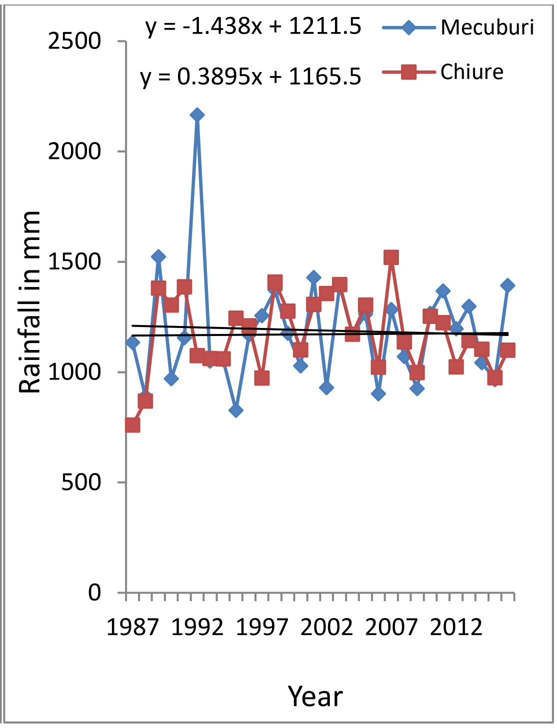


Figure 7.Annual rainfall from 1987-2017 in the Mecuburi and the Chiure Districts

Figure 8. Annual rainfall from 1987-2017 in the Mecuburi and the Chiure Districts (excluding 2015).

The annual rainfall trends illustrated in Figure 12 and Figure 13 provide rainfall that was experienced during the rainy season which begins in November and ends in May for both districts. In contrast to the plotted graphs in Figure 13, the annual rainfall in 2015 received was the lowest in both districts and thus drives the decrease in rainfall that is demonstrated in Figure 12. The data were replotted to assess the influence of the very dry year on the rainfall trend. In Figure 13, the regression model indicates a smaller decrease in rainfall in the Mecuburi District and an increase in the Chiure District, however, the changes in both Districts are not significant (Mecuburi R^2 = 0.0024; Chiure R^2 = 0.0004). In the Mecuburi District the rainfall decreased by 1.4 mm with high variability (CV = 22%). This is due to the very high annual rainfall that was received in 2005. In the Chiure District the rainfall increased by 0.4 mm with lower variability (CV = 15%). The average rainfall in the Mecuburi District is 1189 mm and ranges from about 800 mm – 2100 mm, while in the Chiure District it ranges from 759 mm – 1500 mm, with an average rainfall of 1171 mm. Based on the analysis the rainfall experienced in the Districts is not statistically different from each other (p-value = 0.34).

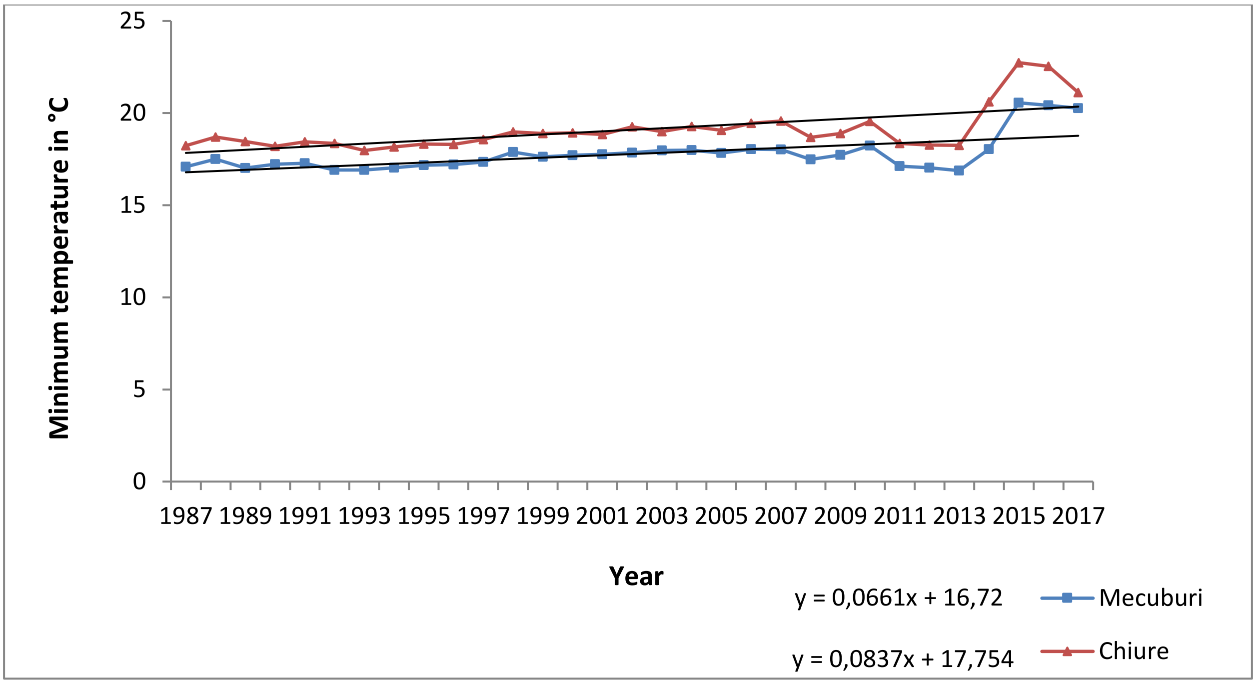


Figure 9. The annual mean minimum temperature in °C from 1987 to 2017 in the Mecuburi and the Chiure Districts, Mozambique.

From the linear regression models the annual mean minimum temperature indicates an increase in both Districts from 1987 - 2017, but not significantly so (Mecuburi R^2 = 0.39; Chiure R^2 = 0.42). The annual mean minimum temperature in the Chiure District has increased by 2.4 °C and has also shown slightly higher variability in the 30 years (CV = 6%) than in the Mecuburi District, where the annual mean minimum temperature increased by 2.1 °C and a CV = 5 %. The minimum temperature in the Chiure District has remained higher than the minimum temperature in the Mecuburi District throughout the 30 years but this is not significant (p-value = 0.42).

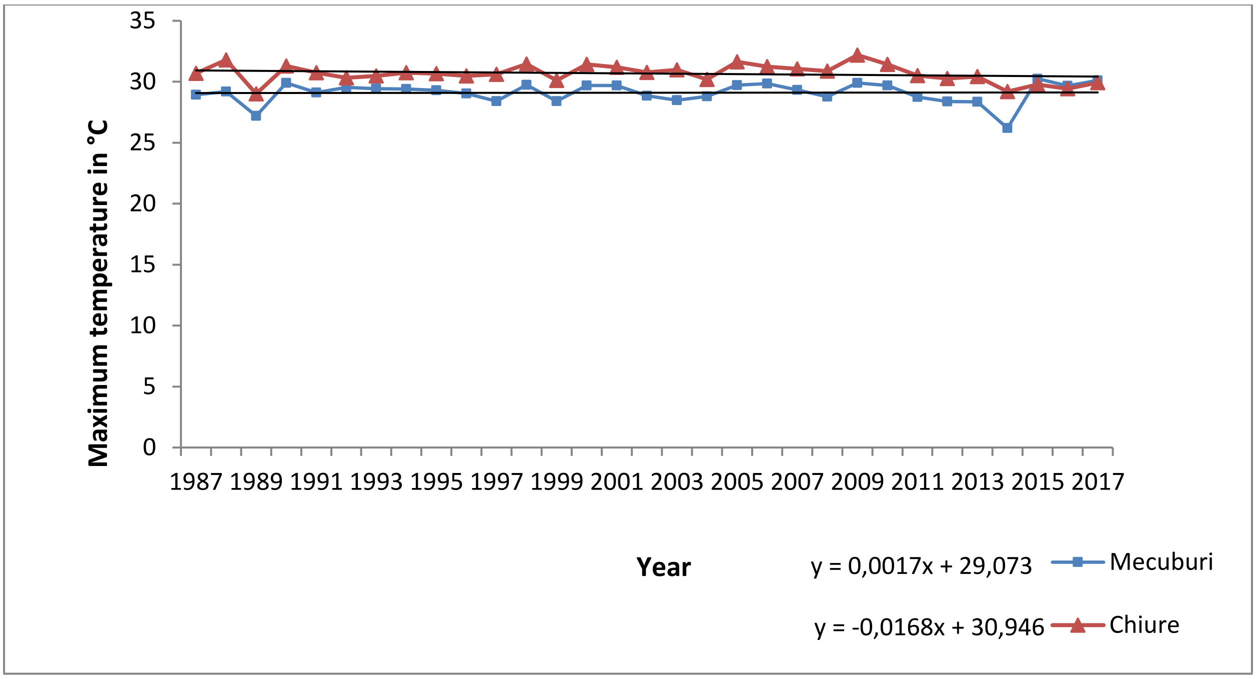


Figure 10. The annual mean maximum temperature in °C from 1987-2017 for the Mecuburi and the Chiure Districts, Mozambique.

The regression models indicate an increase in the annual mean maximum temperature in the Mecuburi District, from 1987 - 2017, by 0.06°C over the 30 years and CV of 3% but not significant ($R^2 = 0.0003$). The annual mean maximum temperature in the Chiure District decreased by 0.51 °C within the same time period, but not significantly ($R^2 = 0.04$, CV = 2%). The change in the annual mean maximum temperature between the districts is not significantly different (p-value = 0.63).

Table 2. Correlation table between the abiotic factors and the annual maize crop yields in the Nampula and the Cabo Delgado Provinces.

	Nampula Province		**Cabo Delgado Province**	
	R^2	p-value	R^2	p-value
Rainfall vs. crop yields	-0.22	0.44	0.1	0.73
Annual mean min. temperature vs. crop yields	-0.09	0.78	0.35	0.22
Annual mean max temperature vs. crop yields	0.5	0.08	-0.06	0.85

The Pearson's correlation test indicates no significant association between the abiotic factors, which are rainfall and temperature, and the maize crop yields in both the provinces. This therefore suggests that the changes in the rainfall, minimum and maximum temperature, over the years did not have a significant impact on the maize crop yields experienced in Nampula and the Cabo Delgado Provinces. This may also suggest that these factors may have not had a significant influence on the yields experienced in the Mecuburi and the Chiure Districts.

4.2. A review of the white maize retail price changes in the Nampula and Cabo Delgado Provinces

Maize is a staple crop in Mozambique, in both the Nampula and the Cabo Delgado Provinces. It is produced by more than 90% of the smallholder farmers, as it is essential for maintaining food security at the household level. The supply and demand for the crop fluctuates between the different seasons, and may explain the variability in the maize crop quantities that are available either for purchase or for sale in the Provinces. Farmers often contribute to the market dynamics by either purchasing additional maize to that produced and harvested, or by selling their excess yields in the market places.

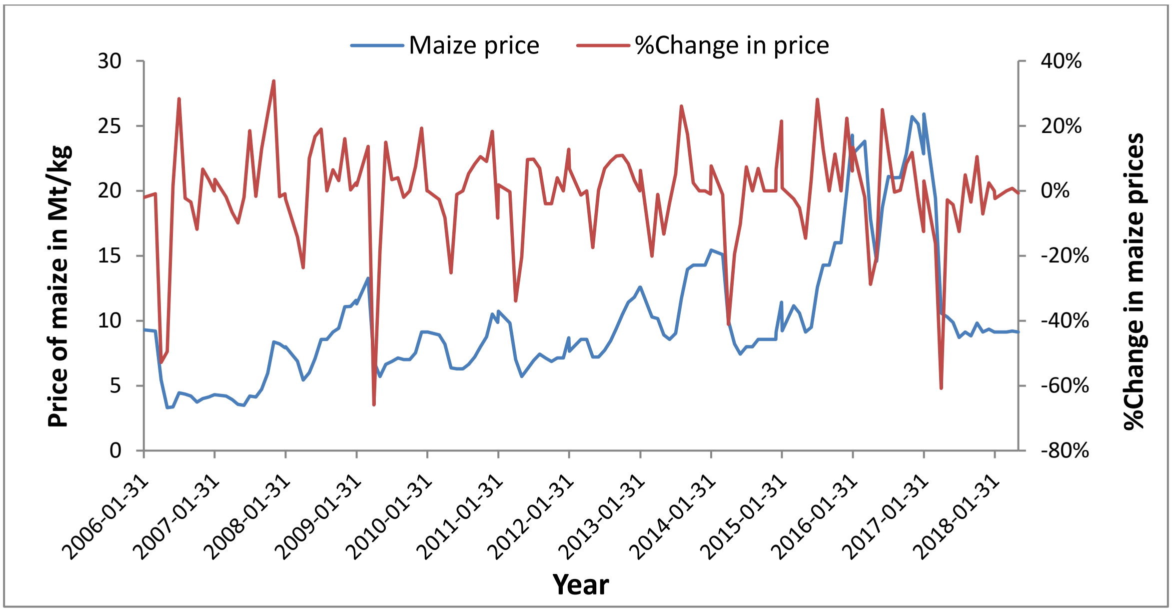


Figure 11. The change in the price of white maize produced in the Nampula Province from January 2006 till May 2018.

The average retail price of maize from 2006-2015 increased and showed high volatility (237%). The average price of maize in the 9 years was Meticals (Mt) 8.62/kg (R4.23). The lowest cost of maize in those years was Mt 3.31/kg (R0.75) in May 2006 and the highest was in December 2015 at the cost of Mt 20/kg (R4.54). The highest maize percentage decrease in price was in 2009 when the price changed from Mt 13.26/kg (R3.01) in March, to Mt 6.86/kg (R1.56) in April 2009. The highest percentage price increase was (34%) a change in price from Mt 5.96/kg (R1.35) in October 2007 to Mt 8.36/kg (R1.90) in November.

In 2016 the prices of maize increased significantly, and continued to rise in 2017. Between 2016 and 2018 the average price of maize was Mt 15.81/kg (R3.59), which is much higher compared to the previous years. The highest cost of maize in those years was Mt 25.91/kg (R5.88) in January 2017, and the lowest was Mt 8.7/kg (R1.98) in July 2017. The highest percentage decrease in price was in March 2017, when the price of maize dropped from Mt 19.43/kg (R4.41) to Mt 10.58/kg (R2.40) in April (61%). The highest percentage price increase was in June 2016 when the price changed from Mt 18.72/kg (R4.25) to Mt 21.09/kg in July (25%), which is rather surprising as July falls within the harvest season as stated by the Famine Early Warning Systems Network (FEWSNET). This is also surprising as the harvest in 2016 was good (Figure 11). The price volatility from 2016 - 2018 was very high, reaching a percentage of 246%, which indicates that the price of maize changed often over time and in some instances by very large amounts.

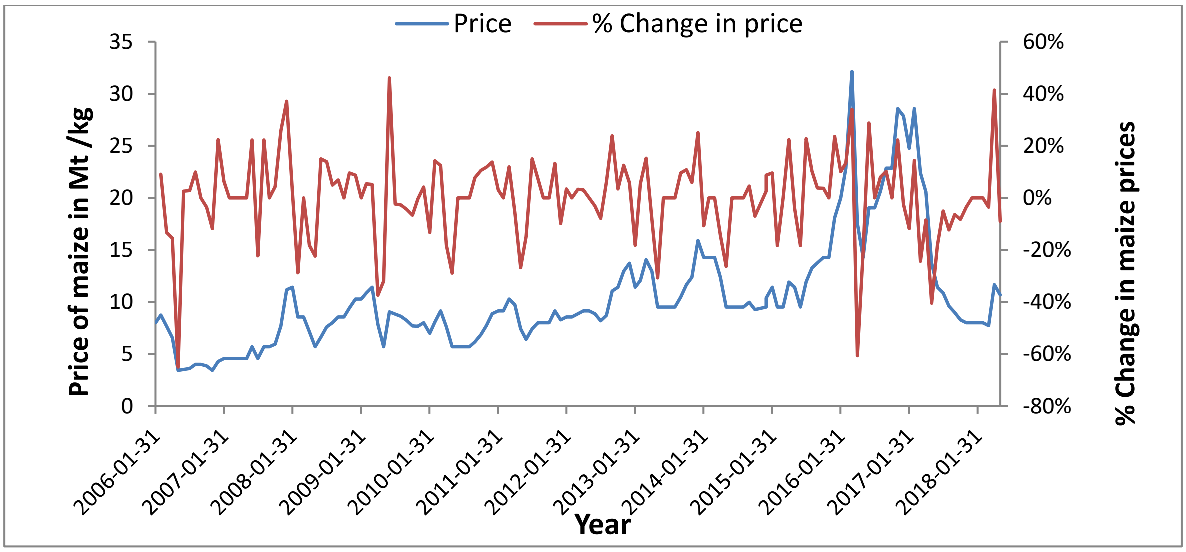


Figure 12. The change in price of white maize produced in Cabo Delgado Province from January 2006 till May 2018**.**

The average retail price of maize from 2006 - 2015 in the Cabo Delgado Province was Mt 8.84/kg (R2.01). The highest cost of maize in those years was Mt 18.10/kg (R4.11) in December 2015 and the lowest was Mt 3.43/kg (R0.78) in May 2006. The variance of the price of maize during the 13-year period was at 240%, which indicates that the retail price of maize were very unstable. The highest maize percentage decrease occurred when the price changed from Mt 6.57/kg (R1.49) in April 2006 to Mt 3.43/kg (R0.78) in May 2006 (65%). The highest maize percentage price increase occurred in 2009, when the price increased from Mt 5.71/kg (R1.30) in May to Mt 9.05/kg (R2.06) in June (46%). However, from 2016 – 2018, the price volatility percentage in the Province was the highest compared to previous years; 329%, thus suggesting that Cabo Delgado had the most unstable food prices from 2016 - 2018. The highest maize percentage drop occurred in March 2016 when the price of maize decreased from Mt 32.14/kg (R7.90) in March, to Mt 17.55 (R3.99) in April (61%). The highest price increase was a change in price from Mt 7.72/kg (R1.75) in March 2018 to Mt 11.68 in April 2018 (41%).

4.2.1. The change in maize prices between seasons

According to the seasonal calendar provided by the Famine Early Warning Systems Network (FEWSNET) for northern Mozambique, the harvest season is from April to July. The planting season begins in November and ends in February. The rainy season begins in November and ends in May of the following year. The years 2014 and 2015 were selected for this analysis because there was no missing data.

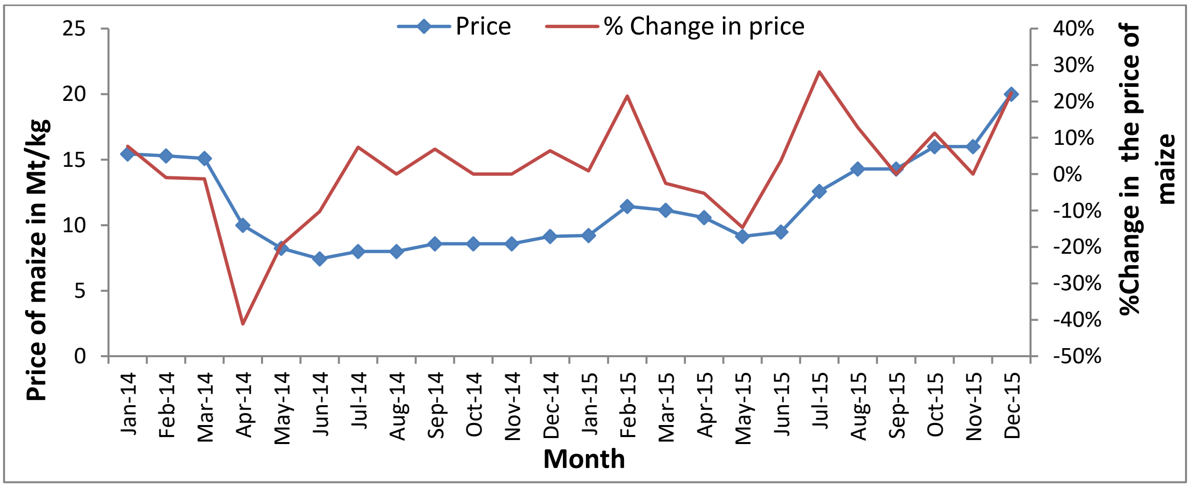


Figure 13. The change in price of white maize produced from January 2014 to December 2015 in the Nampula Province.

The retail price for maize was high from January - February 2014. From March to August 2014 the price decreased and remained low. From September right through to December the prices increase slightly. In January 2015 the price of maize increased significantly as it is a month within the non-harvest season. The prices remained high from January till February, which is a similar pattern as the previous year. The price of maize decreased from March and remained low until June 2015. From July 2015 prices are showing marked increases until December, which is aligned with the change in season. The average price of maize from January 2014 to December 2015 in the Nampula Province was Mt 11.52/kg (R2.62). The highest cost of maize in the two years was Mt 20/kg (R4.54) in December 2015, and the lowest price was Mt 7.43/kg (R1.69) in June 2014. The Province showed a very high price volatility of 225%. This suggests that the price of maize in the Nampula Province was highly variable primarily due to the variability in the supply and demand for the food crop in the Province. Or perhaps it may be due to the changes in the US$ exchange rate. An important factor to note is that the maize produced is not only consumed in the Nampula Province but it is also traded with neighboring Provinces in Mozambique and countries such as Malawi and Tanzania.

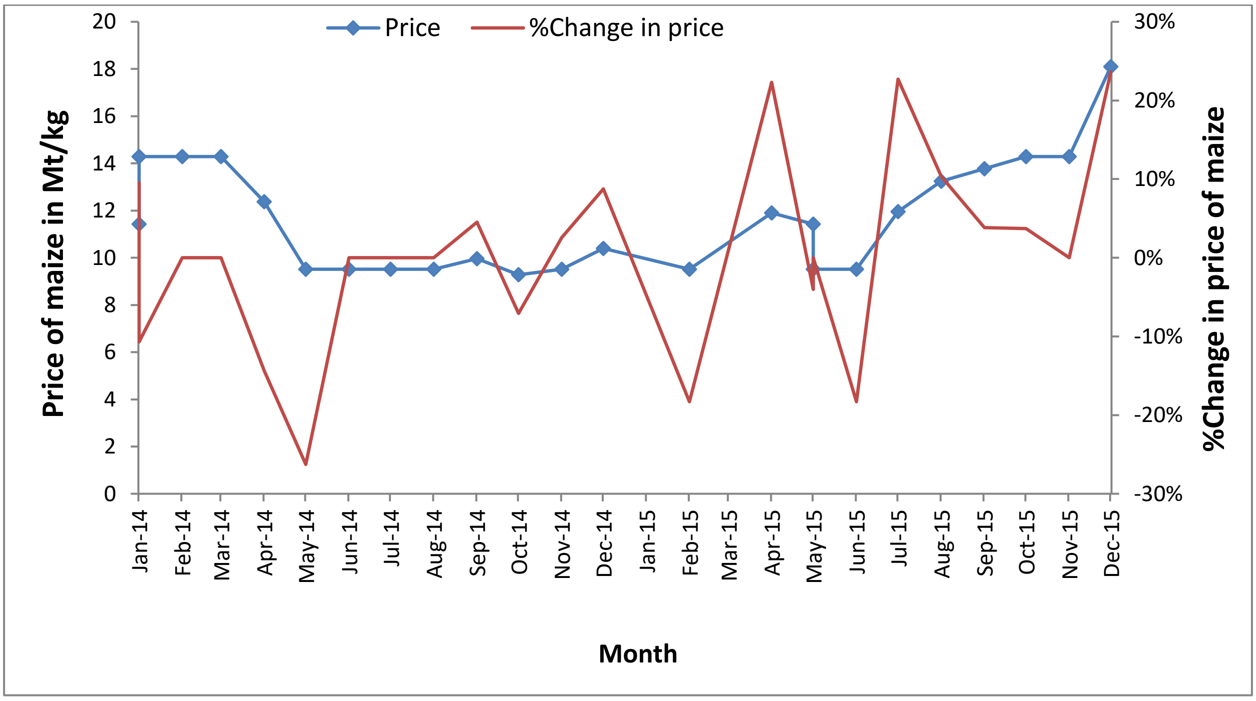
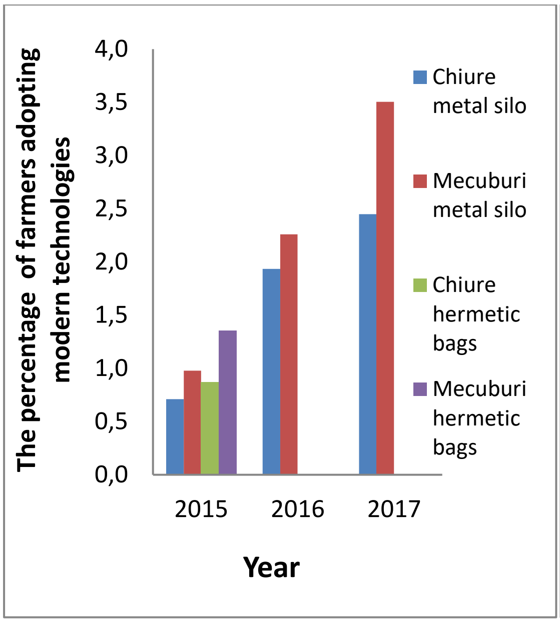


Figure 14.The change in price of white maize produced from January 2014 to December 2015 in the Cabo Delgado Province.

A similar pattern in the retail price change in the Nampula Province is demonstrated in the Cabo Delgado Province. The price of maize was high from January to March 2014; from April to August the price decreased and remained low. In September 2014 the price increased slightly and reached another high in December 2014. In February 2015 the price decreased but increased from March and May, which is unusual as these months fall within the harvest season. In June and July the price of maize was low, but from August 2015 the price increased until December 2015. This indicates a pattern of high maize prices during the non-harvest season and low maize prices during the harvest season in 2014. However, in 2015 there was a usual price increase in the cost of maize during the harvest season. This may be attributed to the drought that occurred in SSA that year. In the Cabo Delgado Province the average price of maize in the two years was slightly higher compared to the Nampula province; Mt 11.73/kg. The lowest price that the consumers purchased maize was Mt 9.28/kg in October 2014, which is rather surprising as October does not fall within the harvest season, but it is the period in where the farmers are preparing the fields for planting. The highest cost of maize was in December 2015 with a price of Mt 18.10/kg. The maize prices from January 2014 to December 2015 were highly variable with 200% volatility, lower than the Mecuburi district. This indicates that the farmers in the province were experiencing highly variable maize crop availability. This may also suggest that the supply and the demand for the crop may have changed frequently throughout the months due to trade in the province and with the surrounding districts and provinces.

4.3. Adoption level record by Helvetas

The data on the adoption of the hermetic bags and the metal silos were provided by Helvetas from 2015 - 2017 and are represented in Figure 20 and Figure 21. Although the PHM project started in 2013, the first two years of the project were allocated to baseline studies and no data were collected. The total number of farmers who are participants in the Helvetas PHM is 5757; 2654 are from the Mecuburi District and 3103 are from the Chiure District.



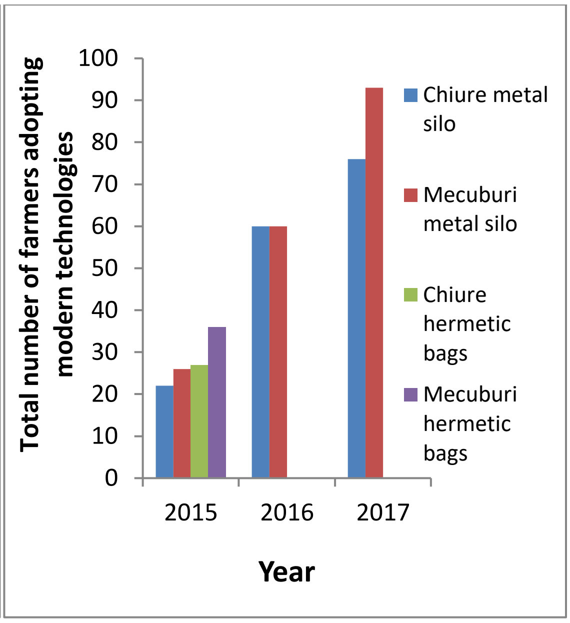


Figure 15.The percentage of farmers who have adopted the hermetic bags and metal silos from 2015-2017 in the Mecuburi and the Chiure Districts based data collected by Helvetas

Figure 16. The total number of farmers who have adopted the hermetic bags and metal silos from 2015-2017 in the Mecuburi and Chiure Districts based on data collected on data collected by Helvetas.

Figure 20 shows the proportion of the total number of farmers who have adopted the technologies in each district. Figure 21 shows the absolute number of farmers who have adopted the technologies in the Districts. The proportion of farmers who have adopted the technologies is dependent on the total sample size, which indicates extremely low adoption levels. The adoption of the modern technologies was recorded from 2015 - 2017. The highest adoption level in that year was in the Mecuburi District, hermetic bag (1.4%) and the metal silo (1%). The District with the highest adoption of metal silos in the three years was in the Mecuburi District, which is indicated by the cumulative percentage count in the three years (6.8%). The Chiure District maintained lower adoption levels within the same time period (5%). In view of the total number of farmers who are participants of the PHM project and have been offered the modern technologies, both Districts indicate very low adoption levels.

4.3.1. Adoption level from the interviews with the farmers

The results presented in Figure 22 are modern and traditional storage technologies that have been adopted by the farmers in the Mecuburi and the Chiure Districts. These data were collected from the interviews which were conducted with the farmers in each District in 2017. A total of 85 smallholder farmers were interviewed; 22 were from the Mecuburi District and 63 from the Chiure District. The farmers in the Chiure District were interviewed over three days, which allowed for a larger sample size, while in the Mecuburi District, interviews were conducted for one day.

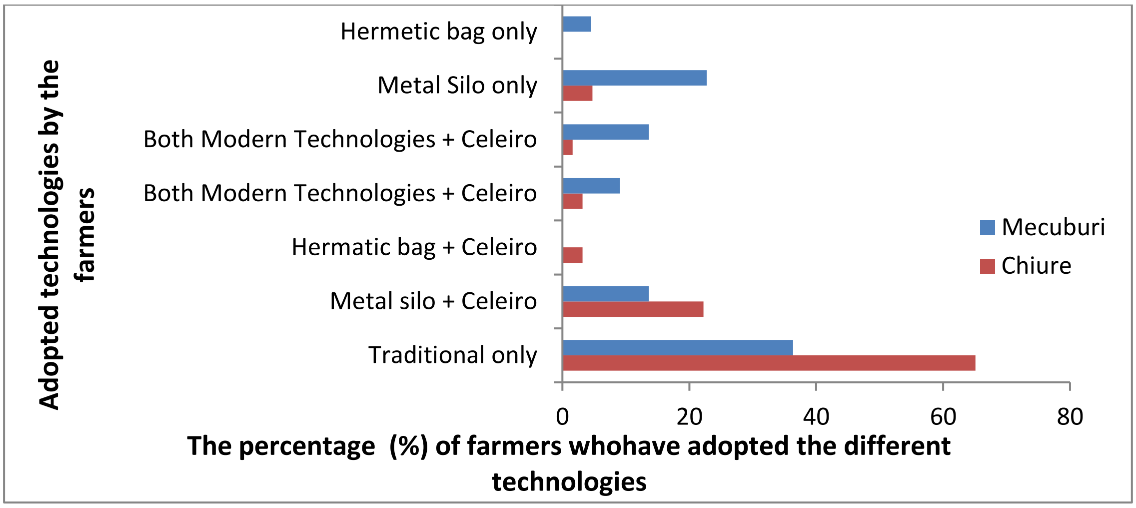


Figure 17. The percentage of farmers who have adopted various technologies in the Mecuburi and the Chiure Districts.

The results in Figure 22 are the percentages of the total number of farmers who were interviewed in each District. Mecuburi is the only district with farmers who have adopted only the hermetic bag, in addition, it has the highest majority of farmers who have adopted only the metal silo and the metal silo together with the hermetic bag (5%, 23%). In the Chiure District there are farmers who use the hermetic bag and the *celeiro* (a traditional storage technology) which is a combination of technology usage that is not found in the Mecuburi District (Figure 22). The adoption of the metal silo together with the *celeiro* appears to be a more popular practice among the farmers in both Districts, especially in the Chiure District. The adoption of the *celeiro* or *thethera* is the highest in the Chiure District (65%) and low in the Mecuburi District (36%). The overall adoption of the modern storage technologies in the Districts also confirms the low adoption levels. Although that is the case, the Mecuburi District indicates a higher adoption level compared to the Chiure District. There are a large number of farmers who continue to use the traditional technologies in the districts, especially in the Chiure District.

4.3.2. The farmers' self-reported changes in the amount of maize stored in the technologies

The farmers were further asked to state the type of crops they produced and stored in the various technologies. Among the several crops that were stated, maize was one of the commonly cited crops and it was selected as the focus crop for the study. The table below focuses on the farmers' responses to the amount of maize they were able to store in their adopted technologies. It is predicted that the farmers who adopted the modern technologies, either alone or in combination with the traditional technologies, will experience an increase in the amount of maize stored and made available for consumption or sale. The opposite is predicted for farmers who have not adopted any of the modern technologies, but continue to use the traditional *celeiro* or *thethera.* The percentages represented in the Table 3 are the frequency counts of the total number of farmers who were interviewed in each District.

Table 3. The farmers' self-reported changes in the amount of maize crop stored in their storage technologies.

Adopted technology	**Mecuburi District *(n=22)***			**Chiure District *(n=63)***		
	Increased %	Decreased %	Same %	Increased %	Decreased %	Same %
Metal silo	14	0	0	6	0	0
Hermetic bag	5	0	0	0	0	0
Celeiro+*thethera*	0	5	32	6	49	8
Both modern	0	0	14	0	2	0
Both modern+ *celeiro*	0	0	9	2	0	0
Metal silo+*celeiro*	0	0	9	2	11	10
Hermetic bag + *celeiro*	0	0	0	3	2	0

The majority of the farmers in the Mecuburi District felt that the amount of maize they stored in their modern technologies did not change since they were introduced but overall they did allow for greater storage (Table 3). Many of these farmers have adopted more than one metal silo, in order to increase the amount of maize made available for households. In the Chiure District, almost half of the farmers' report to have experienced a reduction in the amount of crop stored in their traditional *celeiro* or *thethera*, which has the highest adoption level compared to the modern technologies (Table 3). The farmers who adopted the modern technology chose to store more oftheir crop in the adopted technology and have thus seen an increase in the amount of crop stored in their adopted technologies since introduction. However, this represents a small proportion of the farmers.

4.4. The farmers' stored maize and their purchasing patterns

The farmers in both the Mecuburi and the Chiure Districts were asked to specify the duration for which they stored their crops in their adopted technologies. This question was targeted at farmers who had adopted the modern technologies and those who did not. Despite the use of these technologies, whether modern or traditional, farmers still had to purchase additional crop to that they harvested and stored. The table below provides the details.

Table 4. The percentage of stored and purchased crops by the farmers in the Mecuburi and the Chiure Districts

Category	**Description**	**Mecuburi District *n=22***	**Chiure District *n=63***
Purchase additional staple food crop	No	41	52
	Yes	59	48
Months purchased the additional staple food	None	38	54
	1-2 Months	24	43
	3-4 Months	24	3
	≥ 5	14	0
Source of the money used to purchase the additional food	Farm produce	80	35
	Off-farm products	20	57
	Loan	0	8

The majority of the farmers in the Mecuburi District had to purchase additional crops for 1 - 4 months. A few of the farmers in the District had to purchase additional crops for at least five months, which is almost half of the year (Table 4). In the Chiure District the majority of the farmers did not have to purchase additional food, however, those that did, purchased for only 1 - 2 months and in very few cases for 3 - 4 months. This is rather surprising as most of the farmers in the Chiure District continue to use the *celeiro* or *thethera* to store their grain (Figure 22). This suggests that the farmers may have been dishonest in their response to this question, to avoid embarrassment. The primary source of income to purchase the additional maize in the Mecuburi District was from the sales the farmers made from the excess crop they had harvested. Excess crop refers to a fraction of the crop that is left over within the harvest season, once the farmers have stored enough quantities to feed their households. Farmers who have access to the markets sell the excess crop at nearby local markets. Those who often face difficulties to access the markets sell their maize to their neighbors. During the interviews very few farmers in the District specified that they acquired the money from selling other products, which are classified as off-farm products in the table above. This includes products such as baskets, alcohol, wood work products and artisanal products (Table 4). However, in the Chiure District, more than half of the farmers acquired the money from selling other products (off-farm products) beside the portion of maize they sold to avoid spoilage in 2017. There were a considerably large number of farmers in the Chiure District who sold their portions of their maize crops for an income to buy additional food and very few farmers in the same District acquired a loan to make the additional purchases (Table 4).

4.4.1. The socio-economic drivers of adoption

The results presented in this section are the famers' responses to the questions they were asked regarding their storage and purchases of crops to maintain their livelihoods, their main reasons for adopting the technologies, the finances required to acquire the adopted technologies, the household characteristics and their exposure to the work of the extension services personnel in introducing and promoting the modern technologies. The questions were targeted at the farmers who adopted either the modern technology or the traditional storage technology.

Table 5. The main drivers that have influenced the adoption or lack of adoption of the hermetic bag and metal silo.

Category	Description	Mecuburi District	Chiure District
		Percent (%)	**Percent (%)**
		n= 21	***n=63***
Main reason for adopting the technology	For sale	32	22
	Only storage option	18	16
	Long-time storage	50	59
	Affordable	0	2
	Word-of-mouth	0	2
		n= 22	***n=61***
Main advantage for adopting the technology	Prevents rotting	41	54
	Family consumption	46	35
	Sell	14	5
	Clean house	0	6
		n=20	***n=62***
Financial source used to acquire the technology	Cash	9	19
	Self-Constructed	27	71
	Donation	9	10
	Loan	46	0

The main reason for the farmers in the districts to adopt the modern technologies was primarily to store their maize crop for longer time periods, especially in the Chiure District. The main advantage that the farmers in the Mecuburi District experience from using the modern technologies was the increase in the amount of crop that was made available for family consumption (Table 5). In the Chiure District, the main advantage experienced from the use of modern technologies was how the technology prevented the crop from rapidly rotting (Table 5). In the case of the Chiure District, the storage of maize in the traditional technologies reduced the rate at which the crop rot compared to when the crop is not stored in any storage container at all.

Almost twenty percent of the farmers in the Mecuburi District use the *celeiro* or *thethera* because it was their only storage option; fewer farmers expressed the same views in the Chiure District (Table 5). It would be expected for the majority of the farmers in the Chiure District to express the adoption of the traditional technologies as their only storage option, as they have the highest adoption level of the *celeiro* and *thethera*. The farmers in the Districts used various financial sources to acquire the modern technologies. Almost half of the farmers in the Mecuburi District acquired a loan in order to adopt either of the modern technologies whereas the majority of farmers in the Chiure District built their own traditional storage technologies. More farmers in the Chiure District paid cash compared to the Mecuburi District and no farmers took loans in that District (Table 5). An equal number of farmers received the modern technologies via a donation from Helvetas (Table 5). These farmers were identified as the most vulnerable in the District, and were thus given the technology as part of the project experiment.

Table 6. The household characteristics of the farmers in the Mecuburi and the Chiure Districts.

Category	Description	Mecuburi District (*n*= 22)	Chiure District (*n*=63)
		Percent (%)	Percent (%)
		n=22	***n=59***
Age (years)	18-20	5	2
	20-29	18	12
	30-39	23	24
	40-49	46	34
	≥ 50	9	29
Gender of the farmer	Male	63	63
	Female	37	37
Decision Maker	Household head	50	56
	Husband	18	6
	Wife	5	5
	Both	18	32
	Other	9	2
Highest school level finished	Primary	64	70
	Secondary	18	6
	Pre-University	14	2
	None	5	22
No. of years farming	<5	5	2
	6-10	14	2
	11-20	41	27
	21-30	14	35
	31-40	27	23
	41-50	0	4
	51-60	0	6
Total no. of household members	1-5	68	65
	6-10	27	35
	11-15	5	0

The majority of the farmers in the districts are in the 40 - 49 years old age group, more so in the Mecuburi District. The district has the highest percentage of farmers aged between 18 - 39 years old. In the Chiure District, almost thirty percent of the farmers are 50 years old and above, which is greater than that in the Mecuburi District (Table 6). The presence of more male farmers than female farmers appears to be a common trend in the districts (Table 6) which is very different from studies reported in the literature. The males are often the household heads and their responsibility is to make decisions about everything that occurs or needs to occur within a household.

The farmers in the Districts rely on the household head to make the decision on whether to adopt the modern technology, more so in the Chiure District. However, a few other families in the Districts make joint decisions, where both the husband and the wife make the decision on the adoption of the modern technologies, this is more apparent in the Chiure District (Table 6). The highest percentages of farmers who have attained a basic level of education are in the Mecuburi District. Although the vast majority of the farmers in the Chiure District have the highest number of farmers with a primary level of education, a very large number of them are without any form of education (Table 6). The majority of the farmers in the Mecuburi District have been involved in subsistence farming for 11 - 20 years and in the Chiure District for 21 - 30 years. The Mecuburi District also has more farmers who have been involved in farming for 1 - 10 years. None of the farmers in that district have farmed for more than 40 years (Table 6). The basic structure of a family unit in the Districts follows the nuclear design, where households not only live with their immediate family members but also with extended family members (Ministério da Administração Estatal, 2014). The Districts predominantly have total household sizes with one to five family members, this is more so in the Mecuburi District (Table 6). There are considerably more households in the Chiure District with 6 - 10 family members, compared to the Mecuburi District, although it's not the majority. Mecuburi has a small number of households with up to 15 family members, which is very large (Table 6).

Table 7. The organizations responsible for the introduction of the technologies in the Mecuburi and Chiure Districts.

Category	**Description**	**Mecuburi District (*n*= 22)**	**Chiure District (*n*= 63)**
		Percent (%)	**Percent (%)**
The organization that introduced the modern technologies to the farmer	NGO	59	25
	Farmer's Union Group	18	54
	Coosen (metal silo producing company)	0	13
	Social Media	0	3
	Other	23	5

Most of the farmers in the Mecuburi District were introduced to the hermetic bag and metal silo through Helvetas, which is the NGO that is responsible for introducing the PHM project in the Districts (Table 7). More than fifty percent of the farmers in the Chiure District were introduced to the technologies through the Provincial Union Farmer's Group, which works closely with Helvetas (Table 7), Coosen, a private company that produces metal silos was also involved (Table 7). Social media platforms (sms' and radio broadcasts) were also used in the introduction and promotion of the modern technologies, but in a very limited way (Table 7). More than twenty percent of the farmers in the Mecuburi District were introduced to the technologies through government extension services and family or community members in the District. Very few farmers expressed the same view in the Chiure District (Table 7).

4.4.2. The introduction and promotion of the modern technologies in the Districts.

The extension services that were provided through the PHM project in the districts were organized by Helvetas. The activities involved in the introduction and the promotion of the technologies began in 2014, and continued until 2017. These services were offered to the farmers who are participants in the PHM project by Helvetas in the Mecuburi and the Chiure Districts.

Table 8.The activities involved in the introduction and promotion of the modern technologies in the Mecuburi and Chiure Districts.

Promotion of the modern technologies	Year	Mecuburi District	Chiure District
	2016	23	13
Radio broadcasts (adverts and talk shows on the technologies)	2015	56	64
	2016	103	127
Action weeks	2015	1	1
	2016	2	2
	2017	1	1
Trained technicians for the project		10	8
Trained promoters for the project		7	7

The earliest introduction of the modern technologies occurred in 2014, with a demonstration field in only the Chiure District. In 2015 there were no demonstration fields in both districts; however, in 2016 the number of fields increased considerably, with the highest in the Mecuburi District (Table 8). Social media were also an important tool that was used in the promotion of modern technologies. The radio broadcasts began in 2015 with the highest number of broadcasts that year in the Chiure District (Table 8). The radio broadcasts in 2016 increased in both districts, more so in the Chiure District which has a larger population of radio listeners. The total number of radio listeners in the Mecuburi District is 9,008 people, and in the Chiure District 11,697 listeners.

Action weeks were also conducted with the farmers in the Districts, in which the farmers and stakeholders involved in the agricultural sectors engaged on PHM in the Districts were invited. This occurred once in 2015 in both Districts, twice in 2016 and once in 2017, which was the time in which the interviews with the farmers were conducted for this research study (Table 8). The total number of technicians who were trained for the project was the highest in the Mecuburi District and in both Districts more females were trained as technicians and trainer promoters. An equal number of promoters were trained; they were responsible for demonstrating the use of the technologies as well as the practices associated with the use of the modern technologies.

4.5. Systems analysis variables

The table below demonstrates the variables that are predictors in the logistics regression model. The B variable predicts the dependent variable; SE is a measure of the standard error from the mean. The Walds chi-squared value and the 2-tailed p-value test the null hypothesis, and if both values are below 0.05 there is a statistically significant difference. The odds ratio (Exp (β)) predictor variable represents the constant effect of the predictor; on the likelihood that one outcome will occur, which in this case is whether the farmers will adopt the technology or not.

Table 9. The key factors that influence the farmers' adoption of modern technology in the reduction of post-harvest losses in the Mecuburi and the Chiure Districts.

District	Variable	B	SE	Wald	Sig.	Exp (β)
Mecuburi	Financial source to purchase the technology	-2.121	0.973	4.745	0.029	0.12
Chiure	Financial source to purchase additional food.	-2.548	0.961	7.035	0.008	0.078

The Districts do not have any common variables which have influenced the adoption level; the significant findings are shown in Table 9. However, both Districts indicate finances as a significant influence in the farmers' decision to adopt the modern technology. This association is significant in the adoption of the metal silo alone and not the hermetic bag. In the Mecuburi District farmer could not adopt the metal silo because there were limited loans available, to purchase the metal silo on credit. In the Chiure District, the intent to adopt the metal silo decreases with every farmer that sells off-farm products to purchase additional maize to those they produce and store.

4.5.1. Systems analysis of the adoption of the technology and the factors of influence in the Mecuburi and Chiure Districts.

The conceptual model aims to highlight the key factors that have influenced the farmers' decisions in both districts in the adoption of the modern technologies. The interactions between these variables are further described by the positive and negative sign beside the arrow heads. An arrow with a positive sign indicates a positive feedback relationship; an arrow with a negative sign indicates a negative feedback relationship between the variables. The variables that have been used to construct the model were drawn from the factors listed in Table 9 and abiotic factors in the previous tables and figures of the results sections.

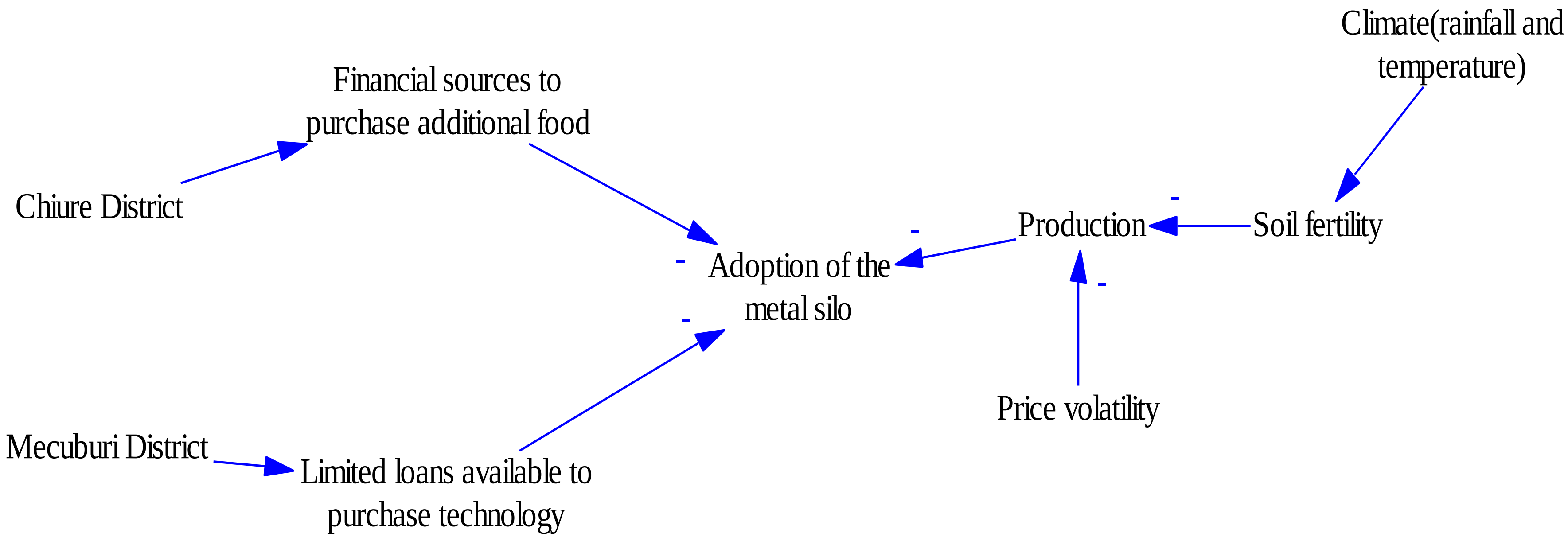


Figure 18. Conceptual model of the socio-economic and other factors that have influenced the adoption of the metal silo in the Districts.

One part of the conceptual model above demonstrates the relationship between the climate, soil conditions and the annual maize crop yields experienced in the Mecuburi and the Chiure Districts. It also shows the socio-economic factors that have significantly influenced the adoption of the metal silo in the Districts (Figure 23). The abiotic factors (climate and soil conditions) are not significantly different from each other and are shown as a combined single variable in the diagram (Figure 23). The assumption in the model is; an increase in the crop production that occurs as a result of adequate rainfall, minimum and maximum temperature and soil conditions may result in an increase in the likelihood of the adoption of the modern technologies.

The Districts demonstrate climatic conditions which may have been conducive for maize crop production. There was sufficient rainfall and the minimum and maximum temperatures were not too low or high to hinder maximize production in the Districts. However, both Districts indicate nutrient poor sandy soils, with extremely low P content levels, which may have limited the optimal production levels in the Provinces and perhaps the Districts as well (Figure 23). Due to insignificant changes in the annual maize crop yields and the climate over time, this may suggest that the farmers may have not experienced a significant increase or decrease in the amount of maize produced. As such, the farmers may have perceived the annual yields to be normal and may thus have not seen the necessity to adopt the technology when the yields are so small. The farmers in the Districts consume very large proportions of their produce. The retail maize price changes coincide with the season change. Immediately after harvest, the price of maize is low due to low demand suggesting that the availability of maize is high. During the non-harvest season, the retail price of maize increases due to a very high demand and limited availability of the crop. This may suggest that the farmers may be consuming less maize due to limited access to purchase the maize during the non-harvest seasons. As a result, they may not be consuming much maize during that season and may be reverting to other food types as a coping strategy to maintain a constant supply of food in order to maintain food security (Figure 23). This is therefore viewed as an easier survival strategy than to purchase the metal silo which cost a lot of money, hence the negative feedback in the model.

The main driver for the lack of adoption of the metal silo is finances. For the farmers in the Mecuburi District, the adoption of the metal silo decreases due to the limited loans made available to the farmers to purchase the technology on credit (Figure 23). In the Chiure District the probability to adopt the metal silo decreases as farmers purchase additional crops to those they have harvested and stored, by selling off-farm products in order to generate an income (Figure 23). These are the main financial factors, for the lack of adoption of the metal silos that have constrained the farmer in both Districts.

Chapter 5: Discussion

As outlined in the results section, there are several factors that need to be considered to understand the factors that influence maize production and the adoption of modern storage technologies in the Districts. The discussion will firstly elaborate on the relationship between the maize yields and the abiotic factors, such as soil conditions, rainfall and temperature. The consumption and storage patterns in response to the changes in the retail price of maize, the socio-economic factors that have influenced the adoption levels in each District will also be discussed. This will provide a comprehensive understanding of the system in the Districts.

5.1. Maize production in the Districts

The basic assumption in this study is that the yields in the Districts and the Provinces would be similar. There is no evidence to suggest that this is not the case given that the two Districts are in the same agro-ecological zone. The results show that there is little association between the annual maize yields and the abiotic factors in the study area. According to the most recent Mozambique Household Budget Survey in 2008/9, the average household maize production was 326 kg per annum. Households consumed 410 kg of maize each year, which is considerably more than what the smallholder farmers produce from a single harvest season (FAO, 2014). On average, 70% of the household expenditure is spent on food, thus proving that most of the households in rural Mozambique primarily produce maize to consume to maintain household food security (FAO, 2014). If the household production levels in the Districts are low, then low adoption levels of the modern storage technologies can be expected as farmers may have very little crop to store and may further not have the finances to purchase the modern technologies.

The average amount of maize that is produced in the Mecuburi District over the 15 years is 640 kg/annum, and in the Chiure District it is 480 kg/annum. In line with the Mozambique Household Budget Survey, the Districts produce more than enough maize for consumption, more so in the Mecuburi District. However, the average yields experienced in the Districts, as illustrated in Figure 11, do not account for the losses that the farmers experience post-harvest. According to the APHLIS data the highest food losses in Mozambique are experienced during field drying and on farm storage stages. This is due to poor post-harvest handling practices where farmers store their grain with high moisture content. It can therefore be stipulated that the farmers may have experienced the highest maize losses in those phases of the value chain due to the aforementioned reasons, ultimately leading to reduced maize available for consumption, despite the yields in the Districts (Figure 11).

Approximately 70% of the population in Mozambique resides in the rural areas, and they are mostly involved in agriculture (Chilonda *et al.*, 2011). These farmers contribute to the country's economic development as the agricultural sector contributes 25% toward the GDP (World Bank Group, 2016). The most consumed staple crop in the country is cassava followed by maize (Chilando *et al.*, 2011), however, data on cassava are almost impossible to acquire and that is why this study focused on maize. Based on the Food Security Monitoring Report by the Ministry of Agriculture, Mozambique experienced a reduction in the maize crop yields from 1990 - 2012 (FAO, 2014). The increase in production levels in the country is mainly attributed to land expansion and not necessarily to the quantity produced per hectare (Donovan and Tostoa, 2010). In the Nampula Province the farmers experienced a decrease in yields while in the Cabo Delgado Province the farmers experienced an increase in yields, which may also reflect on the yields experienced at the District level. The increase in yields may be attributed to the expansion of the total area cultivated in the Provinces and not necessarily the quantity produced. Although that may be the case, the changes in annual yields in the Provinces were not significant (Figure 11).

The agricultural systems in Mozambique are not as mechanized as those found in the developed countries within SSA. As such, a very large majority of smallholder farmers in Mozambique are involved in labour intensive, small-medium scale agriculture, which predominantly functions using manual labour (Moyo, 2016). Factors such as soil infertility and agro-ecological conditions often have an impact on production, especially when resources are limited.

5.2. Maize production and soil fertility

The types of soil in the Mecuburi and the Chiure Districts are characterized by sandy soils; with 18% clay and more than 68% sand (Bruand *et al.*, 2005). Young (1989) states that agricultural production in these soil types depends on the resources provided by the soils and the climate. The agricultural sector in developing countries such as Mozambique is dominated by smallholder farmers who rely on rainfall and provide very little to no inputs to the agricultural practices due to economic constraints, which is presumably the case for both Districts (Young, 1989). A national survey conducted by the Ministry of Agriculture revealed that less than 4% of the smallholder farmers in Mozambique could afford to purchase fertilizer (Donovan and Tostao, 2010). This raises concerns, as agricultural production is the main source of food and income for the poor and thus contributes tremendously toward household food security in the country. One of the main limitations in maize production in sandy tropical soils, such as those found in the Districts, is the low nutrient and organic carbon content (Young, 1989). It is not surprising that the soils have organic carbon material that is at 1.1% at most (Table 1), accounting for the low volumetric water content at field capacity as organic matter, through decomposition, not only acts as a source of plant nutrients but also improves soil structure (Oyedele and Aina, 2006). It can therefore be stipulated that the farmers in the Districts may have been unable to apply organic or inorganic fertilizer to their agricultural fields due to economic constraints.

Large areas across SSA are inherently infertile, and with limited fertilizer usage it is a challenge for smallholder farmers to maximize yields (Zingore *et al.*, 2008). The low CEC in the Districts can also be attributed to the low levels of organic carbon and clay content. An increase in the soil organic content increases the CEC and thus improves the physical properties of the soils, which in turn improves the soil fertility (Zingore *et al.,* 2008). Maize production responds positively to repeated applications of nitrogen (N) and phosphorus (P) from fertilizers (Zingore *et al.*, 2008). However, the Districts have extremely low levels of Nitrogen and Phosphorus which may be the primary limiting factor for the low production levels, which has that have caused farmers to purchase additional maize to that which they produce. Apart from using inorganic fertilizer, farmers who own livestock can apply cow manure, which also increases soil fertility. However, most of the farmers in the Districts do not own livestock and thus do not apply manure to fertilize their agricultural systems (Ministério da Administração Estatal, 2014).

The livestock production in Mozambique is still small and requires support in veterinary services for mainly foot-and-mouth disease, training, and extension and food safety control (Vernooij *et al*.2016). Beef production in Mozambique is mostly based on natural grazing, which makes the system vulnerable to climatic shocks such as floods and droughts (Vernooij *et al*., 2016).

An alternative method to limit the impacts of poor soil fertility on maize production, is to burn their fields at the end of the season to cultivate more easily as well as to increase the cation concentration, which would be found in the ash which reduces the pest and pathogen loads (Wikland, 2017). A few other conservation agricultural practices that may be adopted to improve soil fertility include no-till farming which prevents soil erosion. Mulch retention is another technique that could be applied to preserve soil fertility; it helps to retain water in the soils, as soils provide water reserves for crops (Andriesse and Giller, 2015). These agricultural practices may partially improve the soil fertility in the Districts, however, for significantly measurable increases in soil fertility; the farmers would need to apply fertilizers to their soils.

The occurrence of natural disasters, such as tropical cyclones and droughts which are exacerbated by climate change, reduce the availability of food and affect the livelihood of most of the smallholder farmers in the region (USAID, 2012). In such cases, farmers have had to resort to food aid, the next harvest, or sell crops in advance; wage-based work or they trade other goods and services in order to generate income to purchase additional food (Administration of Mozambique, 2012). The farmers in the Districts mentioned firewood and charcoal as products they sold in order to generate income in order to purchase additional food. Based on field observations, farmers use firewood for household domestic use such as cooking and warmth during the cold seasons. It was also observed that farmers made beds and chairs from the harvested wood; it was also used in the construction of their houses. This has resulted in extensive deforestation in the Districts, which consequently makes the soils vulnerable and susceptible to erosion, which is another mechanism responsible for the depletion of soil nutrients (Ministério da Administração Estatal, 2014). Water erosion can be the greatest limitation to maize production in SSA and for countries such as Mozambique, as 227 million hectares of soil in the region is affected by water erosion (Pennock *et al*., 2015). In January 2015, Mozambique experienced heavy rainfall which affected many parts of the Nampula and the Cabo Delgado Provinces, and other Provinces in northern Mozambique (ACAPS Briefing Note, 2017). About 100 000 individuals in the region were affected by the floods, while 20 000 were displaced and had to be relocated from their homes to places of shelter (ACAPS Briefing Note, 2017). The ecological impact associated with surface runoff due to flooding, is the removal of topsoil, which in turn may result in reduced soil fertility and maize production (Pennock *et al*., 2015). In that same year leading into 2016, SSA experienced one of the most severe droughts in history due to the El Nino effect. This reduced the smallholder farmers' production levels in Mozambique, mainly because their maize crop production is solely dependent on rainfall (Steward *et al*., 2018). The country had to import maize from South Africa to make up for the limited yields that year (FEWS NET, 2015). The occurrence of these natural disasters, in northern Mozambique, in recent years, has affected the soil fertility considerably. Due to the low yields, it would be unnecessary for farmers to adopt the modern storage technologies to store their grains.

5.3. Maize crop yields and climatic shocks

The regional climate projections reveal that the combined effect of climate change and population growth will most likely result in an increase in water scarcity (Cooper *et al*., 2008). Close to 90% of the agricultural production systems in Mozambique are small-scale and rain-fed, which has become highly variable over the years (Ministério da Administração Estatal, 2014). A study by Cooper and colleagues proves that there is a direct association between rainfall and production levels, therefore variability in rainfall patterns may result in highly variable production levels (Cooper *et al.*, 2008). Meaning, an increase in rainfall will increase the production levels, provided that the temperature and soil fertility support maize production and vice versa (Cooper *et al.*, 2008). If finer resolution data for rainfall were available, such as the seasonal or growth period data, it would have been possible to make direct correlations between the yields and rainfall in the Districts; in order to have more precise measures of the association between the variables. However, the annual rainfall in the Districts ranges between 800 mm – 2200 mm with some extreme events, and in order for a maize crop to grow it requires 450 mm – 600 mm of water per season (du Plessis, 2003). Although the annual rainfall experienced over the previous 30 years in both Districts may have been sufficient to support maize production for the most part, the variability in that rainfall was high and may have contributed toward the low production levels experienced by the farmers. This may have been further exacerbated by the low phosphorus content in the soils of the Districts, which is very crucial for the growth of crop and thus appears to be the other limiting factor in the production levels.

The projected 5% reduction in rainfall in SSA, particularly during the maize growing season, due to the impact of changing climate (Collier *et al.*, 2008), together with the predicted high temperatures, are expected to reduce water availability as it increases evapotranspiration (Steward *et al*., 2018). Increased plant transpiration increases plant water use which in turn reduces the available soil water for plants (Cairns *et al.*, 2013). Drought conditions have an extremely negative impact on the early stages of development, particularly the emergence of the tassel and the grain filling stage (Cairs *et al.*, 2012). Based on this study, it may be that the production levels were low due to the highly variable rainfall, which suggests that the Districts may have experienced prolonged dry, hot seasons, thus reducing the production levels. Many farmers in Mozambique do not have access to improved quality seeds that are resistant to droughts. The seedlings they have access to, that grow in high temperature soils, are most likely to fail, and thus reduce the farmers' agricultural output (Cairs *et al.*, 2012). A study by Cairs and colleagues (2013) revealed that each day with temperatures above 30°C, resulted in a 1% - 1.7% reduction in maize production under rain-fed and drought conditions, which may have been another contributing factor to the low yields in the Districts (Cairns *et al.*, 2013).

Average temperatures that are above 30°C, over a long period of time, may cause severe reductions in soil moisture (Cairs *et al.*, 2012). The average maximum temperature over the 30 years in the Chiure District was 31°C and 29°C in the Mecuburi District. This suggests that the maize crop production in the Chiure District experienced more stressful maximum temperature conditions compared to the Mecuburi District. This in addition to the very low phosphorus levels in the soils may account for the low average yields in the Provinces and subsequently the Districts as well (Figure 11).

5.4. Market dynamics

The availability of maize, particularly in domestic economies, often manifests itself in unstable maize prices. The majority of smallholder farmers in northern Mozambique have agricultural fields that are on average 0.9 hectares in size, which is very small (Donovan and Tostao, 2010). Households consume more of their agricultural production, which is usually insufficient to sustain them throughout the entire year (Anderson and Ahmed, 2016). Some of these farmers have thus adopted a pattern of specific periods in which they purchase additional maize in a year. When the price of maize is low, farmers retain their maize for consumption, but when the demand for maize increases and the price subsequently increases, they sell large proportions of their maize and revert to cassava as their staple (Donovan and Tostao, 2010). This highlights how maize is not only a food crop but has become a cash crop and may, to a limited degree, explain the maize price volatility between seasons in other Districts and Provinces. It is important to note that these patterns of purchasing maize do not reflect the behavior of the entire population group of farmers in northern Mozambique. The majority of smallholder farmers in one of the Districts had to purchase additional food to those they harvested for almost six months. This suggests that the farmers may have produced insufficient crop to sustain them throughout the year, thus making the adoption of modern technology less of a priority.

It is understood that several factors influence the supply and demand of maize within a certain area, in this regard, often the retail price changes are exaggerated as they only account for a small market of consumers; this is referred to as a thin market (Manda, 2010). In other words, the traded maize is a representation of a proportion of the total production and consumption (Manda, 2010). A study revealed that there was unequal participation of smallholder farmers in markets in Malawi (Manda, 2010). Certain rural population groups consumed all the staple maize they produced, which is most likely the dominant group present in the Districts; other farmers purchased and sold grain within an agricultural year and other farmer groups were found to not purchase additional grains at all. For the latter group, it is suggested that they produce enough grain to sustain them throughout the agricultural year. One other possible explanation for the latter group could be that the farmers have a supplementary intake of carbohydrates from cassava, which is the primary staple crop in the country (Manda, 2010). The classification of the different types of smallholder farmer groups involved in the markets provides insight into the adaptation strategies that have been employed to remain food secure by small-medium scale farmers in other Districts and Provinces (Donovan and Tastao, 2010). These different farmer groups may also be present in the two Provinces; however, the Districts mainly consist of farmers who experience low yields and consume all of their produce. Farmers with large agricultural fields are less active in off-farm income generating work activities, because they produce enough crops for consumption and sale (Manda, 2010; Jayne *et al.*, 2003). The opposite holds for farmers with smaller agricultural fields. Therefore, within these small-scale agricultural systems, the different farm sizes create instability in retail prices, due to variations in the amount of maize available for sale (Manda, 2010). Households with smaller agricultural fields are more vulnerable and prone to experiencing the greatest shock when food prices peak during the non-harvest season (Mghenyi *et al.*, 2011). These households may then reduce their dietary options in order to maintain a constant supply of staples during the non-harvest seasons (Anderson and Ahmed, 2016). As aforementioned, the farmers may revert to eating cassava as an alternative staple to maize, which is perhaps a better coping strategy than to purchase modern storage technology (Donovan and Tostao, 2010). This may possibly explain the low adoption in the Districts.

5.5. Adoption of modern technology

Following the successful dissemination of the hermetic bag and metal silo in Central America through the Postcosecha project, several initiatives and projects have promoted the use of the technologies in African countries (Jones *et al.*, 2011; Baoua *et al.*, 2013; Moussa *et al.*, 2012; Tefera *et al.*, 2011; Gitonga *et al.*, 2013). Both technologies are effective because they create anaerobic conditions which prevent the increase in pest populations once the grains have been stored (Baoua *et al.*, 2014). The hermetic bag is relatively more affordable than the metal silo; it has a lifespan of about 2 years before it can be replaced (Chisvo and Jaka, 2017). In Mozambique it would cost a farmer roughly US$ 5 to purchase and install a 50 kg bag (Chisvo and Jaka, 2017).

The hermetic bag is therefore expected to have a higher adoption level compared to the metal silo, in both Districts, however, that was not the case. In the single year in which data were collected by Helvetas, the adoption of the hermetic bag was lower compared to the metal silo (Figure 20 and Figure 21). Furthermore, the data collected from the survey interviews also reveals a lower adoption of the hermetic bag (Figure 22). However, conclusions cannot be made about which technology had the highest adoption level due to the one year in which data were collected for the hermetic bag, by Helvetas. The farmers in Mozambique are required to purchase the bags at a higher cost, due to the 30% tax the government charges the farmers to import the material used to make the technology (Chisvo and Jaka., 2017); this will constrain the rate of adoption.

This is an illustration of how the country's government is not as engaged as in Central America, despite the effectiveness of the technology in preserving grain for long. The metal silo has a lifespan of about 20 years before it has to be replaced, which is far longer than the hermetic bag (Chisvo and Jaka., 2017). Just like the hermetic bag, it also creates anaerobic conditions which prevent pests from entering the container (Gitonga *et al.*, 2013). Based on the Cost Benefit Analysis Report by FANRPAN, for a 300 kg silo tank, it would cost a farmer approximately US$ 40 to purchase and install the technology (Chisvo and Jaka, 2017). The farmers would further be required to pay an additional US$ 0.3 for the Phostoxin, a pest control tablet that is applied once the grain is stored in the technology (Chisvo and Jaka, 2017). The metal silo is manufactured and produced in the country by local private companies such as Coosen, which has been working in close collaboration with FANRPAN since the beginning of the PHM project in 2013 (Chisvo and Jaka, 2017). However, since the introduction of the technology, there are still very few farmers who use the metal silo, in the Districts, but continue to use traditional storage technologies, more so in the Chiure District (Figure 22). The cost to purchase, install and maintain the metal silo might be an expense that most farmers cannot afford, due to other household demands.

5.6. Extension services personnel and their influence on adoption

SSA is predominantly rural and the dissemination of information regarding new agricultural technology can be a difficult task (Altalb *et al.*, 2015). A study in Nigeria revealed that smallholder farmers may have demonstrated very little interest in the adoption of the modern agricultural technology that was being introduced, due to the limited interaction that the farmers had with the extension services personnel (Elemasho *et al.*, 2017). These services play an important role in spreading information about new technologies. The extension services personnel are responsible for persuading the farmers into adopting the technologies, by presenting the technologies as a much better alternative compared to traditional technologies (Elemasho *et al.*, 2017). Therefore, special attention should be given to the methods adopted in transferring information from the research to the farmers. There were very few promotional activities in the Districts in the first few years of the project and they only began to increase mid-way into the PHM project (Table 8). It was also noticed that the years in which the promotional activities increased so did the adoption of the metal silo

(Figure 20, Figure 21 and Table 8). Therefore, this may suggest a positive association between the promotion of the technology and adoption. There are several methods that have been adopted to transfer information regarding new technologies. One approach involves radio broadcasts or SMSs, which is a medium of communication that reaches a large portion of the population of any given area. These media were used extensively in the Districts. One other effective method of promoting modern technology use, involves physical demonstrations of how these technologies can and should be used if a farmer were to adopt one. This may be in the form of a skit, where farmers within a selected area render a performance that is aligned with the promotion of modern storage technology use. It was through this approach that the farming practises of farmers in Uganda changed (Manda, 1998). These skits or short drama performances provide the farmers with a broader point of view that demonstrates the interaction between several factors that influence their livelihoods (Munro, 1998). The likelihood of the success of this method of promotion work in the Mecuburi and the Chiure Districts or other countries is high. During the focus weeks, members of the Farmers' Association Group, in the Districts, performed a skit to illustrate the use of the modern technology. This plays an important role in persuading the rest of the farmers in the communities to consider the adoption of the technology. Within the context of modern technology adoption, it shows the farmers the potential benefits that can be gained from using modern storage technology.

In an informal conversation with one of the government representatives from the Mecuburi District it became apparent that, extension services personnel are sent throughout the Districts to host workshops before every harvest season. It is in these gatherings that the extension services personnel demonstrate and promote the use of the hermetic bag and metal silo. These involve handling practices the farmers have to take note of before storing their grain in the technologies, i.e. how the grain needs to be left to dry before transferring into the storage container. There are also demonstration fields in the respective Districts where they display the technologies for the farmers (Richardson, 2003). The extension services personnel use the demonstration fields in the learning process by providing visual material of how the technologies are effective and beneficial for the farmers (Richardson, 2003). In order to have an effective promotion project, there needs to be a work force. If the PHM project was able to train promoters and technicians that would help to promote the adoption of the technology as well as to construct the technology, then more engagement with the farmers in the District would be expected. This may have resulted in an increase in the adoption of the technologies. The trained technicians and promotors in the Districts may have been insufficient and bearing in mind that the promotion only intensified much later in the years of the project, it is no surprise that the adoption level is so low. Another way to increase adoption levels would involve, identifying the limiting factors to production, this will increase yields drastically thus making the purchase of the modern technology feasible. Alternatively, farmers could store their grain in a large centralized storage facility for a small fee.

5.8. Main drivers of adoption

One of the fundamental objectives of the study was to identify the main factors, whether social or economic, that have influenced farmers to adopt or not adopt the hermetic bag or metal silo. The farmers expressed that the modern technologies store grains for longer periods compared to the traditional technologies. Despite the extremely low adoption levels, one of the greatest benefits farmers have gained from using the metal silo is the increased amount of grain that is made available for family consumption. This supports the socio-economic state of the Districts, as households consume large amounts of their produce and have very little to sell. This suggests that the farmers may have experienced a distinct improvement in the quality and quantity of grain stored in the technology, thus contributing towards household food security.

It was interesting to note how the farmers in the Chiure District expressed the importance of the protection of stored grains from pests which results in prolonged storage, as the main benefit gained from using the adopted modern technology. It is no surprise, however that the farmers express this sentiment as the vast majority of the farmers in this District continued to use the traditional storage technology, which does not preserve grains for long (Figure 20, Figure 21 and Figure 22). The infestation of pests in grains that are stored in traditional technologies may be attributed to the material used to construct the technologies. The *celeiro* and *thethera*, which are the commonly used traditional technologies in the District, are made from reeds, mud and straw. These are materials that not only provide habitat for pests, but they also expose grain to pests and microbial toxins as they do not create the anaerobic conditions required to prevent pest or fungal infestation. This then leads to the rapid deterioration of the stored grains, which explains the reduction in stored maize seen by the farmers in the Chiure District (Table 3). This may have forced the farmers to purchase additional maize to that which they produced, which consequently may have been the primary reason for the reduced likelihood of more farmers adopting the metal silo, hence the low adoption (Table 9 and Figure 23).

Many farmers do not have available cash to purchase the technologies, it is noticed that most of the farmers have resorted to purchasing the technology on credit, particularly in the Mecuburi District (Table 5). However, the problem with the credit system in the Mecuburi District is that farmers are unable to pay back the money, which then cripples the system by not allowing more farmers to be able to purchase the metal silo on credit. This may have caused a very low adoption of the metal silo by the farmers in the District (Table 9 and Figure 23).

5.9. Conclusion

To understand the reason for the low adoption levels, the study has identified the impact of the abiotic factors on maize production from a very broad viewpoint, and how that may have influenced adoption. Furthermore, the patterns in the market dynamics have been identified to understand the consumption and purchase patterns of the farmers in the Districts and how those may have affected adoption levels. Lastly, the confounding socio-economic factors that have influenced the adoption of the modern technologies, particularly the metal silo, in the Districts have also been identified and thus provide insight into the shortfalls in the system.

Based on the findings from the study, the annual maize yields in the Provinces did not demonstrate any significant changes over time and may suggest the same for the Mecuburi and the Chiure Districts. The rainfall and temperature have also shown insignificant changes over the years. However, the soil conditions, in both Districts, indicate nutrient poor soils, to which little to no fertilizer is applied by the farmers. As such, farmers may perceive the annual yields as normal, where they produced enough maize for consumption, and perhaps had very little maize to sell during the lean season. This may therefore suggest that the farmers may have found it unnecessary to adopt either of the modern technologies. It was noticed that maize price volatility coincides with the different seasons, in that immediately after the harvest season; the price of maize was low due to low demand, and during the non-harvest season the price increased, due to high demand. This may provide some insight into the consumption and purchase patterns that farmers in other the Districts or Provinces have adopted to ensure that they remain food secure. Given that maize may not only be a staple but may also be a cash crop, the seasonal changes in the maize price may have limited access to purchase the maize for the smallholder farmers in the Districts. Instead of reverting to the consumption of cassava as a staple during the non-harvest season for economic gain, the farmers in the Districts may have done so to remain food secure. The changes in maize price may have reduced access to purchase maize for smallholder farmers who consume most, if not all of their produce within the first three months after harvest. This indicates that the majority of the farmers could not produce sufficient crop to sustain them during the non-harvest season.

The Districts had very few farmers who adopted the modern technology and plenty who continued to use the traditional technologies. Both farmer groups had to purchase additional maize to that which they harvested, which suggests that adoption of the modern technology may have not provided the economic gain which was expected. The additional confounding factor that hindered the adoption of the technology in both Districts is the lack of finances by the farmers. This study reveals that the farmers experienced insufficient yields and not food losses.

The recommendation to improve the adoption of the modern technologies would be to provide subsidies and create more sustainable credit systems that will allow the farmers to purchase the technology at more affordable prices. Farmers further need to be assisted with fertilizer, as the soils are in poor condition for maximized maize production. Alternatively, livestock production may be introduced to create fertilizer for the soils as well as contribute toward nutrition security. This therefore calls for policy changes that should encourage more funding into the agricultural systems in the Districts to help in this regard. If the cost to purchase the silo is reduced and the farmers are provided with fertilizer to increase their production levels, then more farmers would be able to store enough maize for consumption and to sell during the non-harvest season at higher prices. This will create an enabling environment for the farmers to not only maintain food security, but also contribute toward the economic development of the Districts, and perhaps the Provinces at large.

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Appendix
Farmer questionnaire

Farmer response to the interaction of the key determinants of adoption in Chiure and Micuburi district

Household Characteristics

1. How many members are there in your household? ____________________

2. What is your position in the household?

Head of the Household	Husband or Wife	Son	Daughter	Other Family

3. Please indicate your age bracket.

18-20 years	20-29 years	30-39 years	40-49 years	50 and above

4. What is your gender?

Male: ☐ Female: ☐

5. When did you finish your last year of school?

Primary school	Secondary school	Tertiary school	Other	None

6. How many years have you been farming for? ____________________
7. What other type of activity work do you work in?

Trade at the market place	Employed in the city	Do other work in agriculture	Housework	Other (specify)

8. Which of the following storage containers do you use to store your grains?

Super bag (hermetic bag)	Metal Silo (tank)	Other (Specify)

9. How many years have you been using it for? ____________________

10. Which type of crop do you store in this specific storage container?

Cowpeas ☐ Maize ☐ Cereals ☐ Pulses ☐

- Other (specify)____________________

11. Did you have to buy any of the food crops (listed above) to feed for your family, in addition to the food crop you produced on your farm?

Yes ☐ No ☐

12. For how many months did you have to buy?

1-2 months	3-4months	5 months

13. If you had to buy more food crops, with what money did you buy?

Money obtained from the farm?	money gotten from out of the farm	Loan	Other (specify)

14. What was the main reason that made you chose this specific storage container? (choose one)
   - To sell grains at better prices in the non-harvest season. ☐
   - You had nowhere else to store grains ☐
   - It stores grains for a long time without rotting ☐
   - Affordable ☐
   - You heard about the advantages from another farmer ☐

15. Who decided to use this specific storage technology container?

Husband	Wife	Son	Daughter	Both husband and wife	Other

16. What is the main advantage that you experience from using this storage technology? (choose one)
   - It prevents the grain from rotting ☐
   - More grain becomes available for the family ☐
   - You are able to sell grains at better prices during the non-harvest season ☐
   - The house is more clean and more space is available ☐

- Other (specify) ______________________________

17. Have you seen an increase or a decrease in the amount of maize or beans you could store in the container?

   Increase ☐ Decrease ☐

18. Have the living conditions of your living family changed in the last 4 years

Yes ☐ No ☐

19. If yes, how have they changed?

	1	**2**	**3**	**4**	**5**
Less amount of the harvest gets rotten					
The family income has increased					
You have been able to harvest more beans or maize					
You are able to sell and store better quality of beans and maize					
Other (specify)					

20. How did you get the storage technology?

Borrowed money to buy the container	You paid in full (cash) to buy the container	You made it yourself	Other (specify)

21. Through whom did you know about the metal silo or hermetic bag?

NGOs	Farmer Union Group	Private companies	Government	Media (radio,sms)	Other (specify)

Ethics certificate

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Thobejane

CLEARANCE CERTIFICATE	PROTOCOL NUMBER: H17/09/41
PROJECT TITLE	An evaluation of the adoption of modern technologies in the reduction of post-harvest losses by smallholder farmers in Mozambique
INVESTIGATOR(S)	Miss P Thobejane
SCHOOL/DEPARTMENT	Animal, Plant and Environmental Science/
DATE CONSIDERED	15 September 2017
DECISION OF THE COMMITTEE	Approved
EXPIRY DATE	16 October 2020

DATE 17 October 2017 CHAIRPERSON (Professor J Knight)

cc: Supervisor : Professor M Scholes

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature

17 / 10 / 2017
Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES