INVESTIGATION OF GRAIN POSTHARVEST TECHNOLOGIES AND SYSTEMS FOR MANAGING CLIMATE-RELATED RISKS IN SMALLHOLDER FARMS OF SHIRE VALLEY, SOUTHERN MALAWI

By

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A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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December 2020

DECLARATION

The author, Charles Diverson Singano, hereby declares that this thesis contains original research work that he conducted and that the document has not been submitted to any other University for a degree.

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DEDICATION

This thesis is dedicated to my three children; Cassim, Raheem and Rafeek, my wife Veroster, my parents Mr and Mrs Singano, my brothers (Peter, Martin, Richard, Frank, Vincent and Phellow) and sisters (Gladys, Joyce and Brenda), and the Maneya family members (the late Dimusa, mother-in-law, Macfield, Blessings, Flora, Ian, Beauty, Sam and Christopher).

ABSTRACT

The world's climate is changing. Increasing temperatures and incidence of dry spells and droughts are projected to continue into the next century. These factors will negatively affect household (HH) food security, crop production and pest problems, including storage insect pests and the performance of storage technologies. A study to evaluate maize postharvest management options was conducted to help farmers strengthen the climate-resilience of their HH food security strategies. The work began with a survey using structured and semi-structured questionnaires and checklists to learn about the postharvest systems and climate-related experiences of farming HHs in Shire Valley, southern Malawi. The results showed that food insecurity in Shire-Valley was perceived to have increased in the last 10-20 years due to crop failure, and most HHs (~65 %) thought the mean ambient temperature had increased during that period. Many respondents (~42.9 %) reported an increased usage of synthetic pesticides compared to 10-20 years ago due to a perceived increase in insect pest pressure. These findings emphasised the need for urgent implementation of increased awareness-raising and training in improved postharvest management in the face of global-warming. Following the survey, farmer-managed participatory trials were conducted comparing existing and newly-introduced storage technologies over a 32 week period in two consecutive seasons. The seven treatments were Neem leaf powder (NM), Actellic Super dust (ASD), ZeroFly® storage bag (ZFB), Purdue Improved Crop Storage bag (PICS), Super Grain Bag (SGB), metal silo (MS) and untreated grain in a polypropylene bag (PP). The trials showed that the storage technology choice and duration significantly affected the level of insect grain damage and the number of insect pests, and that the level of pest attack can differ significantly between seasons. Hermetic bags (PICS, SGB) kept storage insect infestation low for up to 32 weeks, and were more effective than the ASD, NM, or PP. The study recommended the use of PICS and SGB for long-term grain storage. To examine the effect of higher ambient temperatures on the efficacy of maize grain storage protectants and facilities, two laboratory trials were conducted. Experiment I compared five grain protectants [Actellic Gold dust (AGD), Shumba Super dusts (SSD), Wivokil Super dust (WSD), NM and wood ash (WA)] admixed with maize, while experiment II assessed four facilities (PICS, SGB, MS and PP) using untreated maize. Both experiments ran for 12 weeks using climate chambers set at 32 $^{\circ}$C and 38 $^{\circ}$C, and mean ambient temperature (26 $^{\circ}$C). Significantly higher grain damage and weight loss occurred in the non-synthetic (NM, WA) than synthetic protectants (AGD, SSD, WSD) at all experimental conditions. The hermetic containers (PICS, SGB, MS) kept mean insect grain damage below 6.4% compared to 24.5% in the untreated control at all the experimental conditions. These findings imply that the efficacy of synthetic grain storage protectants and hermetic storage containers may not be negatively affected by warmer temperatures (32 $^{\circ}$C or 38 $^{\circ}$C). Warehouse receipt systems (WRS) and community grain banks (CGB) are being promoted in SSA to reduce grain storage losses and improve market access and food security. However, no information on their potential as adaptation strategies in climate change (CC) prone areas existed. Interviews with WRS and CGB managers and beneficiaries, and rapid loss assessment methods were used to learn about the systems and analyse grain weight loss during a 24-week period. Grain deposits ranged from 0.1 and 15 mt per depositor, and quantities of maize produced and deposited were correlated. Weight loss of maize and pigeon peas in WRSs were less than 4.6 % and 9 % respectively. In conclusion, food insecurity has increased in Shire Valley, mainly contributed by climate change. The PICS and SGB are recommended for use by farmers for grain storage in Shire Valley including SSA. Results suggest farmers can continue to use SGB, PICS and MS, or AGD, SSD and WSD for stored maize protection as temperatures increase in CC-prone areas. The WRSs and CGBs could act as grain reserves for use during climate-related events and play a role in the distribution of emergency relief food to the affected HHs.

ACKNOWLEDGEMENTS

The study is an output of the project "Supporting smallholder farmers in southern Africa to better manage climate-related risks to crop production and postharvest handling" funded by the European Union (EU) through the contribution agreement DCI-Food/2012/304-807, coordinated by the Food and Agriculture Organization (FAO) of the United Nations. My sincere gratitude goes to Prof. Brighton Mvumi and Dr. Tanya Stathers for offering me this PhD study opportunity and being my supervisors. I really thank them for providing their time out of their busy schedules. They had to listen, provide guidance and corrected my mistakes to make this a reality.

My profound gratitude goes to all Crop Storage staff at Chitedze Agricultural Research Station for providing support during the setting up of the on-station and on-farm trials, and analyses of samples collected from Shire Valley. These include Technical Officers (Emmie Butao and Cecilia Mumba) and Research Attendants (George Dickson, Grace Dokotala, Penya Langisoni, Visesio Phiri, Doreen Genasi and William Kananji). Let me also acknowledge the crucial contribution from the agricultural extension staff from Chikwawa and Thyolo districts, Shire Valley Agricultural Development Division, farmers and all the stakeholders who participated in this work for their time, interest and information sharing.

I appreciate the role played by Prof. Casper Nyamukondiwa and his team (Dr. Honest Machekano, Nonofo Gotcha, Vimbai Tarusikirwa, Buxton Mmabaledi and Dr. Reyard Mutamiswa) of the Entomology laboratory at Botswana International University of Science and Technology (BIUST) during the laboratory trials. Furthermore, thanks go to the Zimbabwe Postharvest Research Team (Alex Chigovera, Macdonald Mubayiwa, Shaw Mlambo and Tinashe Nyabako) for their morale support and an expose of the Zimbabwean smallholder crop postharvest systems during my stay in Zimbabwe. May Allah bless and reward you for all the time you spared for me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONMYS AND ABBREVIATIONS

ACE	Agricultural Commodity Exchange
ADC	Area Development Committee
ADMARC	Agricultural Development and Marketing Corporation
ADMO	Assistant Disaster Management Officer
AEDC	Agricultural Extension Development Coordinator
AEDO	Agricultural Extension Development Officer
AGD	Actellic Gold Dust
APHLIS	African Postharvest Loss Information System
ASD	Actellic Super Dust
BIUST	Botswana International University of Science and Technology
CARD	Church Aid in Relief and Development
CARS	Chitedze Agricultural Research Station
CC	Climate Change
CGB	Community Grain Bank
DADO	District Agricultural Development Office
DAES	Department of Agricultural Extension Services
DAPP	Development Aid from People to People
DC	District Council
DCO	District Crops Officer
DFO	District Forestry Officer
DLO	District Livestock Officer
DPD	Director of Planning& Development
EAM	Evangelical Association of Malawi
EDO	Environmental District Officer

EPA	Extension Planning Area
FGD	Focus Group Discussion
FISP	Farm Input Subsidy Programme
GLM	General Linear Model
GoM	Government of Malawi
HDPE	High-Density PolyEthylene
HH	Household
IRLADP	Irrigation, Rural Livelihood and Agricultural Development Project
LGB	Larger Grain Borer
LRCO	Land Resources and Conservation Officer
MBC	Malawi Broadcasting Corporation
NGO	Non-Governmental Organisation
NM	Neem
PHL	Postharvest Losses
PHM	Postharvest Management
PICS	Purdue Improved Crop Storage
PP	Polypropylene
RH	Relative Humidity
SGB	Super Grain Bag
SSA	Sub-Saharan Africa
SSD	Shumba Super Dust
UNDP	United Nations Development Programme
WA	Wood Ash
WFP	World Food Programme

WRS	Warehouse Receipt System
WSD	Wivokil Super Dust
ZFB	ZeroFly® Bag

CHAPTER 1: INTRODUCTION

1.1 Background

Across sub-Saharan Africa (SSA), maize, *Zea mays* is mainly stored on-farm and plays a vital role in ensuring food security among communities throughout the year. However, the increasing variability in climatic conditions has serious implications for both food production and poverty (Parry *et al.,* 2004). The environmental factors such as changing climatic conditions will have effects on crop yields. However, the development, reproduction and survival of pests and diseases, including storage insect pests, are likely to be affected indirectly by the environmental factors (Bale *et al.*, 2002).

Global warming is expected to result in the faster development of the immature stages of insects, shortening the length of these stages and leading to the earlier emergence of adult insects, resulting in a faster build-up of pest populations (Roy and Sparks, 2000; Stefanescu *et al*., 2003). Additionally, global warming is expected to lead to changes in the geographical range of some pest species, including insects. Some insect species dominant in tropical regions, may migrate to more temperate regions leading to greater damage of crops such as cereals (Sharma, 2014). Furthermore, global warming will affect the efficacy of some existing pest control measures such as changes in insect–host plant–natural enemy interactions, extinction of pest species, changes in relative abundance and effectiveness of biocontrol agents, and reduced efficacy of different components of insect-pest management (Furlong and Zalucki, 2017; Machekano *et al*., 2018).

Such changes are likely to have implications for crop protection globally, and especially in developing countries such as Malawi (Sharma, 2014). Worldwide, about 10,000 species of insects cause an estimated annual crop loss of 13.6% (Chijioke *et al*., 2011). The increased incidence of insect pests and reduced crop diversity (Sharma, 2014), together with the reduced efficacy of existing crop protection methods resulting from global warming are expected to result in greater crop losses and difficult to predict crop harvests.

Chikwawa district in Shire Valley of Malawi, is viewed as one of the most vulnerable areas to climate change (CC) in Malawi. This perceived high vulnerability led to its selection as the focal site for these studies. Projections suggest the temperature in Chikwawa will have increased by $3^{o}C$ by the year 2065, with monthly mean temperature predicted to be above $32^{o}C$, and drier conditions expected to prevail (Matiya *et al*., 2011). Global climate global models of future (2011 to 2100) rainfall showed a decrease in average monthly rainfall during December and January, and an increase during the months of February, March, and April (Stevens and Madani, 2016). However, the rain day frequency is expected to decrease while dry periods are expected to increase (Stevens and Madani, 2016).

The increased incidence of droughts and floods in Malawi is already heightening the vulnerability of many rural farming households (HHs) causing them to become trapped in a cycle of poverty (Jayanthi *et al*., 2013). This situation is exacerbated by many factors including, the occurrence of the devastating maize storage insect pest, the larger grain borer (LGB), *Prostephanus truncatus* Horn. (Coleoptera: Bostrichidae), which was accidentally introduced to East Africa into the late 1970s from Central America and Mexico (Hodges, 1994). In SSA, postharvest losses of staple food crops such as maize are estimated to be between 20–30% (Babangida and Yong, 2011). Biological organisms, as well as the physical and environmental conditions are some of the major causes of maize postharvest losses (Hell and Mutegi, 2011; Tefera *et al.*, 2011). In the 1980s, prior to the introduction of *P. truncatus*, Malawian farmers typically experienced estimated maize weight losses of up to 3.5% within a nine month storage period due to insect pests, mainly the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) (Tyler and Boxall, 1984). Currently, the estimated damage of maize grain during storage is around 21% under smallholder farmer conditions (Ambler *et al*., 2018).

Increase or decrease in temperature and relative humidity (RH) influence the duration of insect development either positively or negatively. Global warming is likely to affect populations of stored product insect pests, including the devastating *P. truncatus* (Dong *et al*., 2013). In laboratory studies, the duration of *P. truncatus* eggs, larval and pupal-to-adult stages decreased as temperatures increased from 27^{o}C up to 31^{o}C at a RH range of 50-80%, with the highest increase occurring at a temperature of 35^{o}C (Kučerová and Stejskal, 2008). The resultant increased insect pest populations will exacerbate maize storage losses if the grain is inadequately protected from such pests.

In much of SSA, during the 1990s, grain was traditionally stored in outdoor storage structures, such as mudded and woven-granary baskets or woven-polypropylene bags following treatment with botanical or synthetic chemical pesticides (Tefera, 2012). More recently significant resources and attention have focused on promoting modern hermetic storage facilities for smallholder farmer use, such as small metal silos, Super Grain bags and Purdue Improved Crop Storage (PICS) bags (Tefera, 2012; Kimenju *et al*., 2016).

Freshly harvested grain need to be dried to reduce bio-deterioration during storage. Most smallholder farmers in Africa rely on sun-drying to ensure that their grains are well-dried prior to storage. Weather, particularly rainfall, is a key issue during and after harvest, and affects the grain moisture content. When unfavourable weather conditions occur, grain is prevented from drying sufficiently and higher postharvest losses can result. Climate change may result in more unstable and unpredictable weather, including damper or cloudier conditions, which may lead to increases in postharvest losses (PHLs) (Tefera, 2012; Stathers *et al*., 2013).

The pre-dominantly agricultural and natural resource-dependent livelihoods of rural populations in developing countries, including SSA, are expected to be heavily affected by climate change (CC) (Adger *et al.*, 2003; Serdeczny *et al*., 2017). Despite the application of different managing strategies of CC, many countries in SSA will continue to suffer from the impacts of CC and Malawi is categorised as high risk for natural disasters (Brooks and Adger, 2003). Meteorological data reported that the Shire Valley of Malawi received 500 to 700 mm of rain annually during the period from 1990 to 1995 (Mijoni and Izadkhah, 2009), which was the lowest annual amounts of rainfall received since 1971. An assessment report indicated that over 2.8 million people in Malawi were likely to be food insecure during the 2016 food scarcity period possibly between October 2015 and March 2016 (Gelli *et al.,* 2017).

In the Shire Valley of southern Malawi, many communities live and farm on flood plains and hill-side slopes, often suffering from both drought and flooding in the same year. Droughts have increased in frequency and severity in SSA since 2000, including in Malawi (World Bank, 2011). This increased incidence of droughts and floods in Malawi has amplified the vulnerability of many rural farming households (HHs), now trapped in a vicious cycle of poverty (Jayanthi *et al.*, 2013). The additional rapid increase in population has led to the decrease in land availability for crop production and about 36% of Malawi's total human population is estimated to be chronically food insecure (Benson *et al*., 2005). Prolonged periods of devastating drought, such as the one which occurred in the 2001/2002 growing season, result in a drop in maize production. The 2001/2002 drought led to only 1.4 million tonnes of maize being produced, which was insufficient to meet the national annual requirement of 2 million tonnes (Magombo *et al.*, 2006; Potts and Wiley, 2006).

Estimates suggest the negative impacts of CC will cost Malawi about USD 610 million per annum from 2007 to 2050 (Arndt *et al*., 2014). Yield reductions predicted to occur in major staple crops will pose particular threats to smallholder farmers and nations already facing food insecurity (Arndt *et al.*, 2014). Low crop productivity, low adaptive capacity and limited financial access combined with high population growth are major contributory factors to food insecurity among rural smallholder farming households (Parry *et al.*, 2004; APHLIS, 2014). Malawi is vulnerable to many climate-related risks, such as frequent and prolonged dry spells, droughts, floods and high temperatures. The CC projections suggest a mean annual yield decrease of 2% for maize production in Malawi until 2050 (Arndt *et al.*, 2014).

The communities in the Shire Valley use the existing CC adaptation strategies that include the growing of early-maturing and drought-resistant crop varieties, the use of irrigation, sales of assets, winter cropping and crop diversification (Matiya *et al*., 2011). The inclusion of more integrated local adaptation strategies in adaptation policies could increase local resilience to CC in Africa (Stringer *et al.*, 2009a). However, most existing adaptation policies do not include strategies for the reduction of postharvest losses (PHLs). Good postharvest management (PHM) practices such as the use of modern storage facilities, drying grain to the recommended moisture content for safe storage and grain treatment with synthetic pesticides by smallholder farmers can be key aspects of CC adaptation strategies (Stathers *et al.*, 2013). Literature on the existing knowledge, skills or technologies for adapting to climate-related risks in Shire Valley is scarce, and particularly so for crop postharvest aspects (Mijoni and Izadkhah, 2009).

Collective grain storage are mainly used for crop grain storage for marketing and/or consumption, and this has a high probability of becoming successful in complementing agricultural intensification. Collective grain storage systems involve the putting together of large quantities of commodities for commercial buyers or communities, and these include warehouse receipt systems (WRSs) and community grain banks (CGBs) (Coulter, 2007). In Tanzania, cooperative unions were significant players in the coffee sector where donors funded the construction of storage structures under the Rural Structures Programme aimed at storage of surplus production by the communities. However, farmers preferred to store their surplus grain at their homes rather than these stores, as a result they remained empty and underutilized (Coulter and Schneider, 2004). It is important to reconsider the use of WRSs and CGBs in the light of recurrent droughts in Malawi and the rest of southern Africa.

The current studies were conducted to understand:

(1) smallholder farmers' pre- and postharvest maize practices and constraints;

(2) farmers' and other agricultural stakeholders' experiences of CC;

(3) existing and proposed adaptation strategies;

(4) the effects of increasing temperatures on the efficacy of storage insect pest management technologies;

(5) the efficacy of existing and new innovations for smallholder crop postharvest loss reduction as adaptation strategies to climate-related risks;
(6) the potential role of WRSs or CGBs in helping communities cope with and adapt to the impacts of climate change.

The study of these different aspects of smallholder maize postharvest systems aimed to provide information to agricultural stakeholders for assisting farming communities in Shire Valley to strengthen the climate-resilience of their postharvest systems and help improve their food and nutrition security.

1.2 Problem statement and justification

Climate change risks, such as more frequent and prolonged dry spells, droughts, floods and higher temperatures, have negatively affected the livelihoods of many smallholder farming households (HHs) resulting in increased food insecurity in the Shire Valley of Southern Malawi. The expectation is that climate change, particularly higher temperatures, will affect the development of some storage insect pests like *P. truncatus* and *Sitophilus zeamais*. Furthermore, global warming is also likely to increase the rate of crop storage pesticide degradation and negatively affect the performance of storage technologies such as hermetic bags. Presently, there is no evidence of whether warehouse receipt systems (WRS) and community grain banks (CGB) can play a role in improving food security within communities affected by climate change in some parts of Malawi, such as the Shire Valley.

Significant quantities of food are lost during storage due to many factors including damage by storage pests. One of the studies estimates that farmers in Malawi lose a total of 21% of their maize during storage (Ambler *et al*., 2018). The African Postharvest Loss Information System

(APHLIS) estimates a 10-year average postharvest loss of 19.7% equivalent to 450,166 tonnes, valued at over US$148 million and enough to feed over 1.8 million people for a year (APHLIS, 2019).

1.3 Hypotheses

The study hypothesised that:

1) The use of existing local postharvest management options result in higher grain losses, compared to when newly-introduced postharvest management options are used.
2) Increase in ambient temperature negatively affects the development of insect pests of stored-maize grain under existing and new postharvest management options leading to increased storage losses.
3) Collective grain storage options, such as warehouse receipt systems and community grain banks are adaptation strategies that help buffer smallholder farmers against food insecurity resulting from droughts, floods and increased pest activity.

1.4 Objectives

The specific objectives of the study were to:

1) Identify and evaluate existing and new innovations for managing maize postharvest losses from insect pests.
2) Evaluate the effect of increasing ambient temperature on the efficacy of existing and new stored maize pest management technologies.
3) Assess the technical and institutional performance of the warehouse receipt system and community grain banks as adaptive strategies for managing maize postharvest losses in the face of increasing climate-related shocks.

1.5 Thesis structure

The thesis is broken down into eight chapters. Chapter 1 introduces the study covering the background, problem statement and justification, the hypotheses, the objectives and thesis structure. Chapter 2 comprises the literature review on climate change risks and impacts in Malawi, climate change projections and economic implications, effects of climate change on the human population, adaptation to climate change in Malawi, maize postharvest losses and loss reduction strategies, existing and new smallholder grain storage facilities. Chapter 3 describes the **s**ites and procedures used to identify participants for the profiling study, on-farm hosting farmers and participants to the study on warehouse receipt system (WRS) and community grain bank (CGB). A study on the identification of existing and new innovations for managing maize postharvest losses in Shire Valley, southern, Malawi, is provided in chapter 4. Chapter 5 outlines the farmer participatory evaluation of existing and new postharvest innovations under on-farm conditions in Shire Valley. Chapter 6 provides findings on the effect of increasing ambient temperature on the efficacy of grain protectants and grain storage facilities used in smallholder maize production systems during laboratory trials conducted at the Botswana International University of Science and Technology (BIUST). Chapter 7 highlights the findings of a study on assessment of technical and institutional performance of the WRSs and community grain banks as adaptive strategies for managing maize postharvest losses in Shire Valley, southern Malawi. Chapter 8 combines the findings from each of these studies into an overall discussion, and concludes by highlighting the conclusions and recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Climate change risks and impacts in Malawi

The world's climate is changing and these changes are expected to continue into the next century. In addition to increased global temperatures, climate change (CC) is also expected to bring more frequent strong storms, heavy precipitation events and droughts (Serdeczny *et al*., 2017).

Worldwide, South Asian and southern African regions are expected, due to their sensitivity, to suffer heavy impacts of climate change because the populations in these regions rely on rain-fed agriculture which is mainly affected by CC (Hoffman *et al.*, 2018). Crop production, food security and food safety are expected to be negatively affected climate-related changes (Serdeczny *et al.*, 2017). During the 20th century, the warming in Africa was estimated at more than 1°C, with a pronounced trend in the past 40 years. Furthermore, the increase in the extreme weather events, global warming and reduced rainfall amounts may have serious implications for food production and availability in the region (Agoumi, 2003; Chijioke *et al.*, 2011). More people are expected to migrate from the rural to urban or rural (areas worst hit by CC) to other rural areas (areas less affected by CC) due to climate change (Matiya *et al.* 2011). Malawi and other countries in sub-Saharan Africa (SSA) are perceived to be more vulnerable to the impacts of climate change (CC) than industrialised countries due to their reliance on rainfed agriculture which is sensitive to weather and climate variables, such as temperature and precipitation (Kotir, 2011). This will pose a serious threat to the food supply chain of Malawian smallholder farmers who are at risk of the negative impacts of variability of CC.

Globally, food insecurity will worsen with the rapid human population growth (Alexander *et al.*, 2017). Increasing food production and the reduction of postharvest losses will contribute to minimising the food insecurity impacts associated with CC. Studies suggest that critical impacts due to climate change and socio-economic structures will worsen the current gaps in agricultural production and consumption between developed and developing countries (Huq *et al*., 2016).

2.2 Climate change projections and economic implications

Climate change has become a worldwide concern due to its impacts on the human population. In view of this, researchers and other stakeholders have intensified work on climate change projections, negative impacts, mitigation and adaptation to CC risks. Projections on temperature, rainfall and economics assist in development of mitigation and adaptation strategies. The predictions indicate that there will be an increase in global mean surface temperature by the end of the 21st century (2081–2100) in the range of 0.3°C to 1.7°C (IPCC, 2014). Most of the warming is projected to occur on the land surface in tropical and Northern Hemisphere subtropical regions (Mastrandrea and Field, 2010). This will occur throughout maize producing areas in SSA by the year 2050 (Cairns *et al*., 2013). Chikwawa district, the research study site, is viewed as one of the most vulnerable to climate change areas in Malawi. Projections for Chikwawa suggest that mean temperature will increase by 3^oC by the year 2065 with the monthly mean temperature predicted to be above 32^oC. Drier conditions are also expected to prevail into the future (Matiya *et al*., 2011).

The food security of SSA is expected to be negatively affected by climate change. Projections suggest yield losses of 10-20% will occur by 2050 in major staple crops due to higher temperatures and reduced rainfall (Jones and Thornton, 2003; Cairns *et al*., 2012). Low crop productivity, adaptive capacity and financial access combined with high population growth in many lower-income SSA countries, lead to increased concerns about national food security. About 36% of Malawi's population was estimated to be chronically food insecure (Anon, 2006b). The negative impact of climate change for Malawi is valued at an average loss of about USD 610 million between 2007 to 2050 (Arndt *et al.*, 2014). A 2^{o}C increase in ambient temperature is estimated to have the potential to increase the number of insect life cycles during the cropping season by one to five times (Bale *et al.*, 2002). Increased insect pest populations are expected to affect postharvest management (PHM) of maize in Malawi's Shire Valley. Therefore, there is need for the development of new technologies that can minimise PHM problems in the area (Anon, 2011).

2.3 Effects of climate change on the human population

Climate-related disasters are already affecting Malawi. Several crops that are important to large food-insecure human populations in southern Africa, such as maize and wheat, are likely to suffer negative impacts (Lobell *et al.*, 2008). Scientists have predicted that some countries in temperate regions may initially reap some yield benefits from global warming, while many countries in the tropical and subtropical regions are likely to become more vulnerable (Lobell *et al*., 2008). The most vulnerable communities will be those located on flood plains, hill slopes or low-coastal areas (Rosenzweig and Parry, 1994). Shire Valley in Malawi for example, faces both seasonal drought and flooding. The droughts have increased in frequency and severity since 2000 (World Bank, 2011). Malawi was affected by climate-related disasters such as droughts in the 1990s where over 6.1 million Malawians, translating to 46.9% of the population, were food insecure (Khamis, 2006).

2.4 Adaptation to climate change in Malawi

Adaptation to climate change is the adjustment of a system to moderate the impacts of climate change, to take advantage of new opportunities or to cope with the consequences (IPCC, 2014a). The most effective way of assisting farmers to adapt to the greater climate variability anticipated in the future is to understand and start co-developing adaptation strategies with them. Responses to climate change, including new technologies, are key aspects of agricultural adaptation (Lamboll *et al*., 2011). The community members in the Shire Valley have adopted a number of coping strategies such as growing of early and drought-resistant crop varieties, and cropping under irrigation (Matiya *et al*., 2011).

Climate change increases the need for good postharvest management by smallholder farming households in order to conserve their harvests in anticipation of poor subsequent harvests (Stathers *et al.*, 2013). Collective grain storage schemes, such as warehouse receipt systems (WRSs) and community grain banks (CGBs), are being introduced to smallholder farmers in Malawi by various development agencies. The WRS is being implemented in Malawi through the Agricultural Commodity Exchange (ACE), and focuses its operations in three complementing spheres: trade facilitation, implementation of a WRS, and market information dissemination (Hernandez, 2012). The ACE registered its first storage facility and issued its first warehouse receipt in 2011. The first deposits of maize by individual smallholder farmer were 14.5 and 44 metric tons in the first and second year respectively (Hernandez, 2012). However, to-date there has been little study of their role and effectiveness in buffering communities against climate-risk related food shortages. There is need for stronger linkages, coordination and synergies among organisations facilitating community risk assessments and responses to CC (Baulch *et al*., 2018). Furthermore, provision of climate information, particularly the translation of climate information to the communities, is paramount to support community-based disaster risk reduction (van Aalst *et al.*, 2008).

2.5 Maize postharvest losses and loss reduction strategies

Maize is the most important staple food crop in Africa. High postharvest losses of maize contribute to food insecurity in many countries (Kaminski and Christiaensen, 2014). High demand for food worldwide is expected due to population increase and challenges in food production such as climate change and variability, hence the urgent need to reduce PHL (Muir *et al.*, 2010). This increased demand for food will force farmers to use more of their disposable income to purchase staple foods (Gustavsson *et al.,* 2011: World Bank, 2011; Alexander *et al*., 2017). In addition to food losses after harvest, food is also wasted by consumers and retailers. Currently, food wastage per capita by consumers in Europe and North-America is estimated at 95-115 kg/year while in SSA it is between 6-11 kg/year (Gustavsson *et al.,* 2011; Alexander *et al*., 2017).

In SSA, storage insect pests are among the causative factors of grain PHL prior to processing, with annual estimates in the range of 10-20 % (World Bank, 2011). Insects are a major cause of maize PHL. However, storage fungi cause grain quality deterioration and can result in mycotoxin accumulation (Hell *et al.,* 2000; Tefera, 2012). There are also governance-related causes of PHL such as poor sales, procurement, storage, marketing and distribution policies or practices. Furthermore, absence of mechanisms for dealing with cash flow needs such as access to credit or WRSs also contribute to PHL due to the limited capacity to handle surplus grain among smallholder farmers (APHLIS, 2014). However, implementation of proper interventions may reduce PHL mainly by reducing losses due to insect infestation, fungal infection and physical factors.

2.6 Existing and new smallholder grain storage facilities

The majority of smallholder farmers practice on-farm grain storage, while governments in SSA established grain strategic food reserves aimed at stabilising food prices and grain accessibility, and also provide supplies during emergencies (Tefera *et al*., 2011). Grain postharvest losses is one of the challenges faced by both smallholder farmers and the government grain reserves. These losses are caused by, among other factors, storage insect pests, rodents, poor grain handling, inadequate grain storage practices and lack of storage management technologies. To reduce grain postharvest losses, some postharvest technologies have been recommended for use by smallholder farmers, such as botanical pesticides, synthetic pesticides, hermetic storage bags and metal silos.

2.6.1 Botanical pesticides

Botanical pesticides are plant based materials that contain insecticidal properties, and globally, they have been used by farmers for many generations (Bett *et al.*, 2017). However, grain protection using botanical pesticides is common among smallholder farmers (Isman, 2017). Some of the benefits of using botanical pesticides over synthetic pesticides include; the products are commonly found locally within the communities, they are less expensive as some are just collected from the forest reserves within the communities and they are easier to use compared to synthetic pesticides (Sola *et al.*, 2014).

Several studies that assessed the botanical pesticide properties have not assessed their safety. Botanical pesticides control or prevent pests through various ways and normally depend on the physiological characteristics of the targeted pest species and also the type of the pesticidal plant (Hikal *et al.*, 2017). The main botanical components are categorised into six groups including repellents, feeding deterrents/ antifeedants, toxicants, growth retardants, chemosterilants, and attractants (Collins, 2006). Some botanical pesticides have selective toxicity to pests, at the same time they are environmental friendly (Moshi and Matoju, 2017). The majority of these plant based pesticides are mainly available in the tropical regions (Stevenson *et al.*, 2017).

2.6.2 Synthetic pesticides

The use of chemicals in preventing or protecting stored grain against pests is common among smallholder farmers globally (Sola *et al.*, 2014). However, continuous use of these pesticides has led to widespread development of resistance among the targeted pest species (Sharma and Prabhakar, 2014a). Furthermore, some pesticides have contributed to environmental challenges due to their effects on human health and non-targeted organisms (Handford *et al.*, 2015). The commonly used synthetic pesticides in grain storage among smallholder farmers include pyrethroids and organophosphates (Wijayaratne *et al.*, 2018). A result of these challenges some synthetic pesticides have been completely banned or there are restrictions on their use in grain protection (Rajashekar *et al.*, 2010)

ZeroFly® storage bag is woven using polypropylene fibers with the insecticide deltamethrin (3 g per kg) incorporated in them to prevent stored insect pests in cereals, pulses, oilseeds and seeds which come into contact with the bag's surface. Kavallieratos *et al.* (2017) reported that polypropylene bags impregnated with deltamethrin prevent pests such as *P. truncatus* from accessing the stored grain. The deltamethrin is reportedly released on to the surface of the bag in a sustained manner for up to two years so that the commodities stored in the sacks are continuously protected against insect infestation (Baban and Bingham, 2014). Studies have shown that insects were controlled within all main agro-ecological zones of 11 SSA countries on various stored commodities when stored in the ZeroFly® bag for more than 1 year (Adler *et al*., 2018). Initial fumigation of grain is highly recommended for warehouse storage in order to avoid any damage due to resident infestation. More studies on ZeroFly® bags are required to evaluate the efficacy of the bag against insects under smallholder farming conditions.

2.6.3 Hermetic storage bags

Introduction of hermetic storage bags such as the Purdue Improved Crop Storage (PICS) in some SSA countries has shifted the trend of treating grain with pesticides to pesticide-free storage among smallholder farmers (Baoua *et al.*, 2012). One of the grain storage free of pesticide is through use of hermetic storage facilities, this is regarded as an ancient technology which has been modified and developed into modern hermetic storage technologies. These hermetic technologies include rigid containers (plastic, metal silos and drums) and collapsible containers (bags) (Murdock and Baoua, 2014).

The PICS bag is referred to as the triple-layer bag comprising two plastic inner liner bags made from high-density polyethylene (HDPE) plastic material of approximately 80 µm thickness and an outer woven polypropylene bag for extra protection (Murdock and Baoua, 2014). The PICS hermetic bag technology offers farmers a pesticide-free alternative method for storing grain. This is important given concerns regarding the side effects of pesticides to the human health, which particularly occur when pesticides are not applied as recommended (Lane and Woloshuk, 2017). In West Africa, the technology was also reported to be effective in controlling bruchids in stored cowpeas (Sanon *et al*., 2011). In Niger, bambara nuts stored in PICS bags maintained seed viability and effectively reduced grain losses over a storage period of 10 months (Baoua *et al*., 2014)

Njoroge *et al.* (2014) showed that maize stored in PICS bags slowed the growth of *P. truncatus* populations and blocked infestation from the surrounding storage environment. In the polypropylene (PP) bag control treatments a build-up of insect population and cross-infestation occurred. These researchers found that at six months, grain damage was 0.0 % and 50.5 % with weight losses of 0.0 % and 36.3 %, in PICS and PP, respectively. Germination of the maize stored in PP bags dropped from 91.1 % to 37.0 % whereas that stored in PICS bags dropped only marginally.

The "Super grain bag" is another recently developed hermetic bag. The bag's liner is made of tough, transparent multi-layer polyethylene, with a gas barrier between the two layers of polyethylene (PE) each 0.078 mm thick and the double layer material merged into one weighing 150 g/m^2 (Mensah-bonsu, 2016). The super grain bag technology has been scientifically tested and found to be effective against rice storage insect pests in Asia but not on maize (Ben *et al.,* 2006). A similar study in Zimbabwe revealed that the SGB successfully protected stored maize grain from pests but the bag was susceptible to damage by *P. truncatus* which caused perforations to the plastic liner leading to loss of airtightness (Chigoverah and Mvumi, 2016).

The ZeroFly® hermetic bag is a polypropylene bag with a multi-layered plastic liner inside that prevents insect development inside the bag and the impregnated woven bag with the deltamethrin stops infestations from outside.

2.6.4 Metal silos

Small metal silos (up to 3 tonnes capacity) are one of the hermetic storage facilities being promoted for smallholder farmers' use in SSA. Adoption of small metal silos is more likely in areas where metal containers are already used. In these areas metal containers are used for holding water and can be made locally by sheet metal workers. Boxall *et al*. (1997) reported that grain stored in metal bins should be very dry prior to storage. Metal silo storage facilities are ideal for areas with drying facilities or where the crop is harvested in a distinct dry season. With routine maintenance and good management, small metal silos can last for more than 20 years (Boxall *et al.*, 1997). If properly manufactured, the small metal silo provides protection against insects, mould, rodents and birds (Maonga *et al*., 2013). In some cases, insecticides or fumigants are essential for control of storage pests in small metal silos. A study recommended the promotion of metal silos for preventing storage losses and achieving food security in developing countries (Tefera *et al*., 2011b). Although small metal silos were introduced and promoted by Governments in some SSA countries, such as Malawi since 2008, there has been low adoption by smallholder farmers (Tefera *et al*., 2011). In Malawi, metal silos are produced by local artisans who were trained by experts trained under Government of Malawi/FAO programme.

2.7 Adoption of postharvest technologies and associated challenges

There is high demand for botanical pesticides which are regarded as the alternatives to synthetic pesticides which are unaffordable to some smallholder farmers which have less available and sometimes ineffective (Sola *et al.*, 2014). Furthermore, the increase in demand for the botanical pesticides among smallholder farmers is due to the low health risks.

Use of synthetic pesticides (Chemical) as a pest control measure is a common strategy in many countries worldwide compared to other pest control approaches (Williamson *et al*., 2008). Reports indicate that there is wide range of synthetic compounds and formulated products available for farmers whereby an individual farmer may use two to six products per storage season (Adler *et al*., 2018). Studies have clearly shown an increasing trend in use and reliance on synthetic pesticides dating from the early 1990s due to emergence of pest species (Lescourret, 2017).

After hermetic grain storage bags and containers were successfully tested in some West and Central Africa, the technology has been promoted worldwide. However, the scaling-up started with the PICS bag dissemination mainly for cowpea storage and later on maize, common beans, rice, sorghum, Bambara nuts, and mung beans (Murdock and Baoua, 2014). The scaling-up of the PICS in West and Central Africa attracted different agricultural partners such as the private sectors, governments, and donors to invest more in the development and dissemination of hermetic bags for the smallholder farmers. The Super Grain bag was first up-scaled in Asian countries for storage of rice and later on the technology was promoted in African countries mainly in West Africa followed by Central Africa (Harish *et al*., 2014). There is a growing demand for more brands of hermetic bags by the farming communities among smallholder farmers and the private sector is making sure that the bags are readily available. More hermetic bags are becoming commercial and in Kenya alone, more than five brands of hermetic bags are on the market including PICS, AgroZ®, Super Grain bag, ZeroFly®, and Elite bags (Baributsa and Njoroge, 2020).

Metal silo is one of technologies which has been reported effective in reducing grain storage losses by maize-storage insects, and have a big impact in improving the food security at the farm HH level (De Groote *et al*., 2013). Nevertheless, adoption of metal silos by smallholder farmers is mainly hampered by the initial cost of metal silos, hence there is need for new policies to increase access to credit and reduce the cost of sheet metal (Gitonga *et al.*, 2013). Four out of over 40 trained artisans in Kenya were reported to be active and this low number was attributed to lack of effective demand and awareness among smallholder farmers (Gitonga *et al.*, 2013). Metal silos were first developed and disseminated in Central America in 1983 with financial support from the Swiss Development Cooperation (SDC) (Fischler *et al*., 2011). The weak distribution systems of hermetic bags such as PICS and SGB result in poor access and local unavailability of the technologies. Overall, there is lack of publicity and proper training of agricultural extension staff both from the government and non-governmental organisations (NGO), and therefore, many farmers are not aware of the technology. This limits systemic uptake.

CHAPTER 3: STUDY SITES AND GENERAL RESEARCH METHODOLOGY

3.1 Site description

3.1.1 Introduction

The main focal site of the study was the Shire Valley in southern Malawi, where the survey and on-farm experiments were done. In addition a survey on community storage systems was done in six districts in southern, Malawi. Laboratory trials were conducted in Malawi and in Botswana.

The site descriptions are given for the following four studies implemented:

i) the community profiling study to identify farmers' existing and new innovations for managing maize postharvest losses and their understanding of climate change and its impacts was conducted in the Shire Valley of Malawi,

ii)the farmer participatory evaluation of existing and new postharvest (PH) innovations under on-farm conditions was conducted in Dwale and Livunzu extension planning area (EPA) in Thyolo and Chikwawa districts respectively in Shire Valley for two storage seasons (2014/2015 and 2015/2016). The grain samples collected from the on-farm trials were analysed in the Crop Storage laboratory at Chitedze Agricultural Research Station in Lilongwe.

iii) the laboratory trials on the effect of increasing ambient temperature on the efficacy of grain protectants and grain storage facilities in smallholder maize production systems was initially conducted in the Crop Storage Laboratory at Chitedze Agricultural Research Station and later in the Entomology Laboratory at Botswana

International University of Science and Technology (BIUST), Palapye, Botswana in 2018,

iv) a field study of the technical and institutional performance of the warehouse receipt systems (WRS) and community grain banks (CGB) as adaptive strategies for managing maize postharvest losses was done in Shire Valley, southern Malawi and was carried out in six districts (Balaka, Machinga, Zomba, Chiradzulu, Phalombe and Blantyre) in the southern region of Malawi.

3.1.2 Shire Valley, southern Malawi (Profiling study and on-farm trials)

The community profiling study was conducted in March 2014 in the Shire Valley which lies at 16° 10′ South and 34° 45′ East, 112 m above sea level [masl] and is located in Chikwawa and Thyolo districts in southern Malawi (Sehatzadeh, 2011). Shire Valley is characterized by two main agro-ecological zones; Shire Highlands (upstream-Thyolo) and Lower Shire Valley (downstream-Chikwawa). The study was conducted in Dwale (up-stream) and Livunzu (down-stream) EPAs located in Thyolo and Chikwawa districts respectively. Dwale and Livunzu EPAs are located at an altitude range of 148-400 masl and 62-160 masl respectively. Thyolo district shares a boundary with Chikwawa district and receives an average total rainfall of 1,125 mm per year with mean monthly maximum and minimum temperatures of 26.5 °C and 15.7 C respectively. On the other hand, Chikwawa district receives an average total rainfall of 1,240 mm per year with mean monthly maximum and minimum temperatures of 30 °C and 27 °C respectively (Sehatzadeh, 2011).

The Shire Valley was purposively selected because agricultural and meteorological experts view the area as one of the most prone area to climate change-related risks in Malawi (Mijoni and Izadkhah, 2009). Over 40 weather-related disasters (floods and droughts) occurred in Malawi between 1970 and 2006. However, Shire Valley alone experienced almost 16 of these disasters occurring since 1990 (Khamis, 2006). Furthermore, the human activities such as deforestation for charcoal production in the up-stream area of Shire Valley influence the environmental and socio-economic activities of those living down-stream in Shire Valley. The deforestation-related siltation and flooding cause destruction of the agricultural activities in down-stream Shire Valley and the area is characterised by the double burden and increasingly frequent occurrences of prolonged dry spells and floods.

The on-farm trials which facilitated farmer participatory evaluation of existing and new postharvest innovations under on-farm conditions were conducted in Shire Valley, southern Malawi for two consecutive storage seasons; 2014/2015 and 2015/2016 starting from October and July respectively. These trials were conducted at two sites in each season. The sites were Dwale and Livunzu EPAs within Thyolo and Chikwawa districts respectively.

3.1.3 Chitedze Agricultural Research Station (Laboratory trials)

The laboratory trials studied the effect of increasing ambient temperature on the efficacy of smallholder used grain protectants and grain storage facilities. They were conducted for periods of 24 weeks at 32 ^{o}C and 38 ^{o}C in 2014/2015 storage season. However, the trials were stopped as power blackouts in Malawi became frequent, making it impossible to maintain the trial conditions. Subsequently, fresh laboratory trials were carried out at Botswana International University of Science and Technology in Botswana.

All the maize grain samples collected during the on-farm trials (farmer participatory evaluation of existing and new postharvest innovations under on-farm conditions) in Shire Valley were analysed in the Crop Storage laboratory at Chitedze Agricultural Research Station.

3.1.4 Botswana International University of Science and Technology

The trials on the effect of increasing ambient temperature on the efficacy of grain protectants and grain storage facilities in smallholder maize production systems was conducted in the Entomology laboratory at Botswana International University of Science and Technology, Palapye, Botswana in 2018.

3.1.5 Study of Warehouse receipt systems (WRSs) and Community grain banks (CGBs)

The study of the WRS and CGB systems was conducted in October during the 2016/2017 storage season in six southern Malawian districts; Balaka, Blantyre, Chiradzulu, Machinga, Phalombe and Zomba. The districts were purposely selected because the targeted storage systems are located in them and they share similar climatic conditions to those of Shire Valley. The selected storage systems included three WRS and four CGBs. The three WRSs selected were Balaka (14^{o} 59′ South and 34^{o} 57′, 640 metres above sea level), Nsanama (14^{o} 58′ South and 35^{o} 30′, 692 masl) and Mwandama (15^{o} 30′ South and 35^{o} 26′, 710 masl) located in Balaka, Machinga and Zomba respectively. While the four CGBs selected were Mdeka (15^{o} 27′ South and 34^{o} 56′, 518 masl), Nkalo (15^{o} 44′ South and 35^{o} 15′, 882 masl), Namangale (15^{o} 24′ South and 35^{o} 19′, 894 masl) and Gwirima (15^{o} 50′ South and 35^{o} 45′, 726 masl) located in Blantyre, Chiradzulu, Zomba and Phalombe districts respectively

(Trethewey, 2019). All the selected WRSs and CGBs are located in climate change prone areas in southern Malawi (Fig. 3.1).

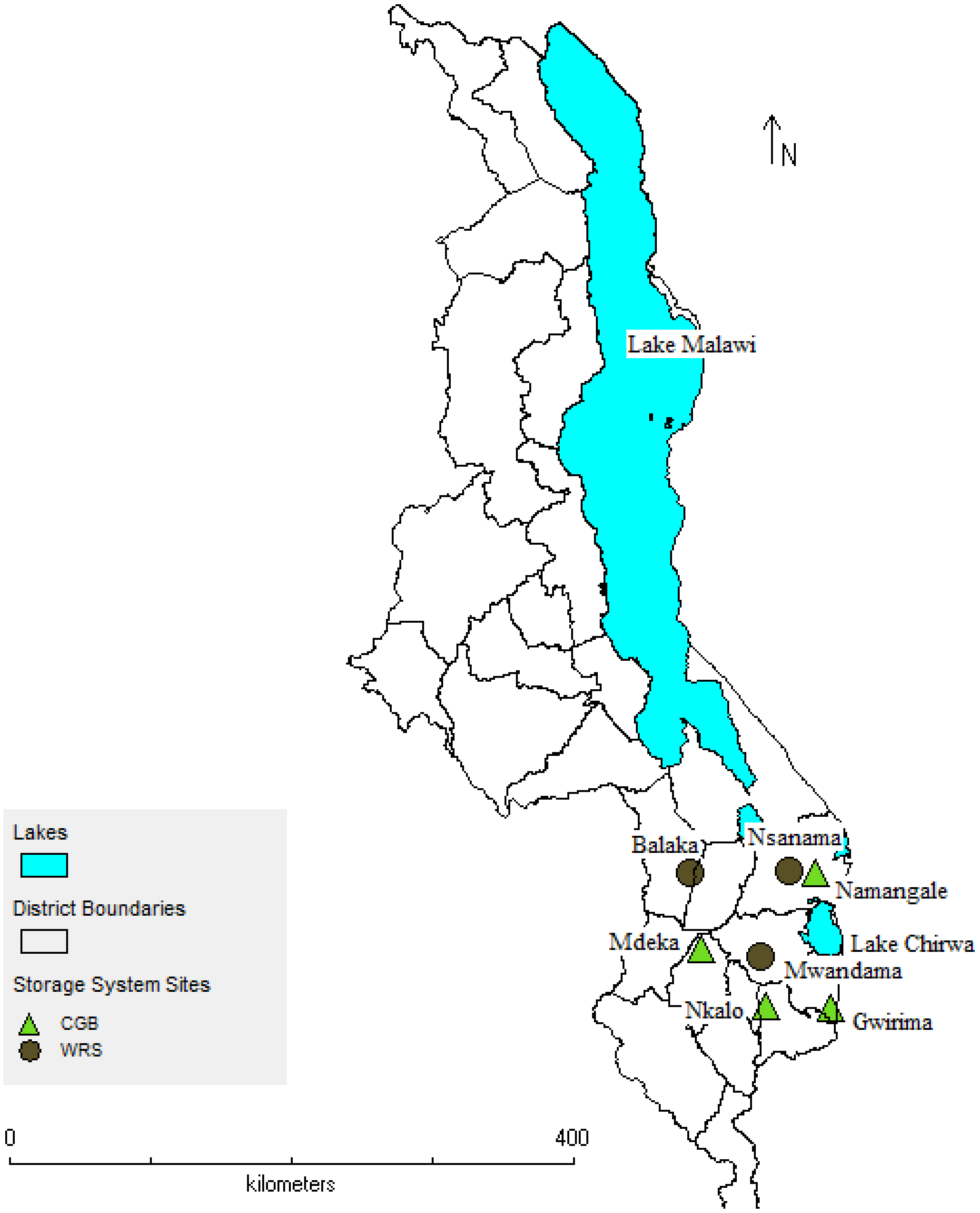

Figure 3. 1: Map showing location of warehouse receipt systems and community grain banks in the six study districts in southern Malawi (Source: prepared by Lawrent Pungulani, the Department of Agricultural Research Services, Lilongwe, Malawi).

3.2 General research methodology

3.2.1 Profiling study

The profiling survey to identify existing and innovations for managing maize postharvest losses was conducted in Shire Valley using three tools: a structured questionnaire for the individual households (HHs) interviews; a checklist for the farmer focus group discussions (FGDs); and semi-structured questionnaires for the key secondary stakeholders and informants interviews (Appendices A to D). The tools were specifically designed to learn about HH and community profiles, particularly their crop postharvest (PH) systems, and how CC affects farmers' crop PH handling in Shire Valley, and the support, knowledge and skills farmers were using to cope with and adapt to the effects of CC. Five villages were randomly selected using a multi-stage cluster sampling technique for Dwale and Livunzu EPAs. Using a random number selection process, 24 HHs were sampled from each of the five villages per EPA; based on existing HH lists provided by the local extension staff. The list was the most up-to-date and reliable available which helped save costs and time of preparing another one. The target was 20 HHs per village, and the extra four HHs were to cater for those HH heads or representatives who were unavailable at the time of interviews.

A total of 203 HHs were interviewed in the two EPAs using the HH questionnaire. The five selected villages from Dwale EPA were Mwanapwa, Liphama, Nahemo, Nsewa and Mwakala because of the highly degraded status of their natural resource environment. In Livunzu EPA, the selected villages were Mwanayaya, Kubalalika, Chikadza, Kusakala and Jeke. Household heads or HH representatives were interviewed at their homesteads to help avoid the risk of interference by other farmers. Each HH interview was conducted by a trained enumerator using the HH questionnaire which had been pre-tested and corrected accordingly, while the student supervised the enumerators to make sure correct data were collected as planned. Farmers participating in the FGDs were purposively selected from the same five villages targeted for administration of the structured questionnaire in each EPA. Farmers who had been individually interviewed during the HH questionnaire were not involved in the FGDs. A total of seven FGDs were conducted; four in Dwale and three in Livunzu EPAs. In Dwale, two separate FGDs involved 17 women while the second involved 16 men, the third FGD involved 15 women and 13 men and the fourth FGD had 16 men and 14 women. In Livunzu, the first FGDs involved 20 men only while the second involved 19 women, and the third FGD involved 7 men and 8 women. The stakeholder and key informant interviews were conducted at their homesteads or work premises, using a semi-structured questionnaire. A total of 17 and 26 key informant and stakeholder interviews were conducted in Thyolo and Chikwawa respectively. The interviews' focus was on PH practices including: timing of harvest, drying, maize grain treatment, storage period, storage facilities, major causes of PH losses, and effect of CC and variability on the smallholder PH farming practices.

3.2.2 On-farm grain storage intervention trials

On-farm grain storage trials were conducted in Shire Valley to assess the performance of storage facilities and grain protectants against storage insect pests. Eight smallholder farmers hosted the trials in two sites; Dwale and Livunzu Extension Planning areas (EPAs) in Thyolo and Chikwawa districts, respectively. Seven grain storage treatments were evaluated: Neem leaf powder (NM), Actellic Super dust (ASD), ZeroFly® bag (ZFB), Purdue Improved Crop Storage bag (PICS), Super Grain Bag (SGB), metal silo (MS) and untreated grain in a polypropylene bags (PP). The stored grain was sampled every 8 weeks for 32 weeks during the 2014/15 and 2015/2016 storage seasons.

The trials used four untreated hybrid maize varieties namely DKC 9089, DKC 8053, SC 719 and SC 627. The hybrids were procured from the farm section at Chitedze Agricultural Research Station during the two storage seasons. The selection of the varieties was based on farmers' preference in the study area. The grain was procured from Chitedze station as it was difficult to get the required volume of untreated maize grain in Shire Valley considering the timing of the studies. Subsequently, the maize varieties were mixed in equal proportions and mixed thoroughly on a tarpaulin using shovels. The thorough mixing was to minimise variations among the treatments. The mixing of different maize varieties mimicked smallholder farmers' practice at storage. Grains that were already infested at the time of set-up were not removed as insect infestation typically starts in the field before harvesting, and so this ensured the treatments were tested under realistic infestation pressures. All the grain was thoroughly mixed. The grain moisture content was determined at Chitedze Station (13.4 %) using an electric moisture meter (Grain Machinery Manufacturing Corporation, Moisture tester Burrows DMC-500, Illinois, USA) before the grain was transported to the study site 377 km away.

All the storage facilities used in the studies had a storage capacity of 50 kg each, the standard size used in Malawi, and were sourced either from the local distributors or imported. There were seven treatments which were sourced from different suppliers. Each of the grain protectants (ASD or Neem) was admixed thoroughly with the maize grain manually using shovels on a tarpaulin. Firstly, the grain was heaped on the tarpaulin and the grain protectant was spread on the grain then admixed with the grain before loading in PP bags. Later, untreated grain was weighed into 50 kg lots and each replicate of the following storage facilities was filled with 50 kg of grain; MS (outlets sealed tightly with rubber bands), SGB, PICS, ZFB and PP (Fig. 3.2).

Figure 3.2: Setting up the trial after filling the storage facilities with untreated maize grain of 50 kg for each facility at one of the farmers hosting the experiments (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

After loading the hermetic bags (SGB and PICS) with grain, the air was squeezed out of the top of each plastic liner, which was then twisted and tied tightly (according to the manufacturer's instructions), and the mouth of the outer bag was then also twisted and tied tightly. After loading the ZFB and PP bags, the bags were twisted and tied tightly. After loading the MS with grain, a burning candle was introduced and placed upright on the surface of the grain to help deplete the available oxygen, while the silo lid was fitted and sealed tightly using large bands made from strips of tyre rubber to reduce movement of air into the MS.

The trials were hosted by four smallholder farmers who were purposively selected from each EPA. Each of the eight farmers from the two EPAs hosted seven treatments which they stored in one room within their house, separately from their own grain. The treatments were placed on wooden pallets to avoid direct contact with the floor and to encourage air circulation and to prevent the grain from absorbing moisture from the floor. The ZFB treatments were kept at least 1 m away from the other treatments to prevent pesticide contamination during the study period while there was no space left between the other pesticide-free treatments. This was done so to maximize the limited storage space in the participating farmers' stores. Besides that, all treatments were placed 1 m away from the walls of the storage room for easy inspection. The treatments were kept under ambient conditions and natural pest infestation as opposed to artificial infestation.

3.2.3 On-station grain storage intervention trials

The effect of increasing ambient temperature on the efficacy of the grain protectants and grain storage facilities used in smallholder maize postharvest systems trials was studied in three sets of trials at 32 °C, 38 °C and ambient conditions. The technologies tested included grain protectants and storage facilities, and all were tested at each of the three climatic conditions (Table 3.1).The trials running at 32 °C and 38 °C were placed in climate chambers (HPP 260, Memmert GmbH + Co.KG, Germany) set at those temperatures with the relative humidity set at 60 % in both chambers (Fig. 3.3). The selected temperatures were based on the mean weekly temperature recordings captured during the field study from November 2015 to May 2016 in Shire Valley, Malawi. During the study the lowest and highest weekly temperatures were 27 ºC and 38 ºC respectively. Therefore, considering a projected mean temperature increase of 3 ˚C in Malawi due to climate change (Matiya *et al.*, 2011), the minimum temperature was adjusted by adding 5 ˚C (above the anticipated increase in temperature to cater for the extreme increase) to 32 ˚C to cover increases during the hottest months of the year.

Table 3.1: List of grain protectants and storage facilities including the grain protectant application rates and storage facility grain holding capacity

No.	Grain Protectants	Application rate
1	Actellic Gold dust	25 g per 50 kg of maize grain (or 0.05 % w/w)
2	Shumba Super dust	25 g per 50 kg of maize grain (or 0.05 % w/w)
3	Wivokil Super dust	25 g per 50 kg of maize grain (or 0.05 % w/w)
4	Neem	153.3 g per 50 kg of maize grain (or 0.31 % w/w)
5	Wood ash	was applied at 15 kg per 50 kg of grain
6	Untreated	None
	Storage facilities	**Grain storage facility holding capacity (g)**
1	Super Grain Bag	200
2	Purdue Improved Crop Storage bag	200
3	Metal Silo	600
4	Polypropylene bag	200

Note: the application rates were based on a weight for weight (w/w) basis

The recorded maximum temperature of 38 ˚C was maintained, as temperatures above 40 ˚C were expected to compromise the survival of the test insects. A relative humidity of 60 % was maintained by setting up the climate chambers at 60% RH because the set RH represented the average relative humidity reported during the field study in 2016. The treatments were placed on shelves in the climate chambers after attainment of the set conditions (temperature and relative humidity) while the ones under ambient conditions was placed on the bench outside the chambers. The conditions inside the climate chambers and outside the chambers (temperature and relative humidity) were recorded using an iButton (model DS 1923, Maxim, Sunnyvale, CA, USA), this enabled the ambient conditions to be compared with the set conditions of 32 ºC and 38 ºC in the chambers. Additionally, one iButton was placed inside one replicate of each of the three treatments; PICS, PP and MS that were in the climate chambers at 32 ^{o}C and 38 ^{o}C to record temperature and relative humidity inside the storage facilities in the chambers for comparison with the conditions inside the chambers.

Figure 3.3: A photo of a climate chamber (showing closed and inside) used in the trials at Botswana International University of Science and Technology: (Left: closed chamber; Right: Open chamber) (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

The iButton recording the ambient conditions outside the chambers was placed amongst the treatments being tested under ambient conditions. The iButtons' recorded the temperature and relative humidity at 40 minutes intervals throughout the 12 weeks trial period. The iButton's storage capacity was too small if measurements had been taken more frequently.

3.2.4 Warehouse receipt system and community grain bank (study tools and grain sampling)

A field study to assess the technical and institutional performance of the WRS and CGB as adaptive strategies for managing maize PHL in Shire Valley, southern Malawi was implemented using two structured questionnaires (Appendices E and F). The questionnaires were developed and pre-tested for data collection from the managers and beneficiaries of the two collective storage systems. The management committee members (included members involved in the day-to-day running of the storage systems) were purposively selected while the beneficiaries were randomly sampled from the list of those active at the time of the study. The management members interviewed were the chairman, secretary, treasurer and committee members. While beneficiaries were considered to be those farmers who deposited grain to the storage system. Additionally, where stocks were available grain samples from the WRS and CGB were collected for weight loss assessment using rapid methods namely visual scales and standard graphs (see section 7.3.3.1 and 7.3.3.2). The questionnaires were administered by a team of four well-trained enumerators through individual interviews. At each of the WRSs and CGBs storage systems included, 10 members (five from management and five beneficiaries) were interviewed resulting in a total of 70 members being interviewed.

CHAPTER 4: UNDERSTANDING SMALLHOLDER MAIZE POSTHARVEST SYSTEMS IN A CHANGING CLIMATE IN SHIRE VALLEY, SOUTHERN MALAWI[1]

4.1 Introduction

Most of the maize grain produced in sub-Saharan Africa is stored on-farm. Safe grain storage, therefore, plays a vital role in ensuring food security among rural communities throughout the year (Pankomera *et al.*, 2009; Manandhar *et al.*, 2018). In the mid-1990s, grain was traditionally stored in outdoor storage structures, such as mudded and woven-granary baskets (Mwangi *et al.*, 2017). More recently, modern hermetic storage facilities have been developed and promoted for use by smallholder farmers including small (1-3 MT capacity) metal silos and hermetic bags (50-100kg capacity) particularly for maize storage in East Africa (Tefera, 2012; Kimenju *et al.*, 2016) and cowpea storage in West and Central Africa (Baributsa *et al.*, 2014). Weather, particularly rainfall during and after harvest, which affects grain moisture content, is a key postharvest (PH) challenge in Africa, as almost all smallholder farmers rely on sun-drying to ensure the moisture content of their grain is reduced to ideal levels for storage. Unfavourable weather conditions prevent grain from drying sufficiently fast, resulting in discolouration and rendering it more easily damaged by storage insect pests (Fields, 2006), and possible mycotoxin contamination due to mould development.

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[1] Modified and submitted for publication as: Singano, C. D., Mvumi, B. M., Stathers, T. E., and Siziba S. (2019). Understanding smallholder crop postharvest systems in a changing climate in Shire Valley, southern Malawi. *Journal of Rural Studies* (Pending)

Climate change (CC) and increasing climate variability (CV) may create more unfavourable crop drying weather such as damper or more cloudy conditions (Stathers *et al.*, 2013), and PH losses (PHLs) may increase as a result (Tefera *et al.*, 2011b).

The agricultural and natural resource-dependent livelihoods of rural populations in developing countries including SSA are expected to be heavily affected by CC & CV (Adger *et al.*, 2003; Serdeczny *et al*., 2017). Despite the use of different coping strategies, many countries in SSA suffer from the impacts of CC & CV and Malawi is categorised as ‘high risk’ for natural disasters (Brooks and Adger, 2003).

In the Shire Valley of southern Malawi, many communities live and farm on flood plains and hill-side slopes, and often face both drought and flooding in the same year. Droughts have increased in frequency and severity in SSA since 2000, including in Malawi (World Bank, 2011). According to the meteorological data, the Shire Valley received rainfall in the range of 500 to 700 mm annually from 1990 to 1995. This was the lowest amount of annual rainfall received since 1971. An assessment report indicated that over 2.8 million people in Malawi were likely to be food insecure between October 2015 and March 2016 (Gelli *et al*., 2017). The increased incidence of droughts and floods in Malawi has increased the vulnerability of many rural farming households (HHs), now trapped in a vicious cycle of poverty (Jayanthi *et al*., 2013). More recent data estimates that about 26 % of Malawi’s total human population are undernourished (Koppmair *et al.*, 2017). Climate-related factors contribute significantly towards this food insecurity, including prolonged periods of drought such as the devastating one that occurred during the 2001/2002 cropping season which created a serious food deficit of 600,000 tonnes (Potts and Wiley, 2006); Magombo *et al*., 2012).

Estimates suggest the negative impacts of CC will cost Malawi about USD 610 million annually from 2007 to 2050 (Arndt *et al*., 2014). Yield reduction predicted to occur in major staple crops will pose particular threats to smallholder farmers and those nations already facing food insecurity (Cairns *et al.*, 2012; Arndt *et al.*, 2014). Major contributory factors for food insecurity among rural smallholder farmers include low crop productivity, low adaptive capacity and limited financial access combined with high population growth (Parry *et al*., 2004; APHLIS, 2014). Malawi is vulnerable to many climate-related risks such as frequent and prolonged dry spells, droughts, floods and high temperatures. The CC projections suggest a 2 % decrease in the mean annual yield of maize in Malawi to 2050 (Arndt *et al.*, 2014). Projections for Chikwawa district in southern Malawi show a temperature increase of 3 ^{o}C by the year 2065, leading to a mean monthly temperature of above 32 ^{o}C and drier conditions between 2046 to 2065 (Matiya *et al*., 2011). As smallholder farmers' livelihoods are so dependent on climatic factors, changes in the climate are a particular threat to these rain-fed agricultural farmers.

Some of the existing CC adaptation strategies used by farming communities in the Shire Valley include the growing of early-maturing and drought-resistant crop varieties, use irrigation systems, sale of asset, winter cropping and crop diversification (Matiya *et al*., 2011). The integration of these adaptation strategies into the local adaptation strategies in adaptation policies could help increase local resilience to CC in Africa (Stringer *et al.*, 2009b). However, most existing adaptation policies in SSA do not include strategies for the reduction of PH losses. Good smallholder PH management practices including: production and storage of varieties less susceptible to storage damage; drying grain to the recommended moisture content for safe storage; careful store hygiene, cleaning and monitoring. Use of effective modern storage facilities and grain treatment with recommended synthetic pesticides or use of other effective pest management technologies can be key CC adaptation strategies (Stathers *et al*., 2013).

Significant quantities of food are lost postharvest due to many factors including storage pests, particularly insects and rodents. A comprehensive study in Shire Valley in the late 1970s (Golob, 1981) reported weight losses of 2 to 5% during maize storage due to damage by insect pests such as *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). The accidental introduction into Malawi of the highly destructive larger grain borer (LGB), *P. truncatus*, in the early 1990s has contributed to at least a trebling of weight losses of stored maize to current loss levels of 15.7 % (Anon, 2011). The African Postharvest Loss Information System (APHLIS) estimates that farmers in Malawi lose a total of 19.7 % of their maize during the various postharvest stages from harvesting through to market storage (APHLIS, 2014).

The purpose of this study was to document the existing crop postharvest knowledge, skills or technologies to help identify opportunities for PH adaptation to climate-related risks in Shire Valley.

The specific objectives of the study were:

1) To critically analyse and understand maize pre- and postharvest practices and constraints,
2) To understand the farmers' and other agricultural stakeholders' experiences of CC, existing and proposed adaptation strategies and their merits and demerits,
3) To identify existing and innovations for smallholder crop postharvest management as adaptation strategies to climate-related risks.

4.2 Materials and methods

4.2.1 The study area

The study was conducted in March 2014 in the Shire Valley (16° 10′ South and 34° 45′ East, 112 m above sea level [masl]) in Chikwawa and Thyolo districts in southern Malawi (Sehatzadeh, 2011). The study area is characterized by two main agro-ecological zones; Shire Highlands (upstream-Thyolo) and Lower Shire Valley (downstream-Chikwawa) (Fig. 4.1). The up-stream study area was Dwale Extension Planning Area (EPA) under Thyolo district and shares a boundary with Chikwawa district. Thyolo district receives an average rainfall of 1,125 mm per year with mean monthly maximum and minimum temperatures of 26.5 °C and 15.7 °C respectively. Similarly, the down-stream was Livunzu EPA under Chikwawa district which receives an average annual total rainfall of 1,240 mm, with mean monthly maximum and minimum temperatures of 30 °C and 27 °C respectively (Sehatzadeh, 2011). Dwale and Livunzu EPAs are located at an altitude range of 148-400 masl and 62-160 masl respectively.

The study areas were purposively selected because the agricultural and meteorological experts view them as the worst climate-risk and hazard-affected areas of Malawi. Over 40 weather-related disasters (floods and droughts) occurred in Malawi between 1970 and 2006, with 16 of these occurring after 1990, and Shire Valley experienced almost all of these disasters (Mijoni and Izadkhah, 2009). Additionally, the study areas were selected because of highly degraded status of their natural resource environment due to careless cutting down of trees, cultivation along the river banks and continuous cropping (Potts and Wiley, 2006). However, the human and environmental factors such as deforestation for charcoal production in the up-stream area of Shire Valley influence the environmental and socio-economic activities of those living down-stream of Shire Valley. The deforestation-related siltation and flooding are destructive for agricultural activities in down-stream Shire Valley. The Shire Valley is characterised by the double burden of frequent occurrences of prolonged dry spells and floods.

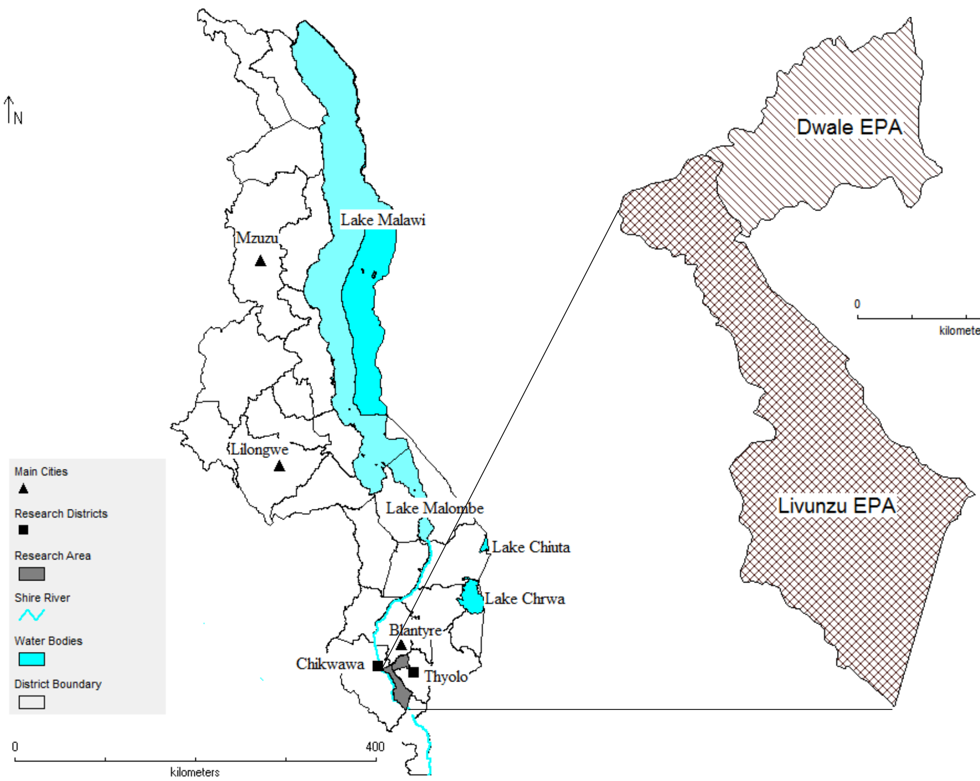

Figure 4.1: Map showing the study areas in Dwale and Livunzu Extension Planning Areas (EPAs) in Thyolo and Chikwawa districts respectively, Shire Valley, southern Malawi (Source: prepared by Lawrent Pungulani, the Department of Agricultural Research Services, Malawi)

4.2.2 Survey tools and data collection

The survey was conducted using three tools: checklist, structured questionnaire, and semi-structured questionnaire. The checklist was used for farmer focus group discussions (FGDs), while individual HHs were interviewed using structured questionnaire. Further, key district-level and community-level informant interviews were conducted using semi-structured questionnaire. The detailed questions, the thematic areas of interview for each target group are summarised in Table 4.1.

Table 4.1: The thematic areas of interview for each target group and respective main data collection tools used

Structured questionnaire (Individual farmer households)	
1	Demographics
2	Access to information and use of indigenous knowledge systems
3	Crop production practices
4	Postharvest practices including grain storage facilities, grain protection measures and changes in PH aspects compared to 10 to 20 years ago
5	Farmer perceptions of long-term climatic and environmental changes
Semi-structured questionnaire (Community key informants, Key secondary informants/District stakeholders)	
1	Community/village background information
2	Livelihoods sources, access to goods and services, information and communication technology (ICT)
3	Climate change and variability during the last 10-20 years
4	Mapping of the institutional capacity currently supporting (or not) communities to enhance their resilience to climate change
5	Climate risk awareness/ perceptions
6	Adaptation strategies
Checklist for farmer focus group discussions	
1	Description of their normal climate and how it is changing
2	Major climate-related events affecting this focal community
3	Livelihoods options in the Shire Valley
4	Information systems (as regards climate and any other information related to crop production and postharvest management including markets)
5	Source of information
6	Climate change-related risks in the area and associated support systems in place
7	Adaptation strategies

The tools were specifically designed to learn about the profiles of the focal HHs and communities, particularly regarding their: crop PH systems; how CC affects farmers' crop PH handling in Shire Valley; and the support, knowledge and skills farmers were using to cope with and adapt to the effects of CC. Comparisons of current (in 2014) crop PH handling practices versus those used 10-20 years ago were discussed to understand the changes associated with climate change that have taken place. These comparisons were conducted to pick up changes over a 10-20 year period. The comparisons focused on PH activities such as storage practices (storage period, storage structures and grain treatment) versus 10-20 years ago. The community key informant and stakeholder interviews were used to provide a broader understanding of the CC issues and adaptation activities within Shire Valley and to corroborate the evidence provided by the HHs and the communities.

Five villages were randomly selected using a multi-stage cluster sampling technique for each of the EPAs. A random number selection process was used to select 24 HHs in each of the five villages per EPA based on HH lists provided by the local extension staff. The target was 20 HHs per village, and the extra four HHs were to cater for those HHs where the HH head was unavailable at the time of interview.

A total of 203 HHs (Fig. 4.2) were interviewed in the two EPAs using the HH questionnaire. The five selected villages from Dwale EPA were Mwanapwa, Liphama, Nahemo, Nsewa and Mwakala. In Livunzu EPA, the selected villages were Mwanayaya, Kubalalika, Chikadza, Kusakala and Jeke. The HH heads or HH representatives were interviewed at their homesteads to help avoid interference by other farmers. Each HH interview was conducted by a trained enumerator using the HH questionnaire which had been pre-tested and corrected accordingly, while the student supervised the enumerators to make sure correct data was collected through the questionnaires as planned. Farmers participating in the FGDs were purposively selected from the same five villages targeted for administration of the structured questionnaire in each EPA. However, farmers who had been individually interviewed during the HH questionnaire were excluded from the FGDs (Fig 4.2).

Figure 4.2: Enumerators conducting focus group discussions and household interview with household members in Dwale extension planning area in Thyolo district during the profiling study (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

A total of seven FGDs were conducted in Dwale and Livunzu EPAs. Four were conducted in Dwale and three in Livunzu. In Dwale, the four FGDs had the following participants, the first had 17 women, the second had 16 mean, the third had 15 women and 13 men, and the fourth had 14 women and 16 men. In Livunzu, participants to the three FGDs were as follows first had 20 men, the second had 19 women, and the third FGD had 8 women and 7 men. The stakeholder and key informant interviews were conducted at their homesteads or work premises. A total of 25 districts key informants (stakeholders) and 18 communities' key informants were interviewed from Dwale and Livunzu EPAs (Table 4.2).

Table 4.2: List of district stakeholders and community key informants interviewed in Thyolo and Chikwawa districts, Shire Valley, southern Malawi

District	District level key informants (stakeholder)	No. of interviews	Community level key informants	No. of interviews
Thyolo	• Government (DADO, DC, DCO, DFO, DLO, EDO, ADMO and DPD)	9	AEDC, AEDO, Disaster Committee chairperson	3
	• NGO-Concern Universal	1	T/A Mphuka, Traditional healer, VDC member and Village headman	4
Chikwawa	• Government (DADO, DCO, DLO, DFO, LRC, EDO, DADO, DIO, DPD and M & EO)	10	MP for Nkhate, AEDC, Head teachers for Nkhate primary and secondary schools	4
	• NGO (EAM, Eagles Relief, Stephano Foundation and DAPP)	4	Nkhate irrigation scheme chairperson, T/A Makhuwira, Village disaster Early warning committee chairperson	3
	• Private sector (Agro-dealer)	1	Agro-dealer, Traditional healer, ADC Chairperson, Village headman	4

Key: DADO = District Agricultural Development Office, DC = District Council, DCO = District Crops Officer, DFO = District Forestry Officer, DLO = District Livestock Officer, LRCO = Land Resources & Conservation Officer, EDO = Environmental District Officer, ADMO = **Assistant Disaster Management Officer,** ***DPD = Director of Planning & Development, NGO = Non-Governmental Organisation, EAM = Evangelical Association of Malawi, DAPP = Development Aid from People to People, AEDC = Agricultural Extension Development Coordinator, AEDO = Agricultural Extension Development Officer, MP = Member of Parliament, T/A = Traditional Authority, VDC = Village Development Committee, ADC = Area Development Committee***.

4.2.3 Data analyses

Qualitative and quantitative data from the HH questionnaires were analysed using the Statistical Package for Social Scientists (SPSS) version 19.0 (Gamble, 2001). Further analysis on measures of central tendency (means, median and mode) were carried out on demographic and crop production data. Qualitative data from the FGDs and key informant interviews were tabulated in Microsoft Excel and examined for differences and similarities across different cases, periods and events. Themes were developed to come up with summary descriptions and explanations. Pearson's correlation test and the Z proportions test were used to check for significance of the relationships among some of the explored variables.

4.3 Results

4.3.1 Demographic and social characteristics of the households interviewed

Demographic attributes of the survey households are summarised in Table 4.3. The headship of households was approximately evenly distributed between the two sexes. Male headed households were slightly more common in Dwale than female headed ones while in Livunzu females were more common than male headed ones. This could be a reflection of the mixture of patrilineal and matrilineal communities that exist in the Shire Valley. The household heads were typically middle-aged, with the "34-64 years" age group being most common in both EPAs. Young HH heads (19-33 years old) constituted about a third of the survey households in both EPAs. The majority of the household heads were in monogamous marriages, with the other marital status (separated, divorced, polygamy). The HH heads had generally low levels of formal education in both EPAs. About half of the HH heads had only attained primary level education, and a notable proportion had no formal education at all. A very small segment of the HH heads had secondary education. However, the proportion in numbers of HH heads without education, primary, secondary and tertiary education were significantly different (χ^2 = 55.07, p = 0.001) between those from Dwale and Livunzu EPAs using Chi-square analysis. The HHs were typically comprised of 1-5 members. Larger family sizes (6-10 members) were relatively more common in Livunzu than in Dwale (Table 4.3). Chi-square tests on the family sizes of 1-5 and 6-10 members showed no any significant proportion (χ^2 = 4.669, p = 0.697) in the number of HHs between Dwale and Livunzu EPAs.

Table 4.3: Demographic characteristics of households interviewed in Dwale and Livunzu Extension Planning Areas in March 2014

	Dwale N = 105	**Livunzu N = 98**
Sex of HH head (%)		
Male	52.0	47.1
Female	48.0	52.9
Age of HH head (%)		
Young (19-33 years)	29.8	27.8
Middle-aged (34-64 years)	51.0	57.7
Old (65-94 years)	19.2	14.1
Marital status		
Married monogamously	68.6	71.4
Married polygamously	5.7	8.2
Separated or divorced	13.3	6.1
Formal education level of HH head (%)		
None	36.2	36.7
Primary level	53.3	50.0
Secondary level	9.5	12.2
Vocational training	1.0	1.0
Household size (%)		
1-5 members	77.1	61.2
6-10 members	22.9	38.8

4.3.2 Maize production

Typically, the farming HHs interviewed produce crops twice a year with the summer crop being rain-fed while the winter crop relies on residual moisture or irrigation along Shire River or the irrigation schemes of Nkhate and Mwanapwa. The majority of HHs (55.2 % Dwale and 51.2 % Livunzu) indicated their land sizes range from 0.1 to 1 ha, followed by 1.1 to 2 ha (22.3 % Dwale and 20.1 % Livunzu). The maize yield ranged from an average of up to 5 metric tonnes (mt) per ha, although the majority of HHs (76.2 % Dwale and 60.2 % Livunzu) only achieve from 0 to 1.3 mt/ha (Fig. 4.3). The proportional percent of HHs who reported different range of yields were not significant ($\chi^2 = 1.442$, p = 0.837) between Dwale and Livunzu respondents. There was a very weak positive relationship (correlation) between the area under maize production and maize yield during the 2012/2013 growing season (r = 0.174).

All the seven FGD interviews conducted indicated that HHs normally get higher maize production under irrigation than with rain-fed production. The key informants (27 of the 43 district and community key informants) explained that reduced soil fertility, erratic rains, late on-set of the main rains accompanied by heavy storms, alternating with prolonged dry spells, have made crop production very challenging in the study area. It was also reported that these challenges have seriously affected many smallholder farmers resulting in reduced crop yields during the past 5 to 7 years in both EPAs. The increased frequency of droughts and floods were among the factors mentioned in all seven FGDs as contributing to reduced maize production under rain-fed conditions. Six of the seven FGDs informed the interviewers that deforestation resulting from the upland (Dwale EPA and the upper part of Livunzu EPA) cutting down of trees for charcoal-burning and fuel wood was one of the contributing factor to droughts and floods which have a negative effect on crop yields with some crops actually being washed away and all these are associated with CC.

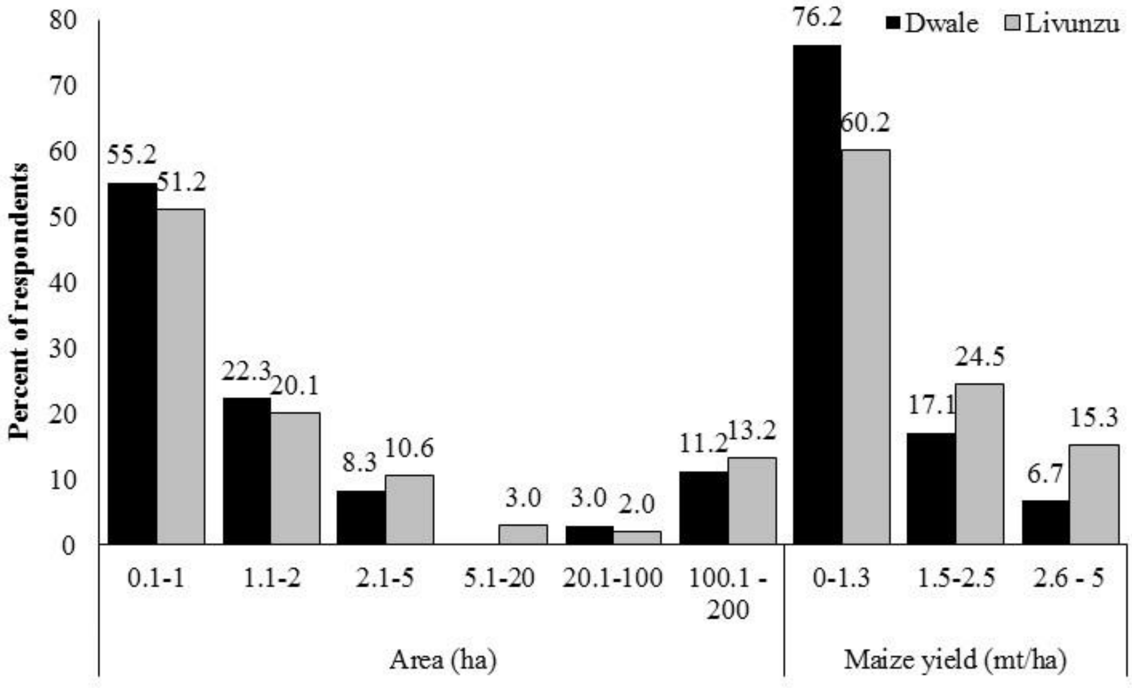

Figure 4.3: Land size and maize yield by the respondent during the 2012/2013 growing season under rainfed conditions in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, respectively (n = 203).

At the time of the study in March 2014, the mean amount of maize in stock per HH was 53.1 $\pm$ 7.7 kg in Dwale and 121.5 $\pm$ 102.1 kg in Livunzu. This was mainly from the winter harvest. The winter maize crop is commonly harvested between August and September. Despite the low yield of the rain-fed maize, HHs reported typically storing some of this maize from May through to March the following year.

4.3.3 Maize postharvest practices

The 50.5 % (Dwale) and 40.8 % (Livunzu) of the respondents reported that female HH members provide harvesting labour in the study sites. According to 8.6 % (Dwale) and 24.5 % Livunzu) respondents, harvesting labour was provided by adults, whereas 15.2 % and 17.3 % in Dwale and Livunzu, respectively, reported that harvesting labour is provided by all HH members. It was reported by 12.4 % and 7.1 % of respondents in Dwale and Livunzu, respectively, that only males provided the harvesting labour. Respondents at both sites also pointed out that they commonly harvest maize as green mealies/fresh cobs which are sold for cash.

Fig. 4.4 shows that the majority of HHs start harvesting maize when it is fully dry, although some of the HHs reported that harvesting was done when the was physiologically mature. The majority of HHs reported that they prefer harvesting maize in the morning in Dwale and Livunzu EPAs compared with the other times of the day (anytime, afternoon and evening) (Fig. 4.4). However, the percent of HHs who preferred specific times of the day for harvesting maize between the two EPAs were not significantly proportional to each other (χ^2 = 1.688, p = 0.793).

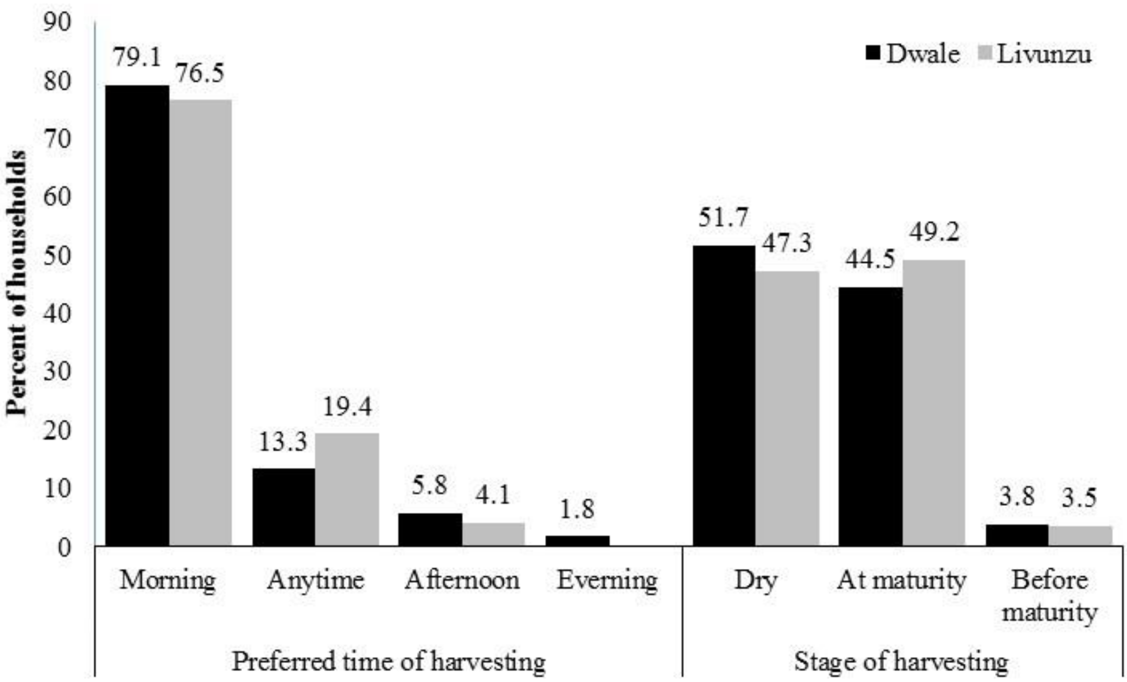

Figure 4.4: Preferred timing and stage of maize harvesting in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, respectively (n = 203)

Farmers reported that they check the moisture content of their maize before storage to prevent losses, as the grain is harvested when the grain moisture content is still above 13.5 % in order to prevent the crop from being stolen in the field. Farmers also reported that sometimes, they harvest maize during late-season rains, which they associated with CC, and the results in wet grain moisture content above 13.5 %. Most of the HHs normally check grain moisture physically using their hands, by squeezing the grains to evaluate the firmness of the grains (Fig. 4.5a). However, a Chi-square analysis showed that the proportions in number of HHs using each method of checking maize grain moisture content were not significantly different (χ^2 = 6.033, p = 0.419) between the two EPAs (Dwale and Livunzu).

After grain drying, the majority of smallholder farmers at both sites treat their maize before storage using recommended synthetic pesticides which contain a cocktail of an organophosphate and pyrethroid (Fig. 4.5b). The different methods of grain treatment used on stored maize by the HHs were not significantly proportional between the number of HHs in Dwale and Livunzu EPAs (χ^2 = 1.594, p = 0.661). Some farmers use plant extracts which are locally found in the communities (Dwale, 14.3 % and Livunzu, 10.2 %). One of the commonly used plant is neem tree, *Azadirachta indica,* where leaves are applied as a dried powder admixed with stored maize grain.

The PH problems and the major causes of maize post-maturity losses reported by HH respondents include field pests, storage pests, hybrid maize variety, storage environment and rotting. The majority of respondents (Dwale 44.8 % and Livunzu 54 %) reported that the major cause of pre-harvest and postharvest maize losses was storage pests. In the FGDs, farmers explained that some maize PH activities like harvesting were not being done at the recommended time. One of the challenges to this was theft, which forced HHs to harvest grain before it was fully filled and dried. A total of 99 and 97 HHs in Dwale and Livunzu EPAs respectively, check grain moisture content to make sure the grain is dried to the recommended moisture content. Five out of the seven FGDs reported notable PH problems included aflatoxin contamination, high insect pest infestation and grain discolouration due to mould attack.

The main crop storage facilities used in the Shire Valley were traditional outdoor woven wooden granaries, sometimes with mud-plastered walls (Fig. 4.6), woven polypropylene bags and hermetic containers such as metal silos. Woven polypropylene bags were the most common and were used by over 75 % of HHs in both EPAs (Fig. 4.45c). A few HHs (3.1 %) in Livunzu indicated they did not have permanent storage facilities because their maize grain gets depleted before commencement of any long-term storage (Fig. 4.5c). The majority of the HHs reported using ordinary rooms as storage facilities for maize in both EPAs but the proportion number of HHs using different types of storage facilities between Dwale and Livunzu EPAs were not significantly different (χ^2 = 1.627, p = 0.653).

Nevertheless, in Dwale all HHs interviewed own grain storage facilities that include polypropylene bags and/or hermetic containers such as metal silos (Fig. 4.5c). The district key informants reported that Stephanos, an NGO, had provided free metal silos with grain holding capacity of 1.0 to 1.8 tons, to some HHs in Livunzu community for use as community grain stores. These grain stores supply maize grain during the lean period at a subsidised price to help alleviate hunger in the area. These storage facilities were hosted by few farmers on behalf of the farmers groups. According to the key informants, CC has partly contributed to the prevalent hunger in Livunzu and Dwale EPAs. The study revealed that few HHs in Dwale and Livunzu EPAs still use the traditional granaries for crop storage (Fig. 4.5c).

The grain protectants currently used on stored maize in the study area of Dwale and Livunzu, include synthetic pesticides and wood ash (Fig. 4.7). However, HHs did not report using any grain protectant (Fig. 4.7). When asked how they had protected their maize grain during 10-20 years ago, few HHs reported having stored it as untreated grain, while the majority of HHs had treated their grain with synthetic pesticides in both Dwale and Livunzu (Fig. 4.7). The Chi-square analysis showed that the Livunzu EPA had a higher significant proportion number of HHs using the synthetic grain protectants on stored maize compared to those in Dwale EPA ($X^2 = 13.369$, $p = 0.010$). However, no significant differences were observed between number of HHs in Dwale and Livunzu EPAs not using pesticides, ash, plant extracts and others methods. Since 10-20 years ago, respondents reported that there has been an increase in HHs using grain protectants on stored grain while some HHs reported that there has been a decrease in the use of grain protectants (Fig. 4.8a). The number of HHs who reported that there were no change, increase or decrease in the quantities of pesticides used showed no significant proportion ($\chi^2 = 1.831$, $p = 0.608$) between Dwale and Livunzu EPA. An increase in insect pest pressure and presence of fewer pests were some of the reasons provided by HHs for the changes in use of grain protectants. There were no significant proportion ($\chi^2 = 8.129$, $p = 0.421$) of the percent of HHs who presented different reasons for the change in grain protectants between the two EPAs (Dwale and Livunzu). A few HHs reported that the change in grain protectant use was due to pests having developed resistance to pesticides (Fig. 4.8b). Furthermore, usage of ash is more frequent in Dwale EPA as compared to Livunzu EPA (Table 4.4)

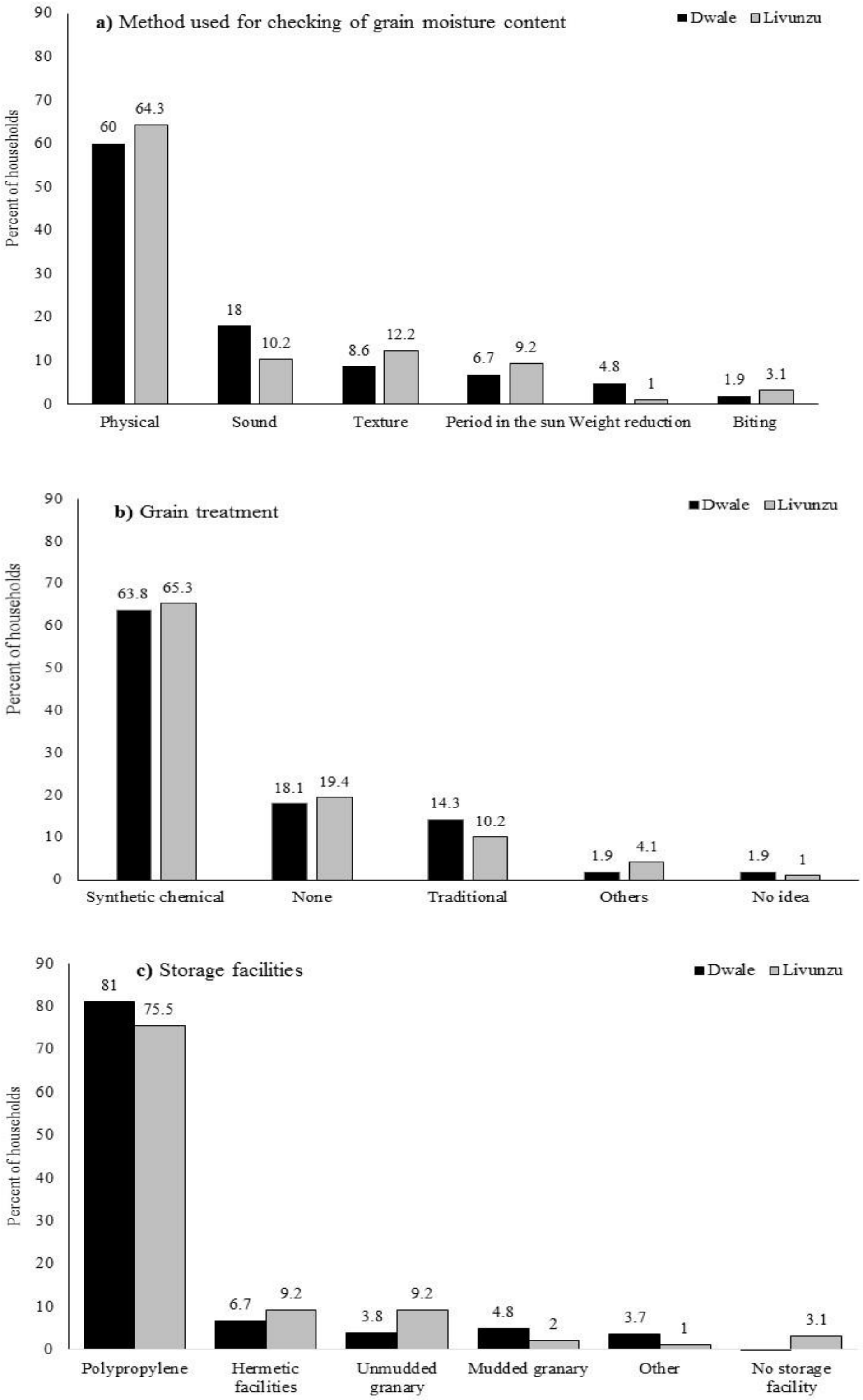

Figure 4.5: Maize grain moisture content checking methods (a), grain treatment (b) and storage facilities (c) used in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, during the 2012/2013 growing season (n = 203).

Figure 4.6: Two traditional outdoor woven granaries constructucted from grass or bamboo for storage of cob maize or groundnuts (left), granary with mud-plastered walls for storage of shelled maize grain (right). Note; the base elevation and the rat guards are not the typical traditional ones with conical shape. (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

At the time of the study in March 2014, 79.4% of the HHs in Dwale and Livunzu EPAs had only enough maize in stock for the HH consumption needs for less than a month. The HHs reported that this maize was mainly from the winter crop's harvest (August and September). However, the HHs were expecting to start harvesting maize from mid-April. Only 4% of HHs had maize stocks sufficient to last them for 3 months, while only 1.3% of HHs had sufficient maize stocks to last up to 9 months.

A Pearson's correlation analysis between the quantity of grain in stock at HH level and the land per capita under maize production showed a weak positive correlation (r = 0.106) and significant (p = 0.023) (2-tailed). The coefficient of determination of suggests that 2.6 % of variability in quantity of grain in stock at HH level was due to land per capita under maize production. Similarly, there was weak positive correlation (r = 0.136) between maize output per capita and the quantity of maize in stock at the time of the study and the relationship was not significant (p = 0.053).

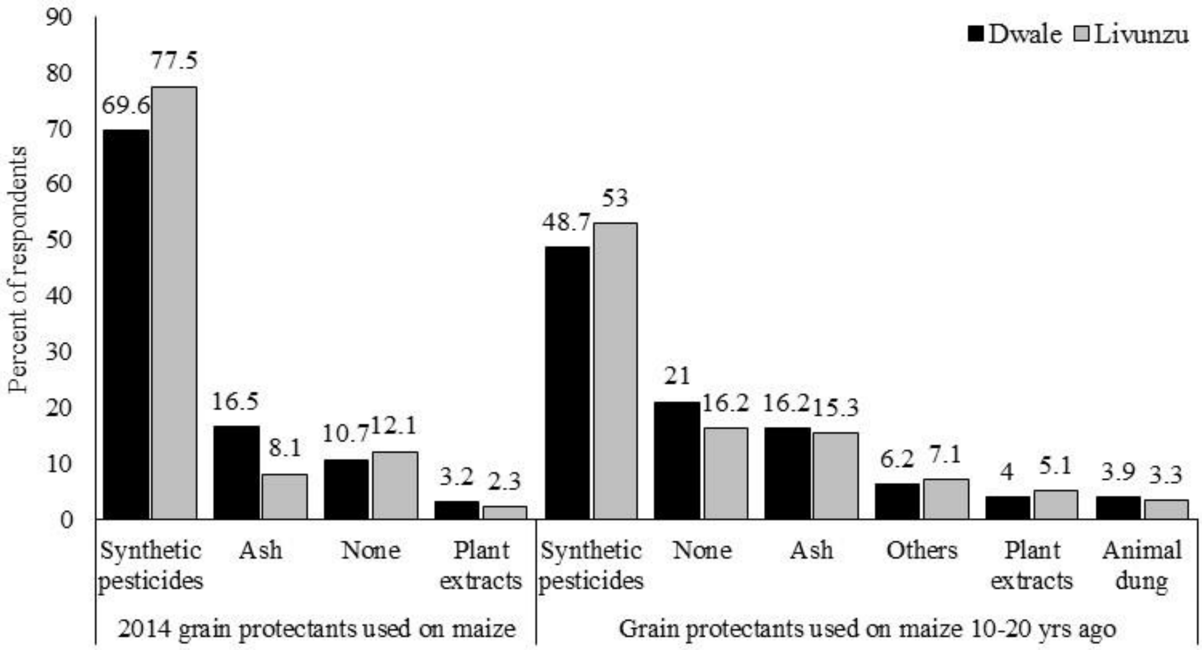

Figure 4.7: March 2014 maize grain protection practices and those used 10-20 years ago in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, respectively (n = 203)

Table 4.4: Results of two samples z-test of proportion on current maize grain protection practices in the Dwale and Livunzu EPAs

	Proportion		p-value
Grain Protectant	**Dwale**	**Livunzu**	
Synthetic pesticides	0.69	0.77	0.207
Ash	0.17	0.08	0.033
Plant extracts	0.03	0.02	0.302

In five FGDs, farmers reported that by January and February each year, most HHs run out of food and as a result are forced to engage in non-farm activities such as mat-making, casual labour, charcoal-making and selling, and selling firewood to generate income to purchase food. Sales of maize grain soon after harvest and storage, is an important source of income for HHs.

The majority of respondents reported that they access PH information through the Government of Malawi (GoM) agricultural extension staff. While the second most important source of PH information reported among the HHs was radio or television. Farmers in FGDs concurred with these findings, elaborating that the main radio stations providing PH information were Malawi Broadcasting Corporation (MBC), Radio 1 and Zodiak. Community key informants estimated that approximately 5% of HHs in the study area own TV sets while many others watch TVs at local shopping centres particularly football matches and then get exposed to televised messages including agricultural messages. Whilst access to PH information is viewed as important, farmers found the content varied in its usefulness. About 44.8% in Dwale and 57.1% in Livunzu of the respondents rated the PH information they had accessed as very good or useful. Further, 5.7% in Dwale and 6.7% in Livunzu of the respondents rated it poor (Fig. 4.9).

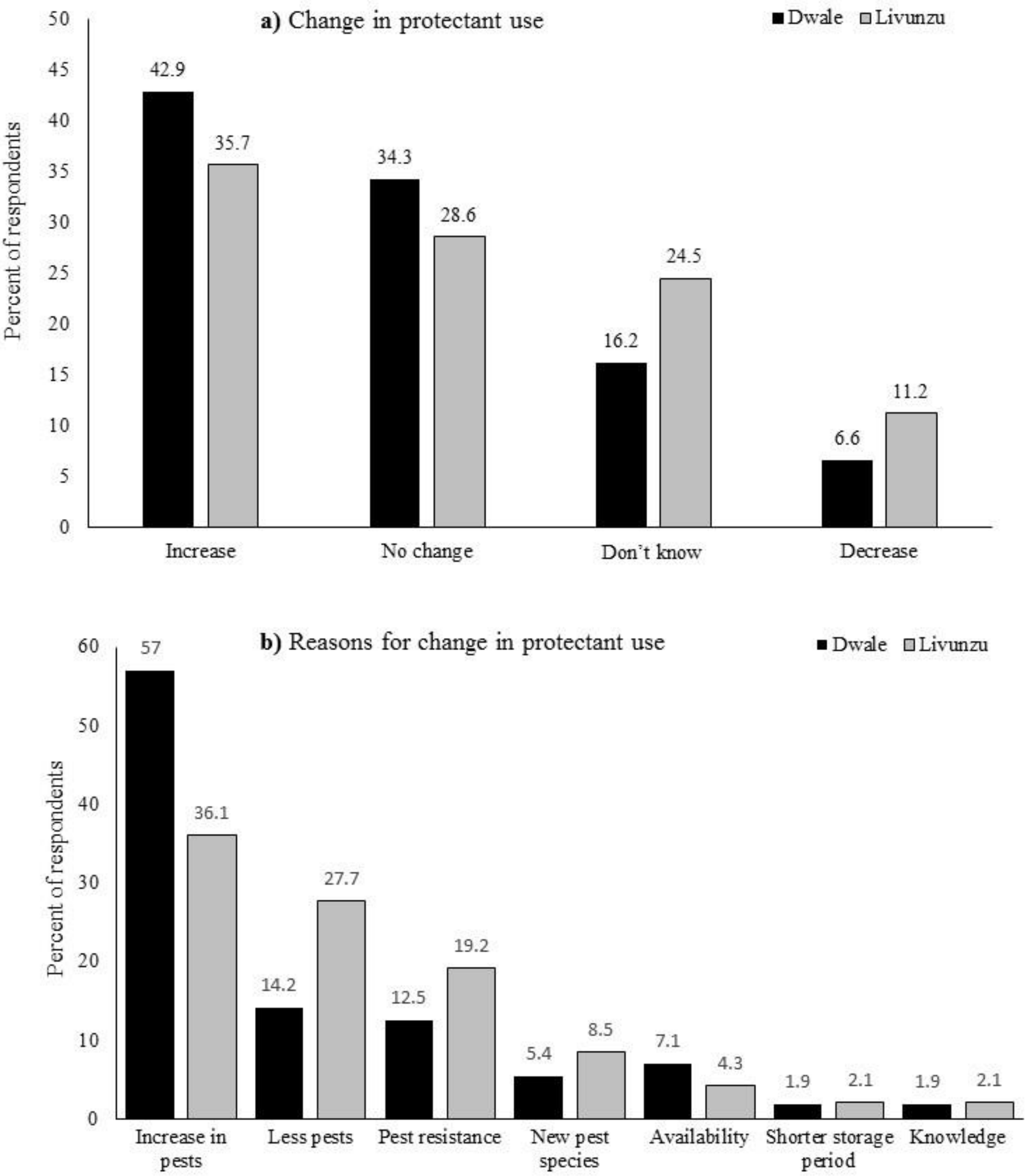

Figure 4.8: Changes in grain protectant use in the past 10-20 years (n = 203) (a) and reasons for the changes (b) in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, respectively (n = 202)

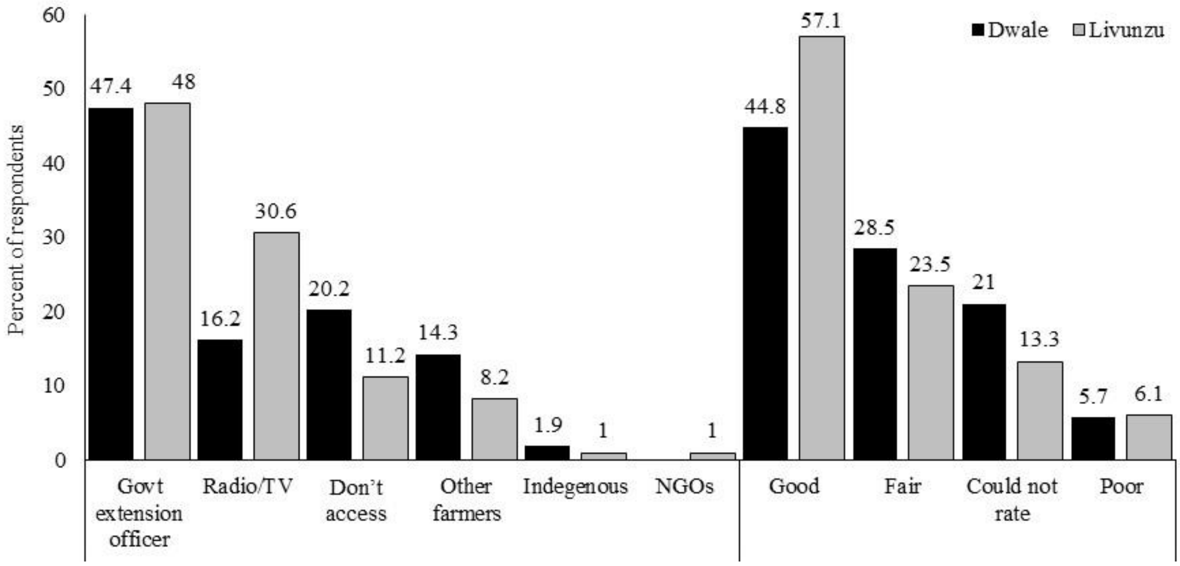

Figure 4.9: Source and reliability of farmers' postharvest information in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, respectively (n = 203)

4.3.4 Climate change and associated risks

In Dwale EPA, 61 % of HHs reported an increase in mean temperature during the past 10-20 years (between 1993-2013 or 2003-2013) while in Livunzu it was reported by 67.3 % of HHs. However, some 23.8 % of HHs in Dwale and 15.3 % in Livunzu reported having no idea whether there had been a change or not in the mean temperature (Fig. 4.10). There were no significant proportion (χ^2 = 2.534, p = 0.639) in the number of HHs on the responses about the kind of change in mean temperature between the two EPAs (Dwale and Livunzu) using Chi-square test. Additionally, 31.4 % (Dwale) and 38.8 % (Livunzu) of HHs reported having observed an increase in the mean annual rainfall for the past 10–20 years. On the other hand, 26.7 % and 16.3 % of HHs in Dwale and Livunzu EPAs respectively, indicated there had been a decrease in the mean rainfall in the past 10-20 years although some HHs had no idea whether there was an increase or a decrease in mean rainfall (Fig. 4.10). Similarly, Chi-square test on the kind of changes in mean rainfall showed no significant differences in proportion number of HHs between respondents from Dwale and Livunzu EPAs (χ^2 = 4.930, p = 0.177).

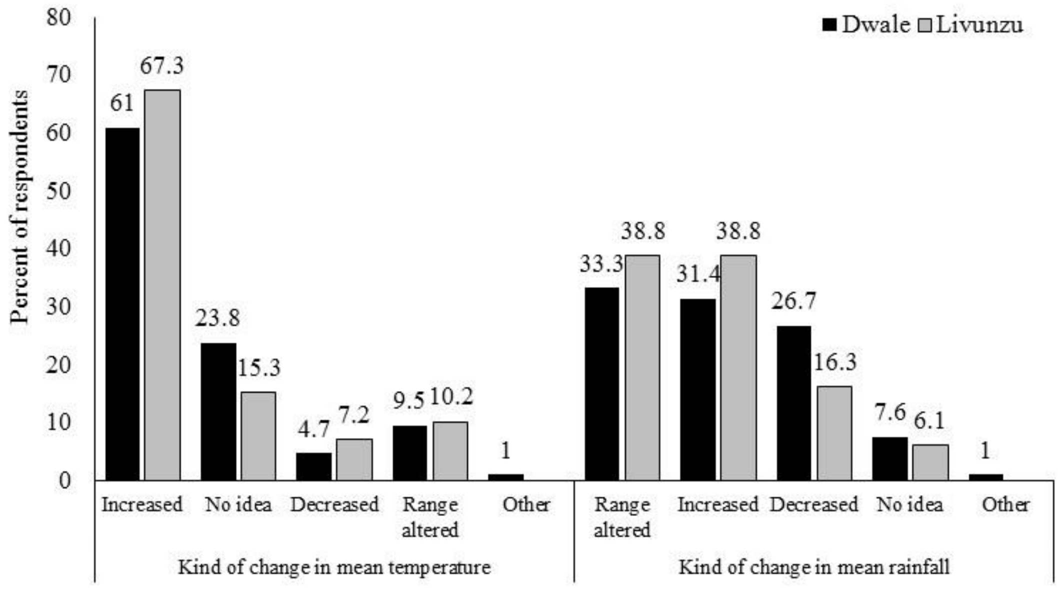

Figure 4.10: Perceived change in mean temperatures and rainfall in the past 10-20 years in Dwale and Livunzu Extension Planning Areas of Thyolo and Chikwawa districts, respectively (n = 203)

Farmers had different ways of describing CC, for instance during one FGDs, farmers said "*In this area a normal season is characterized by its rainfall pattern whereby rainfall should be moderate in amount and timely for planting of crops. Originally in the 1980s and 1990s, normal rains used to start in October with first early rain showers in September but now they start late December or early January*".

FGDs revealed a shift in the onset of the start of the rainy season from October/November to January. To signify the CC and CV one farmer said "*In 2007, rains started in February and we planted our rice in March, this was very unusual to us. Furthermore, the rainfall has become erratic and sometimes it comes as a heavy down-pour leading to disasters, for instance disease outbreaks like cholera, crop damage and property destruction e.g. houses.*" The meteorological officers in Blantyre, confirmed the increase in temperature as an indicator of CC, and explained that Chikwawa district had recorded its historically highest maximum temperatures of 48.6 ºC and 44 ºC in 2013 and 2014 respectively. It was also reported that the cold season was becoming warmer than it had been 10-20 years ago. The most prevalent climate-related risks observed by district stakeholders in Shire Valley are dry spells, floods, hailstorms, drought and strong winds. They reported an increase in floods, heavy storms, hailstorm occurrence and pest outbreaks.

Farmers' main source of the climatic or weather information was radio/TV as indicated by 32.5 % (Dwale) and 50 % (Livunzu) of HHs, while 22.5 % Dwale and 12.5 % Livunzu of HHs indicated GoM extension staff. The source of seasonal forecasts information was radio/TV reported by 42.4 % of the respondents followed by government by 9.9 % of respondents. However, 41.4 % of HHs had no idea on the source of the seasonal forecasts. According to the DADOs of Thyolo (Dwale) and Chikwawa (Livunzu) 38 % and 40 % of AEDO positions are vacant currently in their districts respectively.

The majority of respondents had no idea whether the indigenous knowledge they used was reliable or not in making decisions regarding the climate or weather in general. However, 22.7 % of the respondents indicated good reliability of indigenous knowledge while 13.3 % and 8.4 % rated it as fair and poor respectively. The majority of respondents reported having noticed a relationship between the climatic or weather patterns and crop pest presence, while 26.1 % of respondents had not noticed any relationship. The district experts explained that the sources of CC information included the Department of Disaster Preparedness, GoM frontline staff, radio, farmers' views, focal discussions with community leaders, village committee reports and their own observation of the environment. It was also reported that Church Aid in Relief and Development (CARD) sends weather forecast information every 2 days to all district staff through mobile phones which helped the staff in planning the mitigation of hazards and risks associated with CC. The district experts stated that they knew of no climate projections specifically developed for Shire Valley, but confirmed that the climate had changed with increased temperatures and more erratic rainfall recently than in past years. Some experts such as the DADO for Thyolo district claimed that although he was not aware of any specific CC projections for the district, based on his own experience there he predicted a reduction in rainfall amounts and shorter rainfall seasons in future. The key informants' interviews explained that traditionally, the occurrence of strange birds or multitudes of ants were clear indications that there would be heavy rains. The outbreaks of pests and diseases including storage pests were also linked to the high temperatures, rainfall amount and rainfall distribution.

Some of the strategies used by farmers to cope with climate-related risks include relief food, maize purchases from the market and obtaining maize from their own social networks. Key informants reported that additional adaptation options to climate risks for smallholder farmers in the study area included discouraging farmers from selling green maize before they are sure of the next season's harvest, planting early maturing and drought resistant crops, and treating stored grain with effective protectants.

4.4 Discussion

4.4.1 Demographic and social characteristics of the households interviewed

The study found that most PH activities in the Shire Valley are performed mainly by females, in addition to the household chores. Child-headed HHs and others seek employment to earn cash for food purchases during drought seasons. About 36 % of the heads of HHs in the study area have no formal education. In Kenya, Abtew *et al.* (2016) reported that education and proximity to extension services improved farmers' knowledge on stored grain pests and protection. In Dwale EPA the GoM agricultural extension staff have to travel more than 15 km on a bicycle or motorcycle to reach their working area, which likely affects the quality and frequency of extension service provision to the smallholder farmers.

4.4.2 Maize production and postharvest management practices

The reported small field size of less than 2 ha/ HH was associated to the rapid increase in population in the southern region of Malawi (Fig. 4.3). On average, 70 % of smallholder farmers in Malawi cultivate 1 ha with a median cultivated area of 0.6 ha, with 70 % of the land allocated to maize (Nordhagen and Pascual, 2013). Commonly, the land in Malawi is under customary land tenure arrangement (Beegle and Steele, 2010). A study reported mean maize production per capita of 48.5 kg among the ultra-poor and 63.3 kg for the poor (Dorward and Chirwa, 2011). This results in the majority of the HHs running out of maize stocks after six months of storage due to low production which is also associated with CC amongst other factors. Thereafter, at this point HHs start searching for coping strategies like mat-making to generate income for purchasing of food. For example, at the time of the study in March 2014, 10 months after the harvest, the majority of HHs had no grain in stock.

Conversely, some HHs produce maize twice a year thereby making their HHs food secure. However, sometimes stored crops including maize may be washed away when there are floods; rendering the affected HHs food insecure.

The HHs in Shire Valley use a number of grain protectants on their stored maize grain, compared to 10-20 years ago when far fewer grain protectants were available (Fig. 4.7). However, with the predicted increase in temperature, the efficacy and persistence of these protectants is likely to be reduced as there is likely to be a faster degradation of the product (Mubayiwa *et al*., 2018). In addition to the use of synthetic storage pesticides to treat their maize, a few HHs use plant materials such as dried neem leaves. The limited use of neem as a grain protectant in the area was reported due to it imparting a bitter taste to the treated grain although, this would not prevent it being used to protect retained seed from insect damage during storage (Tofel *et al*., 2016).

A few HHs in the study area use ash to control storage insect pests. Although these HHs (Dwale and Livunzu EPAs) did not specify whether the ash was from burning wood or crop residue, it is most likely to be the former. The HH respondents reported the use of ash to be effective in controlling *P. truncatus* in stored maize. Conidia of *Beauveria bassiana* applied was more effective in controlling *P. truncatus* compared to wood ash when applied at 0.0005, 0.005, 0.05 and 0.2 g /100 g maize (Smith *et al*., 2006). The trials also showed that wood ash applied at 30 % w/w was as effective as pirimiphos-methyl, a synthetic pesticide. However, an application rate of 30 % w/w is considered excessively high and environmentally unsustainable, and would need HHs to deliberately store the ash generated by their daily firewood cooking, until the large quantities required were obtained (Baoua *et al*., 2012). However, CC, particularly an increase in temperature is expected to change the multiplication rate of some stored-grain pests' population which might positively or negatively affect the levels of PHL (Sharma and Prabhakar, 2014). Before *P. truncatus* was introduced into Malawi, farmers would store untreated maize with few problems. The grain weight loss for stored maize recorded in Shire Valley before the introduction of *P. truncatus* was 2 % to 5 % mainly due to *S. zeamais* damage (Golob, 1981), while in the wake of *P. truncatus*, it rose sharply to 15.7 % (Anon, 2010).

According to the current study, the most common grain storage facilities used in the study area were woven polypropylene bags, mostly used in combination with synthetic grain protectants. The increased use of these storage bags since 10-20 years ago, is due to both their easy availability and accessibility, increasing food insecurity and alleged high incidences of maize theft in the southern region of Malawi if maize is stored outside the dwelling houses (Maonga *et al*., 2013; Manandhar *et al*., 2018). The increase in maize theft cases was mainly a result of reduced maize production partly emanating from the reported CC in the study area and the high population density according to the current study. Further, if maize with a moisture content just above 13.5 % is placed in a well-ventilated store it promotes further drying of the grain due to air-flow in the store. However, once that same maize with a moisture content above 13.5 % is placed in polypropylene bags in a store room without proper ventilation, the room becomes humid and hot, which can result in grain rotting and potentially the development of aflatoxins (Matumba *et al.*, 2009). However, the rains that come during the harvesting time which are associated with CC can also contribute to maize PHL during storage if the grain is not properly dried after harvesting. This untimely harvesting result in rotting leading to development of aflatoxins thereafter. This is problematic as HHs lack proper drying facilities to dry grain to the recommended moisture content for safe storage at the homestead. A study of maize grain stored in polypropylene bags with a grain moisture content of 12.3 % in Malawi showed occurrence of Aflatoxin B_1 exceeding the permissible 5 µg per kg limit (Matumba *et al*., 2009).

Small metal silos provide opportunities for farmers to avoid the use of synthetic pesticides for controlling stored grain pests including *P. truncatus* (De Groote *et al.,* 2013; Gitonga *et al*., 2013). Several studies indicate that metal silos are effective in minimising stored maize losses caused by insect pests such as *S. zeamais* and *P. truncatus* in SSA countries including Kenya, Malawi and Zimbabwe (Gitonga *et al.*, 2013; Singano *et al*., 2013; Chigoverah *et al.*, 2014: Chigoverah and Mvumi, 2016). Small metal silos, have recently been distributed for free by the GoM e.g. through the Irrigation, Rural Livelihood and Agricultural Development Project (IRLADP), but still wide adoption by the farming communities in Dwale and Livunzu EPAs has remained low. The low adoption rate is probably partly due to the associated lack of grain security as the silos were being mounted outside dwelling houses, which made farmers worry about the security of their grain (Gitonga *et al*., 2013). District stakeholders confirmed that few HHs still use the traditional granaries constructed from bamboo and timber, and that some HHs do not need storage facilities because their crop harvests are frequently low to justify use of standalone stores.

Proper use of postharvest information and knowledge by smallholder farmers reduces problems of applying storage grain protectants or chemicals and other grain management activities. amongst the Mainly communities that lack of knowledge on crop PH handling end up mis-using the chemicals, by applying field crop pesticides on stored grains. Apart from the low education level, the lack of PH skills and knowledge amongst extension staff and the absence of PH aspects in most agricultural curricula and training courses are contributory factors to poor crop PH management (Stathers *et al*., 2013).

Effective and proper use of grain protectants and storage facilities depend, among other factors, on access to information by farming communities. In Shire Valley, farmers have opportunity to discuss and demonstrate the available agricultural adaptation techniques, when interacting with the GoM agricultural extension staff. The farmers perceive the GoM agricultural extension staff as being a valuable and reliable source of information. In Kenya, Government agricultural extension staff, lead farmers and farm input suppliers were reported to be the information sources for smallholder farmers (Abtew *et al*., 2016). However, newspapers and NGOs were not viewed as important sources of PH information in Shire Valley. Given that 44 % of extension staff positions are vacant under the GoM Department of Agricultural Extension Services (DAES) at EPA level (Maonga *et al*., 2013), it is not surprising that a shortage of agricultural extension staff to meet the growing number of farmers in the two study EPAs was reported. The high number of vacant positions for the extension staff in the two EPAs has impacts negatively on the delivery of extension messages. This may make it difficult to provide effective PH management extension support to smallholder farmers in the target areas. Comparable studies in Kenya showed that the majority of farmers (89.8 %) had never received information on general pesticide use and pest management options due to shortage of extension staff (Abtew *et al*., 2016). To prevent the mis-use of chemicals and to improve general grain PH management, the district key informants emphasised the need to increase understanding and skills in crop PH management such as storage hygiene, harvesting process and timing, drying, moisture content assessment, sorting, protection, storage and monitoring.

4.4.3 Climate change perceptions and associated risks

Farmers perceived that they are now experiencing higher temperatures throughout the year compared to during the past 10-20 years when cooler temperatures were experienced in the rainfall season (Fig. 4.1). This coupled with the current more frequent occurrences of floods compared to the past 10-20 years. Rainfall variations in Shire Valley are known to be associated with floods and prolonged dry spells (Potts and Wiley, 2006). Furthermore, farmers in the study area view CC as being characterised by late on-set of rains, prolonged dry spells and more erratic rains. Previous studies indicated that there are decreasing monthly, annual and seasonal rainfall trends. Further to that there is a complex countrywide rainfall pattern with annual mean of 1,095 mm (Ngongondo *et al*., 2011).

The majority of HHs also reported experiencing both a decrease in rainfall and increase in temperature (Fig. 4.10). Correspondingly, droughts and changes in the timing of rainfall associated with increased variability and intensity has been reported in Southern Africa in the last 50 years (Thomas *et al*., 2007). Most of the information on CC was obtained from district stakeholders who reported the need to increase awareness and understanding of CC and adaptation, and mitigation options among farmers. The district stakeholders suggested incorporating CC awareness and adaptation strategies into educational school curricula including at primary level.

Most district level stakeholders indicated that district technical staff need greater understanding of CC issues including the causes, mitigation options, adaptation strategies and effective approaches for training communities on CC adaptation. Among the coping strategies by Shire Valley communities are increased dependency by HHs on relief food commonly distributed by international aid organisations, maize purchases from the markets such as Agricultural Development and Marketing Corporation (ADMARC) and vendors. Many studies on adaptation strategies to CC have focused on field crop production and not on crop PH systems. These crop production strategies include use of high yielding, drought and disease-tolerant seed varieties, and development of cost-effective production technologies, all aimed at increasing agricultural productivity (Stringer *et al*., 2009b). During the FGDs, it was clear that communities realize the need to acquire information on different credit sources to finance small-scale businesses which alleviate CC impacts and contribute to food and nutrition security. Respondents in FGDs perceived that more men were busy or away doing casual labour to provide food for their families. Therefore, it is logical that the CC information should be provided to the women considering that they are the ones who attend farmer meetings.

The study established that different activities along the PH chain are commonly practised by different HH members. Smallholder farmers have changed their grain storage practices by switching to in-house grain storage in polypropylene bags as opposed to the traditional out-door storage in stand-alone timber or bamboo structures. The switch in storage practices is ascribed to frequent droughts resulting in crop failure and subsequent food shortages which then increases the prevalence of theft in the standalone structures outside living quarters. The reported historical increase in maximum temperature in Chikwawa district creates a conducive environment for the multiplication of some storage insect pests, such as *P. truncatus* and *Sitotroga cerealella* (Olivier) which can tolerate high temperatures (Dong *et al*., 2013). However, increase in maximum temperature beyond 35 °C may result in the suppression of some maize storage insect pest species such as *S. zeamais* (Hodges, 1994; Pražić Golić *et al*., 2016). Furthermore, such increase in temperature reduces the effective period of residual pesticides as degradation of the pesticides is faster with the increase in temperature resulting in increased PH losses in stored maize (Mubayiwa *et al*., 2018).

High temperatures also affect pest biology by shortening insect pest life cycles. Short life cycles are associated with increased chances of development of resistance to pesticides by the insects (Musolin and Saulich, 2012). *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) is typically prevalent in hot and dry agro-ecologies (Munyuri and Tabu, 2013), as found in the Shire Valley of Malawi. Droughts result in poor grain filling, making grains softer and prone to infestation by storage insect pests (Weightman *et al*., 2008). Floods may also dampen the drying grain in the field or at the homestead which may result in the development of moulds. Further, this increases insect pest attack if the grain drying process is not properly managed. The switch from outdoor storage to indoor storage has serious human health implications. Application of synthetic grain protectants to grain stored inside the dwelling house results in increased pesticide exposure for farmers and their families as they stay in the same room as the treated stored grain. Household members will be exposed through continuous inhalation. This can be dangerous and potentially fatal if farmers use fumigants such as phosphine.

4.5 Conclusion

The study respondents reported that the occurrence of food insecurity has increased in Shire Valley due in part to crop failure as a result of high temperatures and/or destruction by hailstorms, floods, prolonged dry spells and/or erratic rains, all of which result in HH level food insecurity. There is a high dependence by HHs in the study area on relief food distributed by NGOs and the GoM. There have also been prolonged hot seasons and high temperatures of up to 45 ^{o}C have been recorded.

Currently, farmers use more synthetic pesticides than 10-20 years ago due to perceived increased insect pest pressure. The farmers have switched from solid outdoor timber or bamboo-based grain storage structures to indoor polypropylene bag storage in response to insect pest attack by *P. truncatus* on both the grain and timber- or bamboo-based structure, and grain theft issues. The majority of HHs in Shire Valley store their grain in woven polypropylene bags while other HHs treat their stored grain with registered synthetic pesticides and few HHs use traditional methods including plant materials such as neem leaves.

Low maize production arising from CC and CV, often result in widespread hunger, and was linked to the increased cases of stored grain theft, causing most farmers to abandon traditional outdoor granary use and opt for indoor grain storage. Rising temperature is perceived to have resulted in higher pest pressure while the performance of different grain protection technologies in the study area is not known.

Many HHs have little or no idea of how PH management practices of maize grain are, and will be, affected by CC and CV, and therefore were not aware of appropriate adaptation strategies to reduce impact of the environmental changes. The development agencies active in Shire Valley, have not incorporated crop PH handling adaptation strategies to CC into their programmes, and many of the stakeholder organisations lacked PH skills and understanding or specific CC adaptation plans despite the prevalent CC-related challenges. A number of PH adaptation strategies were recommended based on the current study including increasing extension PH knowledge and skills through training and on-farm demonstrations, promotion of careful crop drying and good storage hygiene, safe and effective use of grain protectants, and effective use and distribution of improved cost-effective storage technologies such as hermetic bags in Shire Valley. Further research into CC and PH adaptation strategies and their inclusion in agricultural and climate-change policies is paramount and would be beneficial to smallholder farmers struggling to produce and store grain crops in environmental conditions similar to those found in Shire Valley of Malawi.

CHAPTER 5: EFFECTIVENESS OF GRAIN STORAGE FACILITIES AND PROTECTANTS IN CONTROLLING STORED-MAIZE INSECT PESTS IN A CLIMATE-RISK PRONE AREA OF SHIRE VALLEY, SOUTHERN MALAWI[2]

5.1 Introduction

Maize, *Zea mais* is the main staple food crop for the majority of people in sub-Saharan Africa (SSA) where over 70 % of the crop is produced by smallholder farmers. Over 60 million tonnes of maize is produced annually in SSA, excluding South Africa (Alexander *et al*., 2017). Although published data on quantity of grain retained is scarce, anecdotal evidence suggests that 60-80 % is stored on-farm by smallholder farmers. Grain storage is a key household food security strategy practised by the smallholder farmers but storage insect pests are a major problem causing grain damage and economic losses. Additionally, climate change (CC) is another factor expected to negatively affect grain storage in SSA. This is a region that is highly vulnerable to the effects of CC (Stathers *et al*., 2013; Asfaw *et al*., 2014). The strongest warming is projected to occur on the land surface in tropical and Northern Hemisphere subtropical regions (Serdeczny *et al.*, 2017). The temperature projections for Shire Valley in southern Malawi showed a 3 ^{o}C increase by the year 2065 and a monthly mean temperature of above 32 ^{o}C (Matiya *et al*., 2011).

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[2] Modified and published as: Singano, C. D., Mvumi, B. M. and Stathers, T. E. (2019). Effectiveness of grain storage facilities and protectants in controlling stored-maize insect pests in a climate-risk prone area of Shire Valley, Southern Malawi. *Journal of Stored Products Research*, 83, 130-147.

Global warming is likely to affect populations of stored product insect pests, increase degradation rates of storage insecticides and reduce the efficacy of storage technologies such as hermetic bags (Gornall *et al.*, 2010; Sharma and Prabhakar, 2014). A 2 ^{o}C increase in ambient temperature is estimated to have the potential to increase the number of insect life cycles by up to five times during a cropping season (Bale *et al.*, 2002). Laboratory studies showed that the duration of the egg, larval and pupal stages of the Larger Grain Borer (LGB), *Prostephanus truncatus* Horn. (Coleoptera: Bostrichidae) decreased with an increase in temperature up to 31 ^{o}C at a RH range of 50–80 %, but increased at a temperature of 35 ^{o}C (Hance *et al.*, 2007). *Prostephanus truncatus* is among the most devastating pests of stored maize, and was accidentally introduced to East Africa in the late 1970s from Central America and Mexico (Hodges, 1994) and is now endemic in SSA.

Postharvest (PH) losses of maize are estimated to be 10 to 20 % annually in SSA. This is mainly caused by storage insect pests (World Bank, 2011). Losses of this magnitude, are an important contributing factor to food insecurity in many African countries including Malawi (Alexander *et al*., 2017). In Malawi, as across much of SSA, maize was traditionally stored in outdoor woven-basket style granaries (Hernandez, 2012). However, Malawian farmers are now increasingly storing their maize grain in polypropylene bags inside their homes (Singano *et al*., in prep.). The majority (65.5 %) of smallholder farmers in Malawi typically admix synthetic pesticides, either dust or liquid formulations, with their grain prior to storage, or add ash (3.0 %) or plant materials (12.6 %) to manage storage insect pests (Golob, 1981; Jayas *et al.*, 1996). The increasing demand for alternative pest management options to storage synthetic pesticides (Cooper and Dobson, 2007), has led to the development of several new technologies including modern hermetic storage facilities such as the Super Grain Bag (SGB), Purdue Improved Crop Storage (PICS) bag and the metal silo (MS). The ZeroFly® bag (ZFB), a woven polypropylene grain bag with the insecticide deltamethrin incorporated into the fabric so as to prevent any stored insect pests coming into contact with it is another recently introduced technology (Baban and Bingham, 2014). Njoroge *et al.* (2014) showed that maize stored in PICS bags lowered the growth of *P. truncatus* populations and prevented re-infestation from the surrounding storage environment while polypropylene (PP) bag, had a build-up of insect population and allowed cross-infestation. With routine maintenance and good management, small metal silos can last for more than 20 years (Boxall *et al.*, 1997). The use of synthetic pesticides is among the most reliable method of controlling storage pests. However, continuous use of the same pesticides result in development of resistance among the targeted pest species that lenders the pesticide not useful for the intended purpose (Stejskal *et al.*, 2015). Neem leaves contain chemicals that mainly disturb the pest maturation especially insects (Adda *et al.*, 2002). However, performance of these modern storage technologies under smallholder management in different climate-risk prone areas has not been widely tested, and in comparison to local practices.

The objective of this study was to assess the performance of new storage facilities and grain protectants in protecting stored maize grain against storage insect pests under smallholder farmers' storage conditions in Shire Valley, a CC prone area in southern Malawi.

The specific objectives were to:

1) Assess the effectiveness of synthetic and non-synthetic grain protectants in controlling storage insect pests;
2) Determine the performance of storage facilities in controlling storage pests in a climate change prone area in Shire Valley;
3) Determine smallholder farmers' grain storage conditions (temperature and relative humidity) in Shire Valley.

5.2 Materials and methods

5.2.1 Study site and description

The studies were conducted in Shire Valley, southern Malawi for two consecutive storage seasons namely the 2014/2015 and 2015/2016 seasons. The trials were conducted at two sites namely Dwale and Livunzu Extension Planning Areas (EPAs), within Thyolo and Chikwawa districts, respectively. Dwale EPA lies at 16^{o} 19′ South and 35^{o} 12′ East, 222 m above sea level (masl) while Livunzu EPA lies at 16^{o} 11′ South and 35^{o} 00′ East, 99 masl (Magombo *et al*., 2012). The study area is characterized by two main agro-ecological zones namely Shire Highlands (upstream-Thyolo) and Lower Shire Valley (downstream-Chikwawa). The up-stream area was Dwale EPA under Thyolo district and the down-stream area was Livunzu EPA under Chikwawa district. Thyolo shares a boundary with Chikwawa and normally receives an average rainfall of 1,125 mm per year with mean monthly maximum and minimum temperatures of 26.5 ^{o}C and 15.7 ^{o}C, respectively. Chikwawa district receives an average total rainfall of 1,240 mm per year with mean monthly maximum and minimum temperatures of 30 °C and 27 °C, respectively (Ngongondo *et al*., 2011).

5.2.2 Treatments

Four untreated white hybrid maize varieties (DKC 9089, DKC 8053, SC 719 and SC 627) were procured from the farm section at Chitedze Agricultural Research Station (CARS) in Lilongwe district. The selected varieties are also grown by farmers in the Shire Valley. The grain was procured from CARS because it was difficult to get the required volume of untreated maize grain in Shire Valley. Subsequently, the maize varieties were mixed in equal proportions and mixed thoroughly on a tarpaulin using shovels to minimise variations among the treatments. The grain was composed of a mixture of different maize varieties to mimic smallholder farmers' practice. To make sure that the treatments were tested under realistic infestation pressures, the infested grain was not removed because under normal situation, infestation starts in field. The grain moisture content was determined at CARS using an electric moisture meter (Moisture tester Burrows DMC-500, Illinois) before the grain was transported to the study site, 377 km from Chitedze Station. The grain had a moisture content of 13.7 %. All storage facilities used in the studies had a storage capacity of 50 kg each, which is the standard storage container size used in Malawi. The storage facilities were procured either from the local distributors or imported if not locally-available (Fig. 5. 1)

Figure 5.1: Some of the tested treatments with 50 kg maize grain each, placed on wooden pallets inside a farmers house in Livunzu extension planning area in Chikwawa district during the 2015/2016 storage season (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

The homogenized shelled maize grain was subjected separately to seven treatments, which were applied as per manufacturer's or famers' recommendations (Table 5.1). The details of the setting up of the treatments are as described in Section 3.2.2.

Table 5.1: List of the treatments, their sources and application rates as used in the maize grain storage trials in Chikwawa and Thyolo districts, Malawi in 2014/15 and 2015/16

Treatments	**Source**	**Application rate**
Polypropylene bag (PP)	Blantyre Netting Company	Untreated grain
Metal silo (MS)	Fabricated by local master artisans in the Farm Machinery Section at Chitedze Agricultural Research Station	Untreated grain
Actellic Super Dust (ASD) admixed with grain then stored in PP bag	Agricultural Trading Company	25 g per 50 kg of grain
Super Grain bag (SGB)	Chemicals and Marketing Company	Untreated grain
Purdue Improved Crop Storage (PICS)	PolyPack Manufacturing Company	Untreated grain
ZeroFly® bag (ZFB)	Imported from Vestergaard, Switzerland because they were not locally available	Untreated grain
Neem leaf powder (NM) admixed with grain then stored in PP bag	Collected and processed by farmers following their normal practice	153.3 g per 50 kg of maize (application rate derived from farmers' practice)

Note: The ASD (Pirimiphos methyl 16g/kg+ Permethrin 3.0g/kg) treated grain stored in a polypropylene bag and the untreated grain stored in a PP bag were used as positive and negative controls, respectively. ZFB is a polypropylene bag with deltamethrin-incorporated into its fabric at 3 mg/kg

The experiments were laid out in a randomized complete block design (RCBD) and each farmer represented a block.

5.2.3 Temperature and relative humidity

Data loggers (Model RHT10, EXTECH Instruments Corporation) for measuring humidity and temperature were used during the second season (2015/2016). They were not available to the first season (2014/2015). Two farmers from each EPA were purposively selected for the collection of temperature and relative humidity (RH) data using the data loggers which started from week 15 of the storage period, when the loggers became available. The selected farmers were only those who were recommended by the extension staff as being honest and reliable. The temperature and RH data loggers were fixed on walls within the stores where the treatments were placed. Temperature and RH data were recorded every 30 minutes and downloaded to the computer every eight weeks during the sampling visits.

5.2.4 Maize germination tests

Germination tests were conducted at CARS Crop Storage Laboratory at the end of 40 weeks during the 2015/2016 storage season only. The tests were conducted on undamaged grains randomly selected from the maize samples collected at each field sampling interval. Grain from each of the seven treatments collected from each of the four farmers from each of the two EPAs were used for these germination tests. A total of 100 undamaged maize kernels were randomly picked from each sample treatment replicate collected. Cotton wool was placed inside a waterproof petri dishes (Pyrex® United States of America), of 15 cm in circumference and 2.5 cm high. One hundred randomly selected grains were firmly embedded into the cotton wool according to the ISTA recommendations (International Seed Testing Association, 2010). Water was added to moisten the cotton wool with approximately 50 ml per petri dish and over-watering was avoided to achieve normal germination. All petri dishes were maintained under laboratory temperature and RH for 7 to 10 days. The recorded mean weekly temperature and RH during the germination period were 22 ºC and 54 % RH respectively. After that, germinated and ungerminated kernels were separated and counted to calculate the percentage of germinated kernels.

5.2.5 Grain sampling and sample analysis

At the start of each season's trial, baseline samples were collected. Subsequent sampling was done every eight weeks during the 32 weeks long trials in the 2014/2015 and 2015/2016 storage seasons. At every sampling session, a sample of ~ 1 kg of maize grain was taken from each treatment using a 166 cm long multi-compartmented sampling spear (Burrow Equipment Company, Dean gamet MFG CO, Evanston, Illinois) (Fig. 5.2). Each treatment bag or silo was opened in turn and the sampling spear was carefully inserted vertically in at least five different positions from the top surface of the grain, in an identical manner for all treatments. The multi-compartmented sampling spear was used to ensure that grain from bottom, middle and top of the storage facilities was sampled from each treatment. Two sampling spears were used during each sampling session to prevent contamination among the grain protectant treatments and the storage facilities containing untreated grain.

Figure 5.2: Sampling maize grain in a metal silo using a multi-compartimented sampling spear (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

The spears were cleaned using a detergent and dried using tissue paper where necessary to prevent cross-contamination between grain protectants. The high ambient temperature in the area aided rapid drying of the cleaned spears. Special care was taken to prevent the puncturing of the hermetic liners of the SGB and PICS bags during sampling to maintain airtightness.

The collected samples were placed in clearly-labelled transparent plastic bags and tied tightly using elastic bands, and placed in polypropylene bags for safe transportation to the Crop Storage Laboratory at CARS for analysis. At the laboratory, each sample was weighed to obtain the total weight and later sieved using nested sieves (Endecotts Limited, London, England) of 3.35 mm and 1 mm aperture, respectively, to separate grains, insects and trash (flour dust). The sieved adult insects were separated into live and dead per species and were counted. Grain MC was determined three times per sample using an electric moisture meter (Moisture tester Burrows DMC-500, Illinois) (Fig. 5.3). Grain MC was determined during the

2015/16 storage season only as the electric moisture meter had developed a fault during the 2014/15 storage season. The grain samples were divided using a riffle divider (Burrows, Evanston, Illinois, 60204) (Fig. 5.3) to get two sub-samples (~500 g each). Then one sub-sample was discarded while the other one was further divided into two sub-samples (~250 g each). Each of the two sub-samples of 250 g was further divided into two sub-samples (~125 g each), making a total of four sub-samples of ~125 g each.

Figure 5.3: An lectric laboratory moisture meter (left) for measuring grain moisture content, and riffle divider (right) for dividing the grain sample in the laboratory at Chitedze Agricultural Research Station (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

Three of such sub-samples were analysed by manually separating and recording the number and weight of visually insect damaged (grains with storage insect exit and feeding or boring holes) and undamaged grains. The fourth sub-sample was placed in a labelled jar closed using a screw lid fitted with wire mesh of 0.8 mm apertures and kept under ambient conditions for five weeks to monitor the emergence of adult moths such as *Sitotroga cerealella*, *Ephestia* spp. or *Plodia* spp. because these insect species were typically damaged during sieving and so their numbers could not be captured accurately during the normal sample analysis.

5.2.6 Data analyses

Data on % insect damaged grains, % weight loss, number of insect pests by species, and % grain moisture content were initially analysed using descriptive statistics. Statistical analysis was then carried out using R version 3.5.1 (R Core Team, 2018) to test for significant differences among treatments at each EPA. As data were not normally distributed, data for each storage season were subjected to non-parametric Kruskal-Wallis chi-squared analyses followed by Mann-Whitney multiple comparison test at 5 % where significant differences were found. The data from both Dwale and Livunzu EPAs were combined after preliminary analysis showed no significant differences between the sites. The data were split into the early storage stages (week 8 and 16) and the late storage stages (week 24 and 32) as differences between treatments typically become more pronounced during the later stages of storage as grain damage increased.

Box and whisker plots were created and the compact letter display generated during the Mann Whitney multiple comparison tests of the median values of each pair of treatments, was added to these plots to show which treatments were significantly different from each other at ($p < 0.05$). Percentage grain germination data were subjected to one-way ANOVA in Statistical Package for Social Scientists (SPSS) version 19.0 (Gamble, 2001). Tukey's test at 95 % probability was used for post-hoc multiple comparisons where significant treatment differences were observed.

5.3 Results

5.3.1 Insect grain damage during the 2014/2015 storage season

In the 2014/2015 storage season, the baseline percentage of insect damaged grains ranged from 1.4 to 3.4 % in both Dwale and Livunzu EPAs. By 8 weeks storage, less than 12.6 % of grains were insect damaged in all treatments at both Dwale and Livunzu EPAs (Figs. 5.4a and b). Insect damage in the Neem and PP treatments had increased rapidly to above 30 % in both EPAs by 16 weeks storage (Figs. 5.4a and b). The increase in insect damaged grains continued and by 32 weeks of storage was highest in the NM treatment which experienced mean levels of 92.1 % and 72.6 % at Dwale and Livunzu EPAs, respectively (Figs. 5.4a and b). The hermetic storage facilities (MS, PICS and SGB) kept grain damage low throughout the 32 weeks storage with mean grain damage levels of 19.3 %, 3.6 % and 5.3 % occurring in the treatments in Dwale EPA (Fig. 5.4a), respectively, and 29.8 %, 8.6 % and 19.2 % in Livunzu EPA (Figs. 5.4 b). Some rodent and termite damage of the outer woven polypropylene bags for treatments ASD, PP, PICS and SGB was observed at three of the eight participating farmers. Two were observed in Dwale and one in Livunzu EPAs at week 16 during the 2014/2015 season.

When the 2014/2015 data were combined across sites (Dwale and Livunzu EPAs), during the early stages of storage (8 and 16 weeks), there was already a statistically significant difference. The significant different was in insect damage between treatments (Kruskal-Wallis Chi-squared = 58.397, 6df, $p < 0.001$) (Fig. 5.5).

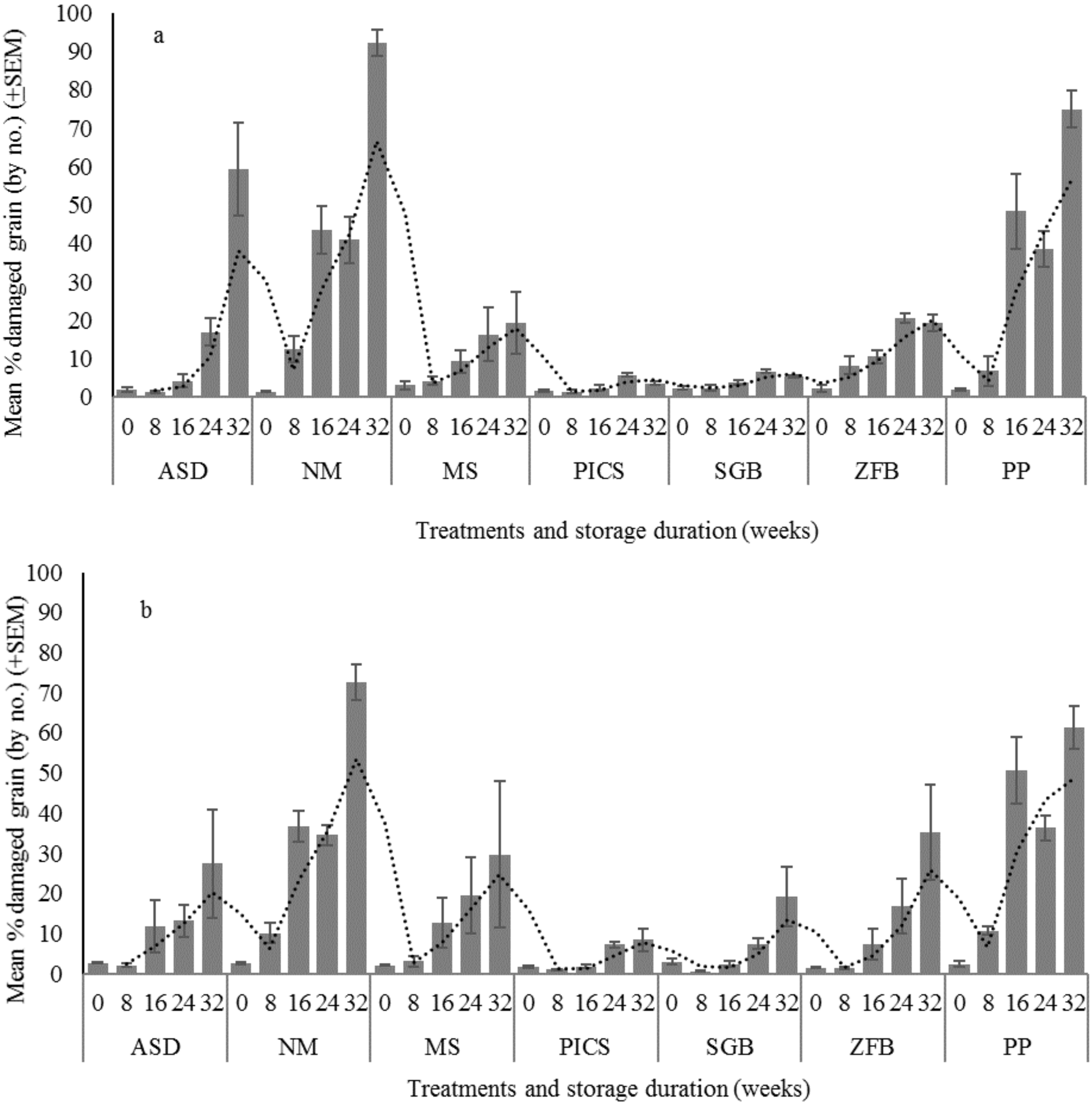


Figure 5.4: Mean percentage number of damaged grains (± SEM) recorded in different storage treatments during the 2014/2015 storage season in: (a) Dwale Extension Planning Area, Malawi (n = 4), and (b) Livunzu Extension Planning Area, Malawi (n=4). SEM = standard error of the mean

Mann-Whitney multiple comparison tests of the median values of each pair of treatments during the 2014/2015 storage season, and early stages of storage, confirmed insect damage was significantly ($p < 0.05$) higher in the NM and PP treatments than in all the other treatments. Insect damage was lowest (< 5 % damaged grain) in the hermetic (PICS, SGB) and the pesticide (ASD) treatments, and these treatments kept insect damage statistically significantly lower ($p < 0.05$) than the MS, ZFB, NM and PP treatments at this early stage of storage (Fig. 5.5a).

The difference in grain damage between treatments was still significantly different by the later stages of storage (24 and 32 weeks) (Kruskal-Wallis Chi-squared = 64.777, 6 df, $p < 0.001$) (Fig. 5.5). Mann-Whitney multiple comparison tests of the median values of each pair of treatments confirmed damaged grain was significantly ($p < 0.05$) higher in the NM and PP treatments, 60.7 % and 47.8 %, respectively, than in the other treatments despite considerable variation between replicates of the MS, ZFB, ASD, PP, NM treatments (Fig. 5.5b). Grain damage was lowest (< 7 %) in the hermetic bag treatments (PICS and SGB), and these treatments had grain damage statistically significantly lower ($p < 0.05$) than in the MS, ZFB, ASD, PP, NM treatments during these later stages of storage.

5.3.2 Insect grain damage during the 2015/2016 storage season

At the start of the 2015/2016 storage season, mean grain damage was less than 1% in all the treatments in both Dwale (Fig. 5.6a) and Livunzu EPAs (Fig. 5.6b). Mean grain damage remained below 25% in all the treatments at both EPAs throughout the 32 weeks storage period (Figs. 5.6a and b). Damage remained lowest in the hermetic bag treatments (PICS, SGB) and the ZFB in both EPAs, at less than 2.0 % during the 32 weeks storage.

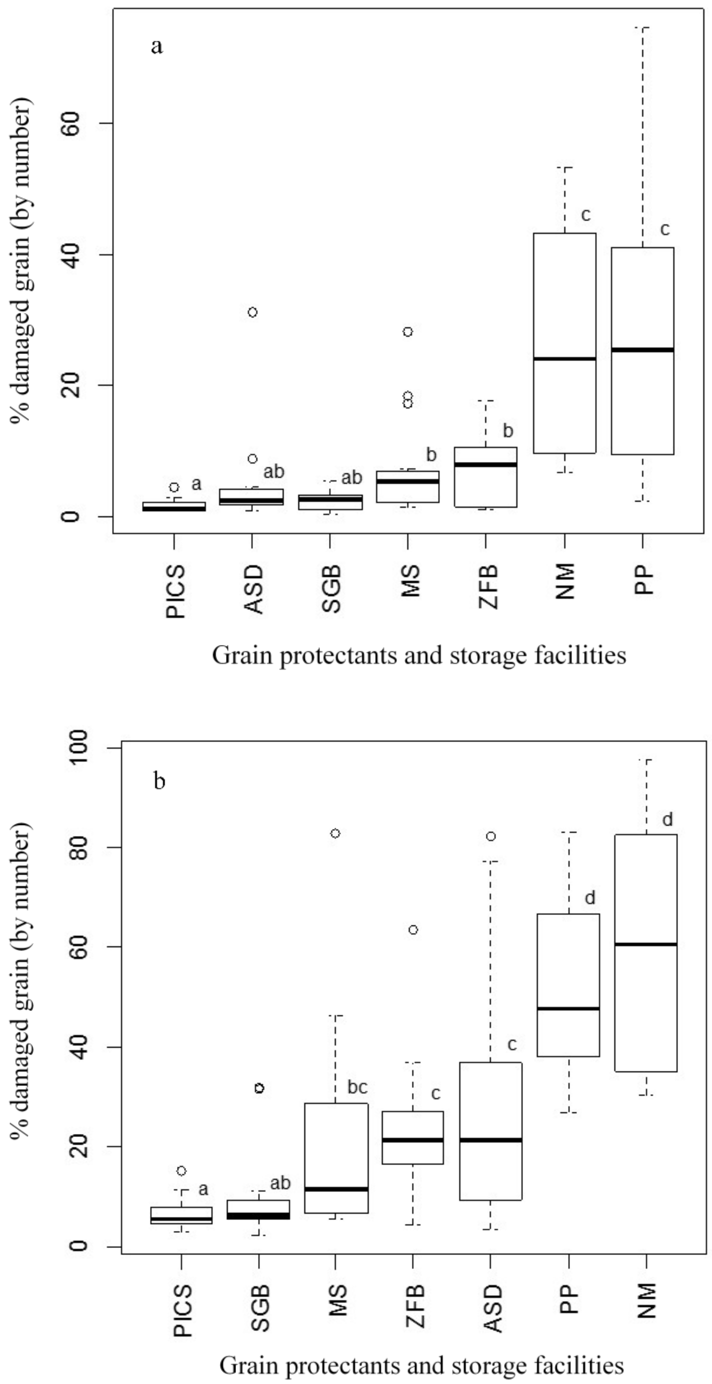


Figure 5.5: Effect of different storage treatments on the mean percentage insect damage to stored maize grain, combining data from both Dwale and Livunzu Extension Planning Areas, Malawi in the 2014/15 season at the early stages of storage (8 and 16 weeks) (n = 16) (a), and the later stages of storage (24 and 32 weeks) (n = 16) (b).

However, grain damage was higher in the NM, MS, PP and ASD treatments than the PICS, SGB or ZFB, and there was a high variation between replicates.

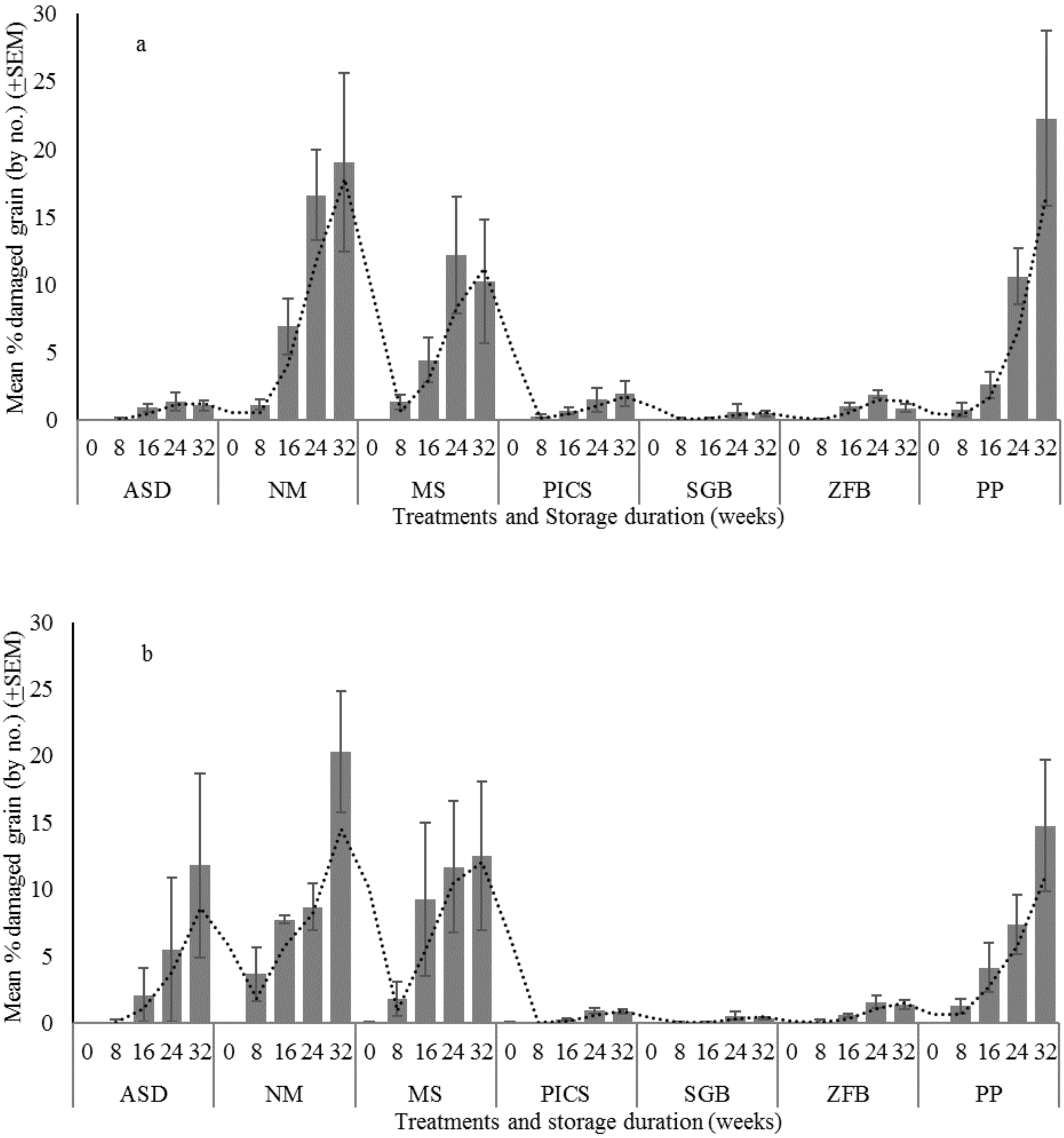


Figure 5.6: Mean percentage number of damaged grains (+ SEM) recorded in different storage treatments during the 2015/2016 storage season in: (a) Dwale Extension Planning Area, Malawi (n = 4), and (b) Livunzu Extension Planning Area, Malawi (n=4). SEM = standard error of the mean

When the 2015/16 data were combined across sites for the early stages of storage (8 and 16 weeks storage), despite the low damage levels there was still a significant difference in the mean percentage number of damaged grains between treatments (Kruskal-Wallis Chi-squared = 55.520, 6 df, $p < 0.001$). Mann-Whitney multiple comparison tests of the median values of each pair of treatments confirmed grain damage was significantly ($p < 0.05$) higher in the NM and MS treatments than in SGB, ASD, PICS, ZFB treatments (Fig. 5.7a).

The difference in damage levels between treatments when data were combined across the two EPAs remained significant as the 2015/16 storage season progressed (24 and 32 weeks storage) (Kruskal-Wallis Chi-squared = 73.965, 6 df, $p < 0.001$). Mann-Whitney multiple comparison tests of the median values of each pair of treatments confirmed grain damage was significantly ($p < 0.05$) higher in the MS, PP and NM treatments during this later stage of storage (week 24 and 32) than in all the other treatments (Fig. 5.7b). Damaged grain levels in the two hermetic bag treatments (SGB and PICS) and the ASD grain protectant were not significantly different, and similarly MS, NM and PP were not significantly different. However, insect damaged grain in the ZFB treatment was significantly different to damaged grain in MS, SGB, PP and NM treatments ($p < 0.05$) (Fig. 5.7b).

During the first 24 weeks of storage in the 2014/15 season, the highest grain weight losses in Dwale and Livunzu EPAs were 4.6 % and 5.3 %, respectively, across all treatments and all times (Fig. 5.8a and b). By week 32, mean grain weight losses had increased to 6.4 %, 17.4 % and 29.0 % in the ASD, PP and Neem treatments, respectively, in Dwale EPA, but remained between 0.1 and 2.1 % in the PICS, SGB, MS and ZFB treatments (Fig. 5.8a). In Livunzu EPA at 32 weeks storage, mean grain weight losses had increased to 7.2 %, 7.8 %, 11.5 % and 18.9 % in the ZFB, MS, PP and NM treatments, respectively, it remained below 3.5 % in the ASD treatments, and below 1.8 % in the PICS and SGB treatments (Fig. 5.8b).

Combined percentage grain weight loss data for the early stages of storage (week 8 and 16) from both EPAs in the 2014/15 season showed statistical differences between treatments

(Kruskal-Wallis Chi-squared = 42.719, 6 df, $p < 0.0001$). Mann-Whitney multiple comparison tests of the median values of each pair of treatments in grain weight loss were significantly different ($p < 0.05$). Higher grain weight losses were registered in PP, NM, ZFB, MS and ASD treatments than in the SGB. Further, grain weight loss in the PICS bags was not significantly different from that in the SGB (Fig. 5.9a).

The difference in grain weight loss between treatments was still evident during the later stages of storage (week 24 and 32) in 2014/15 (Kruskal-Wallis Chi-squared = 52.876, 6 df, $p < 0.0001$). Mann-Whitney multiple comparison tests confirmed that grain weight loss in the hermetic bags (SGB, PICS) had remained significantly lower than in all the other treatments, grain weight loss was highest in the PP and NM treatments, but not statistically significantly higher than in the ASD and MS treatments ($p < 0.05$) (Fig. 5.9b).

5.3.3 Grain weight loss during the 2015/2016 storage season

In Dwale EPA in the 2015/16 season, grain weight loss remained low between 0 and 4 % from week 0 to 32 in all treatments, with the highest grain weight loss of 3.1 % being recorded in the PP treatment at week 32 (Fig. 5.10a). While in Livunzu EPA in the 2015/16, grain weight losses were also low at between 0 and 1.0 % in all the treatments up to 24 weeks storage, it then increased notably to 2.4 % and 2.8 % in NM and ASD treatments, respectively, by 32 weeks storage (Fig. 5.10b).

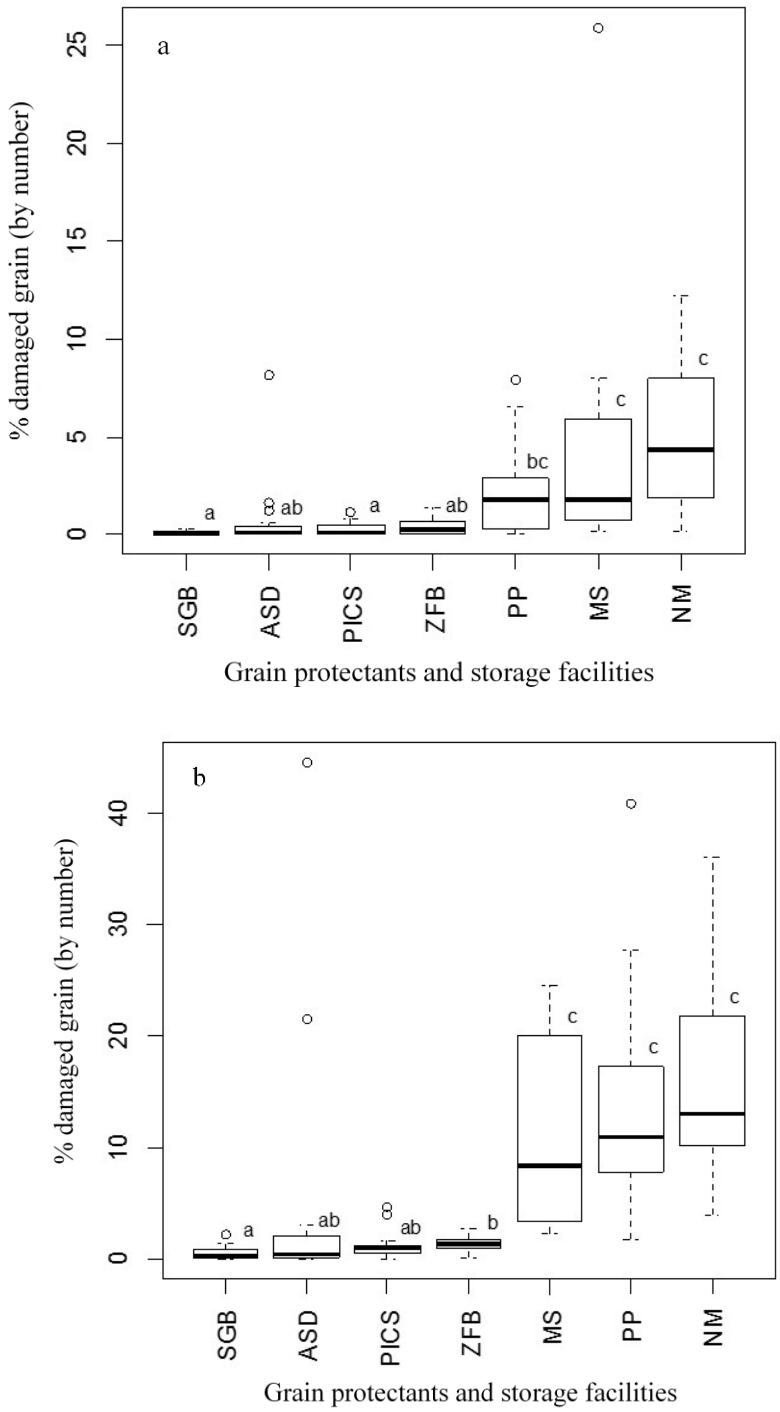


Figure 5.7: Effect of different storage treatments on the mean percentage insect damage to stored maize grain, combining data from both Dwale and Livunzu Extension Planning Areas, Malawi in the 2015/16 season for the early stages of storage (8 and 16 weeks) (n = 16) (a), and the later stages of storage (24 and 32 weeks) (n = 16) (b).

5.3.4 Grain weight loss during the 2014/2015 storage season

All the hermetic storage facilities (MS, PICS, SGB) and the ZFB treatment kept grain weight losses below 0.9 % in Dwale EPA, and below 0.8 % in Livunzu EPA throughout the 32 weeks of the 2015/2016 storage season (Figs. 5.10a and b).

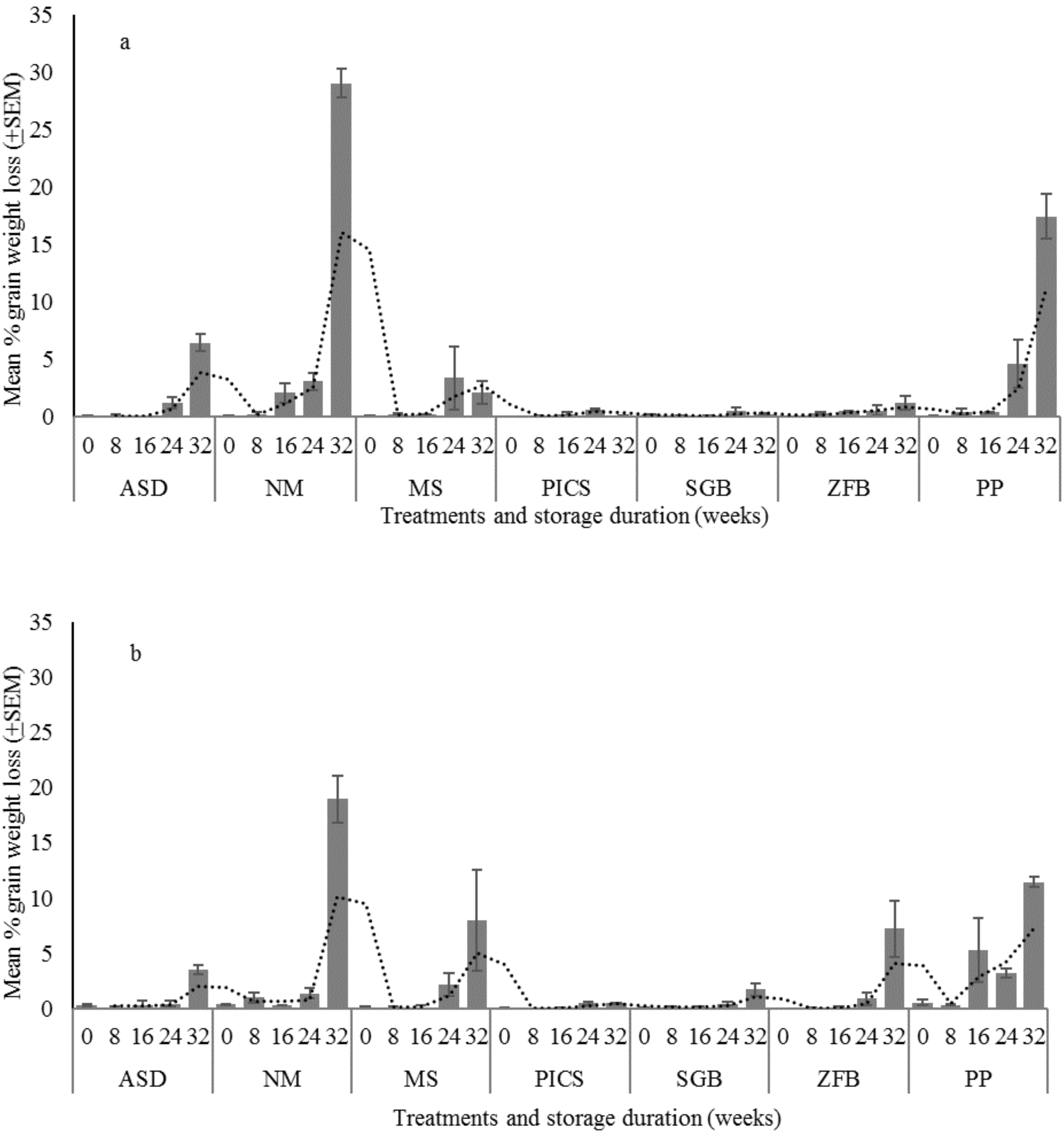


Figure 5.8: Mean percent grain weight loss (± SEM) recorded in different grain storage treatments during the 2014/15 storage season in: (a) Dwale Extension Planning Area, Malawi (n = 4), and (b) Livunzu Extension Planning Area, Malawi (n=4). SEM = standard error of the mean

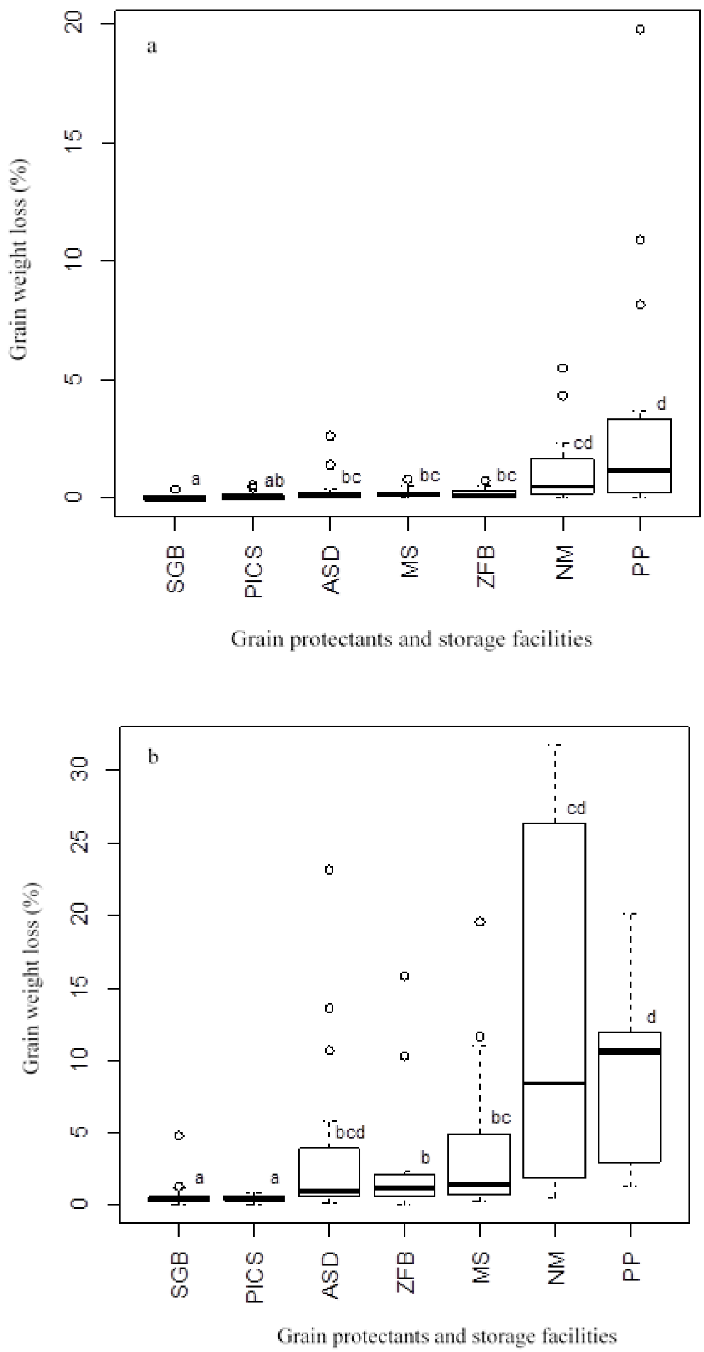
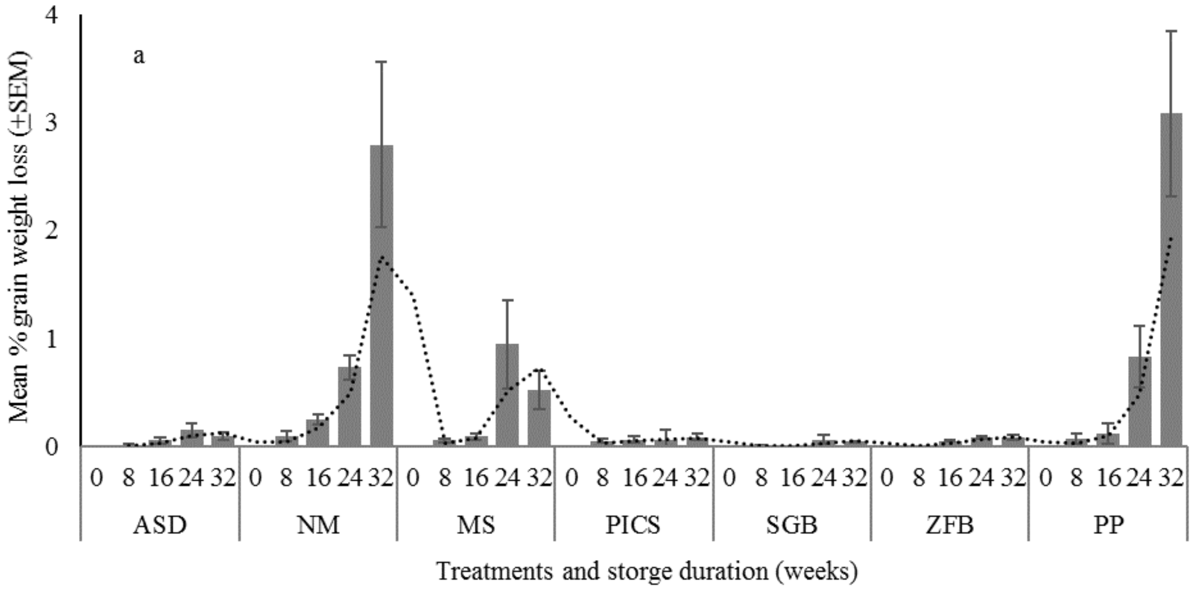


Figure 5.9: Effect of different storage treatments on the mean grain weight loss to stored maize grain, (a) season for the early stages of storage (8 and 16 weeks) (n = 16), and (b) the later stages of storage (24 and 32 weeks) (n = 16).

Combined percentage grain weight loss data from both EPAs for the early stages of storage (week 8 and 16) in the 2015/16 season showed significant differences between the treatments (Kruskal-Wallis Chi-squared = 36.465, 6 df, $p < 0.0001$). Mann-Whitney multiple comparison tests of the median values of each pair of treatments showed that grain weight loss at 8 and 16 weeks was significantly ($p < 0.05$) higher in NM treatments than in all the other treatments except PP and MS (Fig. 5.11a). The grain weight loss in the SGB and ZFB treatments was significantly lower than in the PP, MS and NM treatment but not significantly lower than in the ASD and PICS treatments (Fig. 5.11a). The difference in grain weight loss between treatments was still evident during the later stages of storage (week 24 and 32) in 2015/16 (Kruskal-Wallis Chi-squared = 60.936, 6 df, $p < 0.0001$). Mann-Whitney multiple comparison tests confirmed that the trends in treatment performance seen in the early stages of storage (week 8 and 16), remained at the later stages (week 24 and 32). Grain weight loss was significantly ($p < 0.05$) higher in the MS, NP and PP treatments than in the SGB, PICS, ASD and ZFB treatments (Fig. 5.11b).

5.3.5 Storage insect pest population development during the 2014/2015 storage season

Four different insect pest species; *P. truncatus, S. zeamais, Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) were recorded in the ASD, NM, PICS and PP treatments in Dwale and Livunzu EPAs by 32 weeks of storage in the 2014/15 storage season (Figs. 5.12a and b). *S. zeamais* was the only insect pest species recorded throughout the 32 weeks of the trial in all the treatments in both Dwale and Livunzu EPAs in 2014/15. *Sitotroga cerealella* was only recorded at 32 weeks of storage and only in the ASD, NM, PICS and PP, treatments in Dwale, and in the ASD, NM, PICS and SGB treatments in Livunzu EPA. Only low populations (< 4 insects per kg) of *P. truncatus* were recorded in the samples throughout the 2014/15 trial at both sites. At both sites at 32 weeks storage, insect numbers were lowest in the hermetic bag treatments (PICS and SGB).



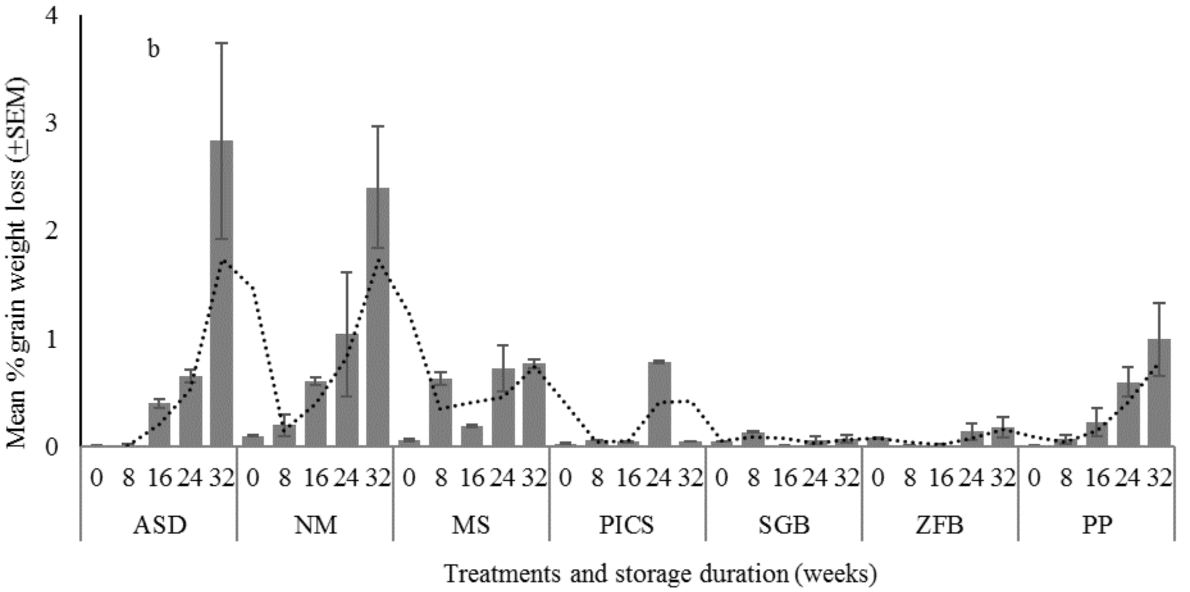


Figure 5.10: Mean percent grain weight loss (± SEM) recorded in different grain storage treatments during the 2015/16 storage season in a) Dwale Extension Planning Area, Malawi (n = 4), and b) Livunzu Extension Planning Area, Malawi (n = 4). SEM = standard error of the mean

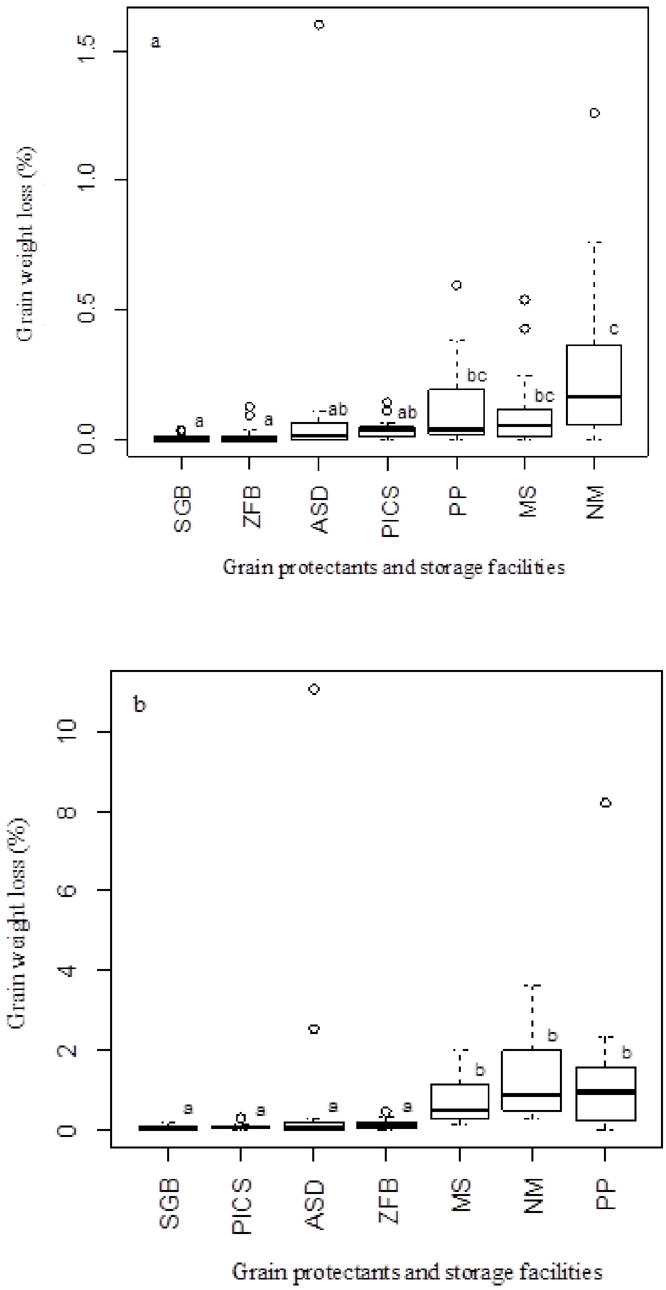


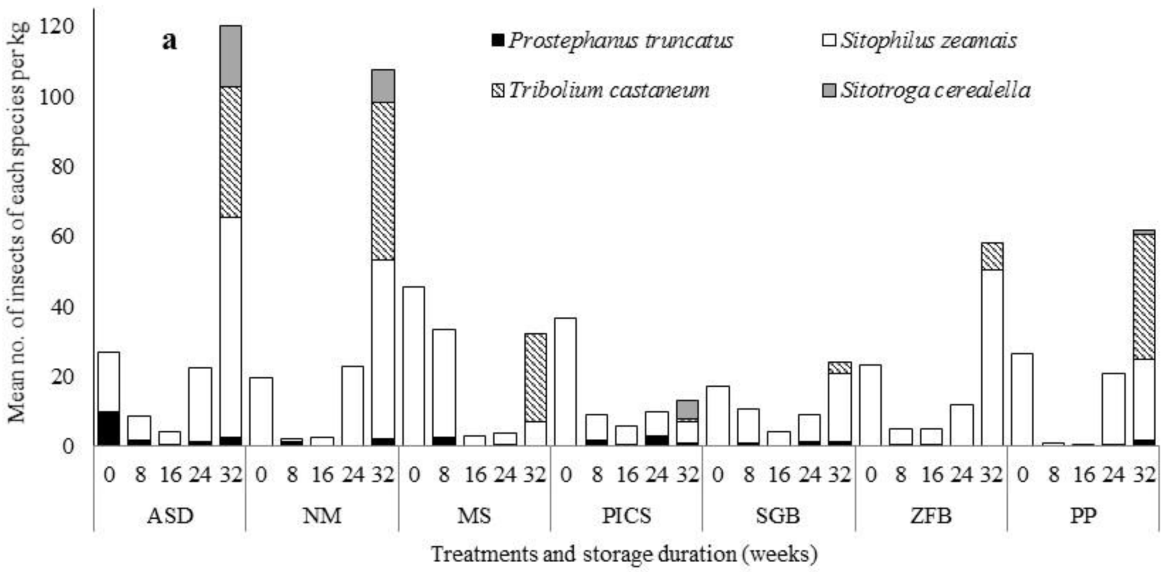
Figure 5.11: Effect of different storage treatments on the mean grain weight loss to stored maize grain, combining data from both Dwale and Livunzu Extension Planning Areas, Malawi in the 2015/16 season for a) the early stages of storage (8 and 16 weeks) (n = 16), and b) the later stages of storage (24 and 32 weeks) (n = 16).

At 32 weeks storage during the 2014/2015 season, the inner liner bags of three out of the sixteen SGB and PICS bags had perforation holes which were likely made by *P. truncatus*. Further analysis of the numbers per kg of the main primary pests *P. truncatus* and *S. zeamais* during the early stages of the trial in 2014/15 (combining data for week 8 and 16) showed that despite the low numbers of these pests, there was a statistically significant difference between treatments (Kruskal-Wallis Chi-squared = 15.047, 6 df, $p < 0.020$). However, when Mann-Whitney multiple comparison tests of the median values of each pair of treatments was used the differences between treatments were not found to be significant ($p < 0.05$).

By the later stages of storage (24 to 32 weeks storage) although mean numbers of these two pests per kg were still relatively low, there was a significant difference in number of *P. truncatus* and *S. zeamais* insects per kg of maize between treatments (Kruskal-Wallis Chi-squared = 25.734, 6 df, $p < 0.001$). Although Mann-Whitney multiple comparison tests of the median values of each pair of treatments confirmed that the number of *P. truncatus* and *S. zeamais* insects per kg of maize was significantly higher in the ZFB treatment than in MS and the PICS treatments ($p < 0.05$), neither group differed significantly to SGB, NM, PP, and ASD treatments (Fig 5.13).

5.3.6 Storage insect pest population development during the 2015/2016 storage season

In the 2015/2016 storage season, five insect pest species were recorded (*P. truncatus, S. zeamais, T. castaneum, S. cerealella and Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) in Dwale and Livunzu EPAs (Figs. 5.14a and b). *Cryptolestes ferrugineus* was not recorded in the 2014/15 trial, but was present in the ASD, NM, MS, SGB and PP treatments in Livunzu EPA in the 2015/16 trial, and in the MS and ZFB treatments in Dwale EPA. During the 2015/16 trial in Dwale EPA, insect numbers remained low (< 19 insects per kg) in all treatments throughout the 32 weeks.



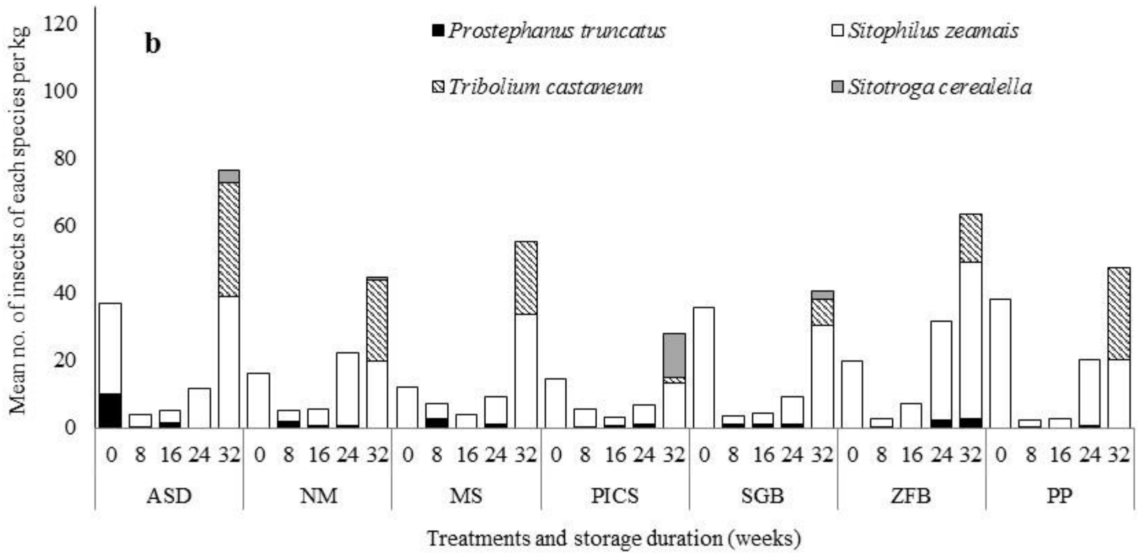


Figure 5.12: Mean total insect pests per species per kg of maize grain in different storage treatments during the 2014/15 storage season in Dwale Extension Planning Area, Malawi (n=4), and b) Livunzu Extension Planning Area, Malawi (n = 4).

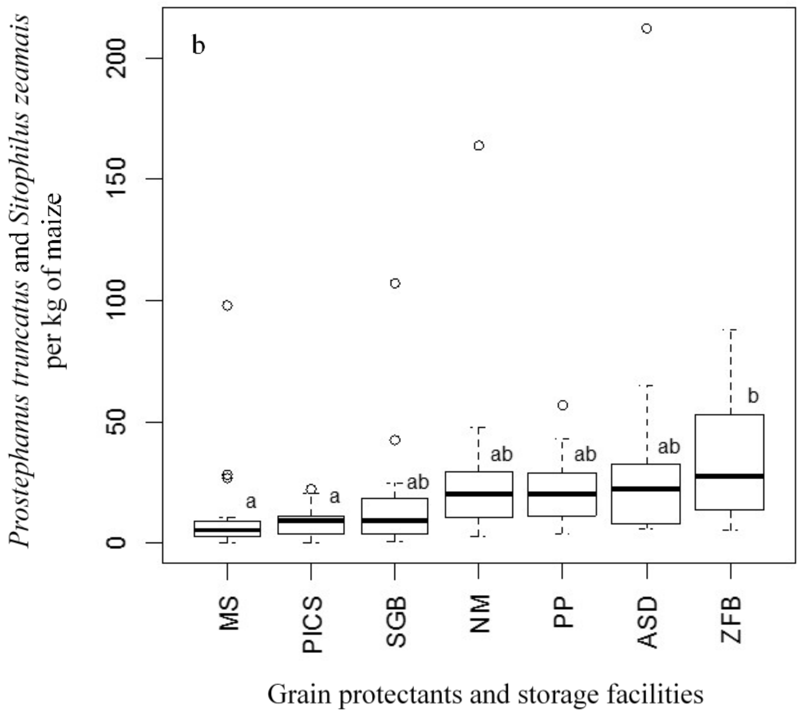


Figure 5.13: Total number of *Prostephanus truncatus* and *Sitophilus zeamais* insects per kg of maize grain stored using different treatments in the late storage stages (week 24 and 32) of the 2014/15 storage season in Dwale and Livunzu Extension Planning Areas, Malawi (n = 16).

Tribolium castaneum was the most common insect pest and recorded in the highest numbers in all the treatments from week 16 to 32 followed by *S. zeamais* (Fig. 5.14a). The lowest number of insect pests per kg of maize grain was recorded in the hermetic bag treatments, PICS and SGB. In Livunzu EPA in 2015/16, insect numbers remained below 20 insect per kg in all treatments except ASD in the later stages of the trial (Fig. 5.14b). The ASD treatment had a mean of 28 *P. truncatus*, 12 *T. castaneum* and 3 *S. zeamais* per kg by 32 weeks storage (Fig. 5.14b).

Further analysis of the combined data for the number per kg of the main primary pests *S. zeamais* and *P. truncatus* from both sites for the early storage stages (8 and 16 weeks storage) in 2015/16 found there was a statistically significant difference between treatments

(Kruskal-Wallis Chi-squared = 13.654, 6 df, $p < 0.034$). However, the Mann-Whitney multiple comparison tests of the median values of each pair of treatments showed no significant difference between treatments at this early stage of storage.

Analysis of the combined data for the number per kg of the main primary pests *S. zeamais* and *P. truncatus* from both sites for the later storage stages (24 and 32 weeks storage) found no significant difference between treatments (Kruskal-Wallis Chi-squared = 5.685, 6 df, $p < 0.459$). This absence of significant difference was confirmed by Mann-Whitney multiple comparison tests of the median values of each pair of treatments. There was high variability between replicates in the ASD treatment.

5.3.7 Grain germination

Grain germination was high (>75 %) in the undamaged grains stored in the ASD, ZFB and PP treatments in both EPAs, but lower in the NM treatment at (53.5 - 57.8 %), and even lower (< 20 %) for the hermetic treatments (MS, PICS, SGB) in both Dwale and Livunzu EPAs after 40 weeks of storage in the 2015/16 season (Fig. 5.15). At both Dwale and Livunzu EPA, percentage germination (< 10 %) of undamaged grains from the hermetic bags (PICS, SGB) was statistically significantly ($p < 0.05$) lower than in all the other non-hermetic treatments tested (ASD, NM, ZFB, PP). None of the grain collected from the MS in Dwale EPA germinated, while in Livunzu 14.3 % germinated from the MS and although lower, this was not significantly lower than in the NM treatment (Fig. 5.15).

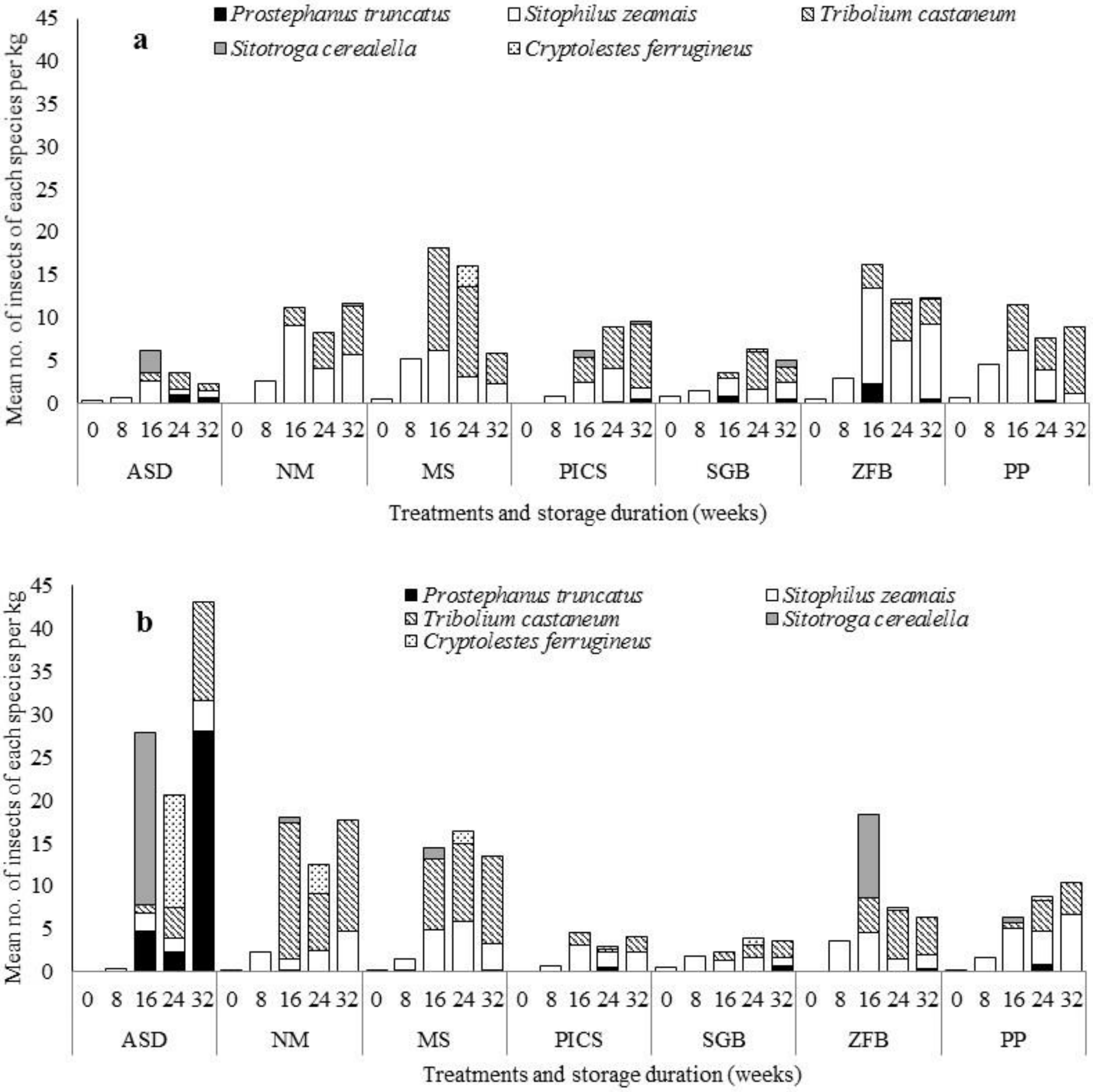


Figure 5.14: Mean total insects of each species per kg of maize grain in different grain storage treatments during the 2015/16 storage season in a) Dwale Extension Planning Area, Malawi (n = 4), and b) Livunzu Extension Planning Area, Malawi (n = 4).

5.3.8 Grain moisture content, temperature and relative humidity conditions inside the grain store

At Dwale EPA, the mean MC of grain stored in the PP treatment decreased from 13.7 % at week 0 to 12.3 % by week 24 during the 2015/16 storage season (Fig. 5.16a). Although prior to transportation of the grain to the trial site the mean grain MC was 13.4 %, this had increased to 13.7 % by the day when the trial was set up.

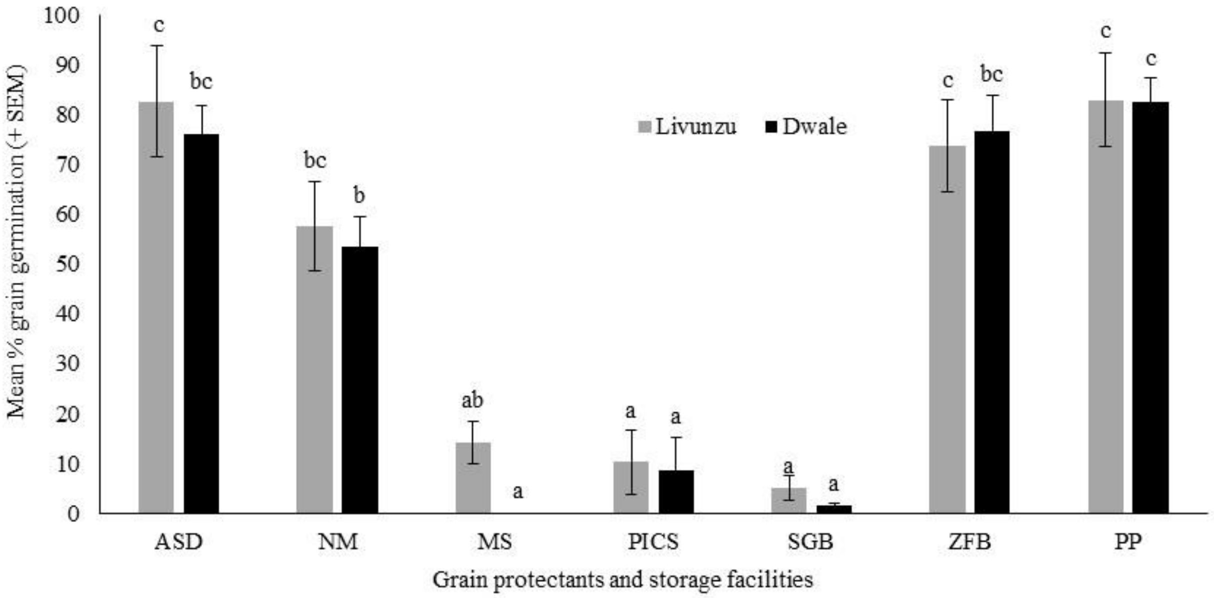


Figure 5.15: Mean percent germination (+ SEM) of undamaged grains stored using different treatments for 40 weeks during the 2015/16 storage season in Dwale and Livunzu Extension Planning Areas (n = 4). SEM = standard error of the mean

The lowest grain MC recorded during the trial in 2015/16 was 12.1 % and was from the ASD treatment at 24 weeks storage. Among the hermetic storage facilities (PICS, SGB, MS) the lowest mean grain MC of 12.3 % was recorded from the MS at week 16, but by week 32 mean grain MC in the MS treatment was 14.8 % (Fig. 5.16a). While in the non-hermetic storage facilities (ASD, NM, ZFB and PP) the lowest grain MC recorded was 12.1 % in NM at week 24 during the 2015/2016 storage season (Fig. 5.16a). The recorded in Dwale EPA showed a positive correlation (r = 0.335) between grain MC and recorded temperature in two storage rooms of the participating farmers. Likewise in Livunzu EPA the relationship between temperature and the grain MC was very week (r = 0.102). At Livunzu EPA during the 2015/16 storage season, the highest mean grain MC of 15.2 % was recorded at week 24 from the MS treatments (Fig. 5.16b). While the overall lowest mean grain MC of 12.3 % occurred in the ASD treatments at week 24. After 16 weeks storage, the mean grain MC of the hermetic treatments (MS, PICS, SGB) increased to above 14.7 % for the remainder of the trial, while the mean grain MC amongst the non-hermetic treatments (ASD, NM, PP and ZFB) dropped to <12.5 % at week 24 and then increased slightly, but remained below 13.5 % (Fig. 5.16b).

The correlation analysis showed that at both Dwale and Livunzu EPAs there was a very weak negative relationship (r = -0.127 and r = -0.017, respectively) between the grain moisture content and the storage duration.

In Dwale EPA, the mean weekly temperature recorded inside the grain stores of the participating farmers ranged from 25.3 ^{o}C to 38.1 ^{o}C in 2015/16 while in Livunzu EPA, the mean weekly temperature ranged between 26.3 ^{o}C and 37 ^{o}C (Fig. 5.17a). Correlation analysis indicated that in Livunzu EPA there was a weak negative relationship (r = -0.127) between the temperature in the store room and the germination percentage of the stored maize. Similarly, at Dwale EPA, there was almost no relationship (r = 0.036) between temperature and germination percent of stored grain.

The lowest mean weekly RHs recorded in the stores of the participating farmers were 36.9 % (at week 15) and 40.3 % (at week 17) in Dwale and Livunzu EPAs, respectively, during the 2015/2016 storage season. The highest mean weekly RHs recorded were 69.3 % and 70.6 % which both occurred during week 25 in Dwale and Livunzu EPAs, respectively, during the 2015/2016 storage season (Fig. 5.17b). In Livunzu EPA the relative humidity had negative relationship (r = -0.355) with the germination percentage of the maize grain. Similarly, in Dwale EPA there was almost no relationship (r = -0.084) between the RH and germination of the grain.

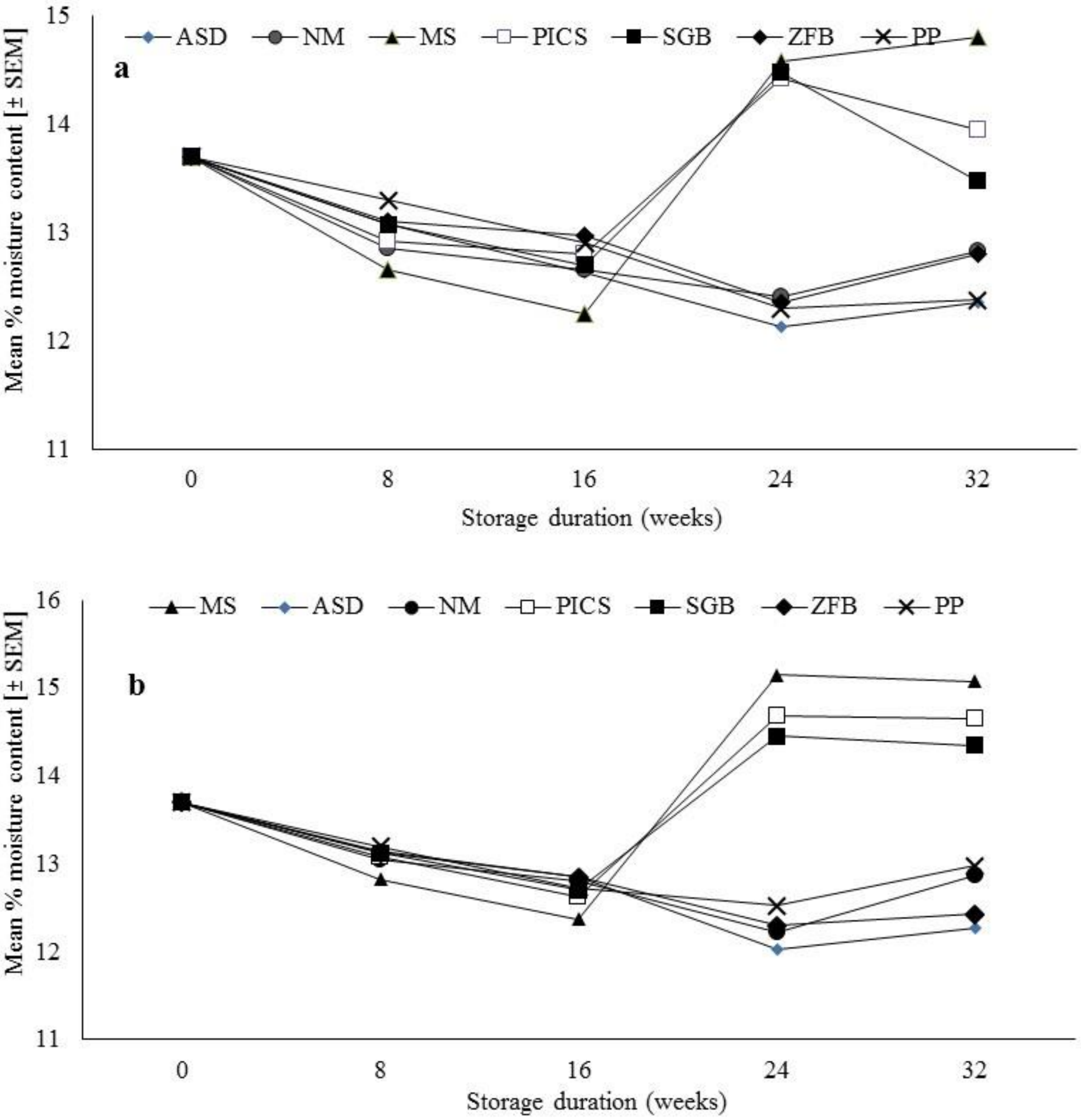


Figure 5.16: Mean % grain moisture content recorded from different storage treatments during the 2015/2016 storage season at a) Dwale Extension Planning Area, Malawi (n = 4), and b) Livunzu Extension Planning Area, Malawi (n = 4).

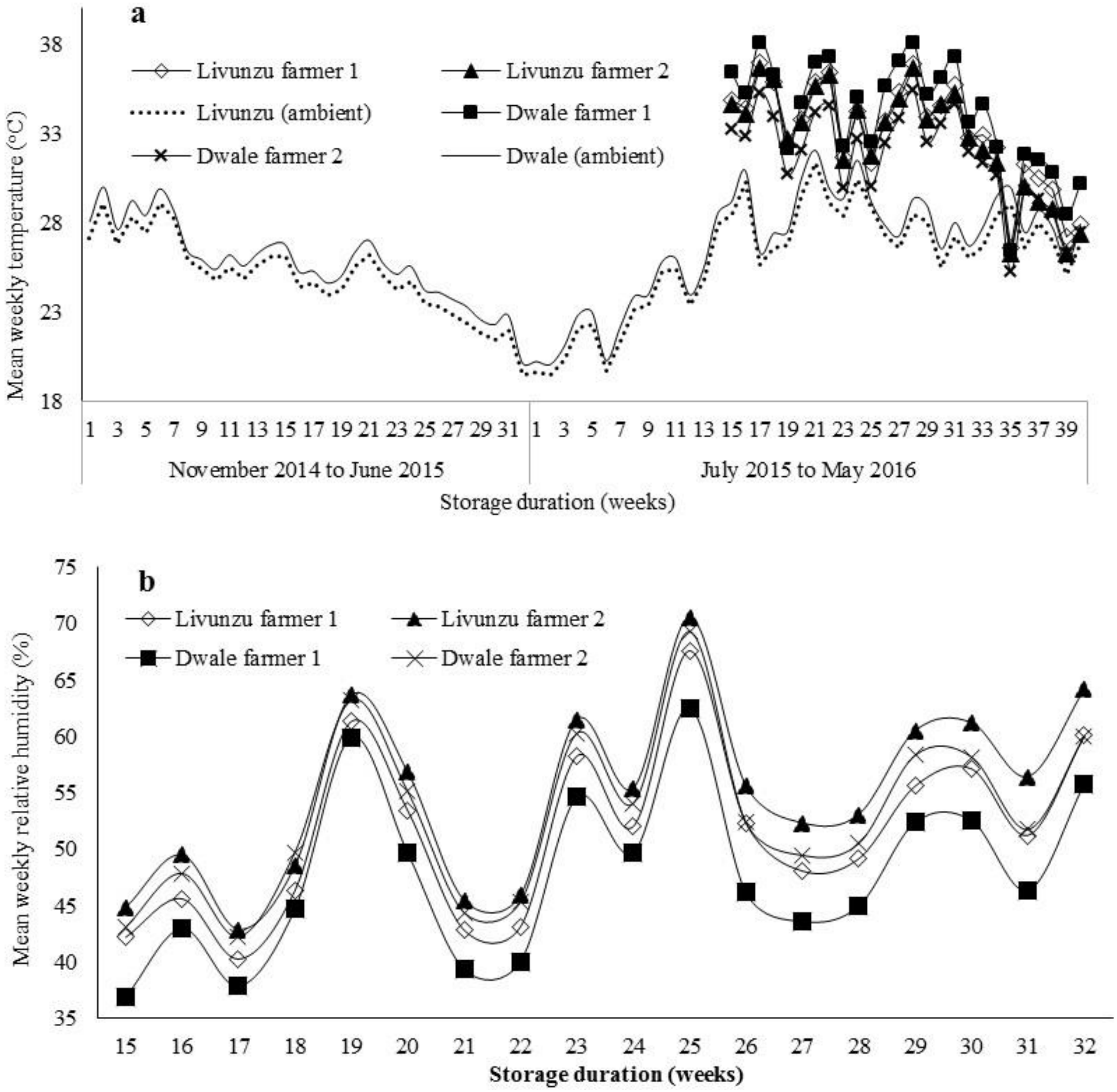


Figure 5.17: Mean weekly data (a) Ambient temperature during the 2014/15 and 2015/16 storage seasons, and temperature inside four participating farmers' stores in Dwale and Livunzu Extension Planning Areas, Malawi during the 2015/2016 storage season from storage week 15 to 32 (*Ambient temperature data collected from Malawi Meteorological Office, Blantyre*); and (b) Relative humidity inside four participating farmers' stores in Dwale and Livunzu Extension Planning Areas, Malawi during the 2015/2016 storage season from storage week 15 to 32 (*Ambient relative humidity data were not available)*.

5.4 Discussion

In the current study, the PICS and SGB bags were the most effective of the seven storage facilities tested, in terms of suppressing insect grain damage and subsequent grain weight losses throughout the two storage seasons. These results from the current study, confirm those of recent studies in other African countries in which hermetic storage bags successfully protected smallholders maize grain during storage (Mlambo *et al.*, 2017; Abass *et al.*, 2018). In thirteen sites across Benin, Burkina Faso and Ghana, trials comparing the storage of untreated maize grain in hermetic PICS bags versus the commonly-used woven polypropylene bags found that percentage insect grain damage did not increase in the PICS bags during the 6.5 months but suffered a 6-fold increase on average in the polypropylene bags (Baoua *et al.*, 2018). In Zimbabwe, hermetic storage facilities (PICS bags, SGBs and metal silos) outperformed a range of different botanical and synthetic chemical grain protection pesticides and the ZFB bags during storage periods of at least 8 months (Mlambo *et al.*, 2017). Similarly, the current study had reported a similar trend in the performance of the hermetic storage facilities compared to other storage options such as synthetic pesticides.

The efficacy of the hermetic bags, three out of the sixteen SGB and PICS bags used were perforated by *P. truncatus* by 24 or 32 weeks of storage. Similarly, laboratory studies in Kenya in which maize grain was artificially infested with *P. truncatus* and stored separately in PICS and woven polypropylene bags recorded 2.3 % and 47.7 % grain weight losses, respectively, within a 6 months storage period (Njoroge *et al.*, 2014). Similar observations were made by Mlambo *et al*. (2017). These perforations caused loss of hermeticity of the SGB and PICS bags, and enabled insect pests to access and damage the stored grain. In another study, PICS bags containing artificially infested cassava chips recorded very high numbers of perforations on the inner plastic liner bags (1913 $\pm$ 114 holes per bag) by *P. truncatus* within eight months storage period (Hell *et al.*, 2014). The large air spaces between the cassava chips are thought to have provided oxygen for the insects to survive inside the bags and subsequently perforate them (Hell *et al*., 2014). The laboratory studies in Kenya indicated that the use of PICS bags slowed the growth rate of *P. truncatus* populations and prevented grain infestation by stored insect pests from the surrounding storage environment (Njoroge *et al*., 2014). Low *P. truncatus* populations observed in PICS treatments up to 32 weeks of storage in the current study concurs with the findings of studies in West Africa where PICS bag prevented cross-infestation by insect pests and slowed down insect population growth in comparison to maize grain stored in polypropylene bags (Baoua *et al*., 2014). The hermetic SGB bag was also reported to be effective against rice storage insect pests but not effective against *P. truncatus*, one of the major insect pests of stored maize (Ben *et al.*, 2006).

Loosening of the rubber bands used for sealing the inlet and outlets of the MS was reported by three farmers on three occasions during the current study in both Dwale and Livunzu EPAs. This would reduce the tightness and allow gaseous exchange to occur between the MS and the environment, thereby providing conditions suitable for insect development, grain damage and weight loss. The loosening could be ascribed to the excessive heat experienced in the Shire Valley. While other studies have shown that metal silos can effectively protect stored maize grains against storage insect pests (Tefera *et al*., 2011; Chigoverah *et al*., 2016; Mlambo *et al*., 2017), in the current study they were not as effective. In the current study, and in both storage seasons, the maize grain stored in the MS was more heavily damaged than that stored in the PICS and SGB hermetic bags and became discoloured, an observation attributed to the high temperatures experienced within the stores. While the efficacy of the MS varied between households, its overall low and variable efficacy for longer-term protection of stored maize grain suggests it would not be an appropriate technology to recommend for smallholder farmers in the Shire Valley circumstances.

The current study found the efficacy of ZFBs varied between years, and during the first storage season (2014/15) they were not effective in protecting grain from insect damage during storage. The grain in the current study was not fumigated prior to trial set-up and contained low numbers of insects even at the start of the study. This is a typical situation for smallholder farmers as grains are often infested while still in the field or during drying. Another study reported that ZFB effectively controlled storage insect pests of cereal grains, pulses and oilseeds (Baban and Bingham, 2014), but only when the grain was fumigated prior to being loaded into the bags as per the manufacturers recommendations. Based on the findings of the current study that high grain damage in ZFB stored grain and insect perforation of the ZFB in 2014/2015, and similar findings in other field trials (Mlambo *et al*., 2017; Abbas *et al*., 2018). However, coupled with the manufacturer's recommendation that grain should be fumigated prior to storage in ZFBs, makes it an inappropriate technology to recommend for smallholder farmer use in Malawi. Use of storage fumigants by smallholder farmers in Malawi and other SSA countries is prohibited due to the associated high risks to human life emanating from the high toxicity of the pesticide. In the Tanzanian study, 40 % of maize grains were damaged in the ZFB treatment by 30 weeks of storage despite the grain having been fumigated prior to loading (Abass *et al*., 2018). High temperatures cause degradation of pesticide (Katagi, 2004; Rumbos *et al*., 2016) including deltamethrin which can be applied to grain or incorporated into woven polypropylene fabric such as in ZFBs. Other studies confirmed that extended periods of high temperatures during grain storage affect the performance of grain protectants, as the active ingredients degrade more rapidly (Afridi *et al.*, 2001; Mubayiwa *et al.*, 2018), and global warming projections would be expected to result in reduced performance of existing grain protectants.

The untreated control grain stored in the woven polypropylene bags (PP) suffered high levels of grain damage (up to 75.0 %) due to attack by *P. truncatus* and *S. zeamais*. The Neem (NM) treatment was not effective in controlling storage insect pest damage even up to 16 weeks of storage in either season at either site. The grain treated with neem leaves had up to 92.1 % grain damage during the two storage seasons mainly due to *P. truncatus* and *S. zeamais*, and often higher than the grain damage experienced in untreated (PP) grain. Similar results were reported by Kamanula *et al*. (2011) where neem leaves were not effective in controlling insect pests in stored maize, but neem seed oil was more effective. The neem tree is commonly found in Shire Valley. While the current practice of admixing dried neem leaves with maize grain was not effective and would be risky to recommend, farmers could benefit if practical strategies to improve the grain protection efficacy of this locally-available plant material were found.

The main insect pests of the stored grain were *P. truncatus, S. zeamais* and *T. castaneum.* The grain was not fumigated prior to the start of the trial in order to mimic the normal situation experienced by smallholder farmers whereby infestation starts in the field before harvesting. Due to this, the grain had some initial infestation and damage even at the start of the study. However, by 32 weeks of storage, insect pest-related grain weight loss reached a maximum of 29.0 %. This occurred in the NM treated grain. In the current study, there was high survival rate of *T. castaneum* in the MS and similar results were obtained in Zimbabwe where *T. castaneum* was a major pest in most of grain protectant treatments after between 24 and 40 weeks of storage (Mlambo *et al.*, 2017). The survival of this insect species warrants further investigation, considering its life span of more than three years.

An early study by Tyler and Boxall (1984) reported just 3 % maize grain weight loss in farmers' traditional granaries (woven basket from bamboos) in southern Malawi within a nine month storage period. This was much lower than the one found in the current study. In the 1970s the majority of Malawian farmers stored their maize untreated and on the cob in traditional granaries, and the major storage insect pest was *S. zeamais* (Golob, 1981). During a further postharvest loss assessment study of farmers' stores in the 1978/79 storage season in Shire Valley, mean maize grain weight losses of 2–5 % occurred during a 10 month storage period (Tyler and Boxall, 1984). The much higher weight losses in the current study are likely due to a combination of factors. These include the presence of *P. truncatus,* the most destructive storage insect pest of maize (Hodges, 1994); the introduction of hybrid maize varieties which tend to be more susceptible to storage insect pests (Giga and Mazarura, 1991) and probably changes in climatic conditions.

During the current study some of the woven polypropylene bags in the ASD, PP, ZFB, Neem, PICS and SGB treatments were partially damaged by rodents and termites at three of the participating farmers (two in Dwale and one in Livunzu) during 2014/2015. Only the MS treatment was unaffected by rodent or termite attack as it provides a physical protection barrier between the grain and the pests.

In the 2015/2016 storage season, germination rates of undamaged grains that had been stored in the hermetic storage facilities (MS, PICS and SGB) for 40 weeks were extremely low (<15 %) compared to that of the undamaged grains from the PP, ZFB, ASD (>75 %) and NM (53-58 %) treatments at both sites. Given the importance of seed viability to smallholder farmers in Malawi, who often retain part of their harvested local maize varieties as seed for the next planting, the potential impacts of these germination findings for smallholder long-term food security are of concern. They suggest that distinct recommendations for storage of grain for food versus storage for seed are required as hermetic storage bags are more widely promoted. However, my findings contrast starkly with those from storage trials in which the germination rates of maize grains (Baoua *et al*., 2014), and shelled and unshelled groundnuts (Baributsa *et al*., 2017) stored in PICS bags for over 6 months did not decrease significantly, while those of maize and groundnuts stored in woven PP bags for the same period of time reduced significantly. Although the reduced germination of the grains stored in the woven PP bags in the two afore-mentioned studies was also due to the seed-embryos of many of the grains having been damaged by storage insect pests, in the current study only non-insect damaged grains from all treatments were used in the germination tests. The low percentage germination of grain stored in the hermetic technologies in the current study, may have been caused by a combination of the high temperatures and hermetic conditions, and the 13.7 % grain MC at the start of the study which is slightly higher than the Malawian recommended 13.5 % safe storage grain MC for maize. A previous study of maize grain stored at high MC (14 % or 16 %) in hermetic storage facilities for 75 days, led to the germination rate of the 14 % MC grain decreasing from 84.3 % (day 0) to 58.3 % (day 75) while the germination rate of grain at 16 % MC decreased from 82.8 % (day 0) to 21 % (day 75) (Weinberg *et al*., 2008). A study in the USA using maize grain of 14 % MC found germination dropped from the initial 43 % to ~ 30 % during three months storage in PICS bags, but dropped even lower in the maize stored in PP bags (Lane and Woloshuk, 2017). In a recent study in central Tanzania using 12.5 % MC maize grain, the germination rate dropped from an initial 92 % to 70-81 % during 30 weeks of on-farm storage in hermetic facilities, but dropped significantly lower to 37 % in the untreated grain stored in PP bags (Abass *et al.*, 2018). These findings highlight the importance of sufficient drying of grain prior to storage, a situation which may become more challenging for some farmers as unexpected rains become a more frequent occurrence in the changing climate (Stathers *et al*., 2013).

During the current trial, temperatures of over 56 ^{o}C were reached in one farmer's store room which could have contributed to the grain discolouration in one MS, death of the grain embryos and lower grain germination rates after 40 weeks storage during the 2015/2016, although the effect was not as severe in the non-hermetic storage technologies. The houses of the farmers in the two EPAs of the current study had low roofs, and few and very small windows which provided only minimal ventilation, while houses roofed with corrugated iron sheets had particularly high temperature recordings within the store rooms. Given the current trend for storing grain inside houses in PP bags as opposed to outside in stand-alone granaries, greater awareness raising is warranted of the need to store grain in well-ventilated conditions and that the bags should not be in direct contact with the walls or floors of the house from which they might absorb moisture (Hodges and Stathers, 2012). Germination reduction of 70% has been reported in mung bean seed stored at 68.1^{o}C (Purohit *et al.*, 2013). Further research should investigate the temperature and RH patterns inside hermetic storage facilities (MS, PICS and SGB) when stored in smallholder farmers store rooms and germination rates should be assessed regularly throughout storage period.

The high temperatures in store rooms also influenced level of grain in the storage facilities and grain protectants which could have resulted in increased grain respiration rate and condensation of air due to airtightness and the drop in night temperatures. Although not directly measured, condensation within the MS, may cause corrosion of the metal inside the MS and over-time render it unsuitable for grain storage. Grain MC increased in these treatments as the grain absorbed the moisture from the condensed air within the hermetic storage facilities. These results confirm those of several other recent studies where the grain moisture content of maize grain stored in hermetic bags and silos increased during long-term storage (Williams *et al*., 2014; Ng'ang'a *et al*., 2016; Abass *et al*., 2018). Another study reported that in grain stored at high MC (14 % and 16 %) in hermetic storage facilities, the grain MC increased by 0.8–1.7 % due to respiration of the grain before the depletion of the oxygen after 75 days of storage (Weinberg *et al*., 2008). In a study in the USA, the moisture content of maize grain stored in PICS bags increased from 14 % at set-up to 14.2–14.3 % after 3 months storage, while that stored in PP bags increased to 14.9–15.9 % (Lane and Woloshuk, 2017). However, in the current study the increase in temperature within the store room allowed the grain stored in ASD, Neem, PP and ZFB treatments to continue drying because of the air movement occurring through the polypropylene bags.

The expectation is that climate change, particularly the increase in temperature will affect the development of some storage insect pests such as *P. truncatus* (Tirado *et al.*, 2010*;* Sharma and Prabhakar, 2014). Laboratory modelling studies showed that increased temperature affects the biology of insects including storage insect pests, therefore global warming is likely to affect the insects (Cammell and Knight, 1992; Fleming and Volney, 1995). Expected effects of global warming on insect pests include changes in the number of generations per year, population growth rate, dispersal and migration (Bale *et al*., 2002). According to Demissie and Rajamani (2014), temperature and RH ranges of 30–32 ^{o}C and 70–85 %, respectively, are the optimal conditions for larval development and survival of *S. cereallella.* The low populations of *S. cereallella* in the current study may be due to the high temperatures between 34.7 to 38.1 ^{o}C during an 8 week storage period experienced during the trial, although the high mobility of the adult moth and the fragility of its body during sampling of stored grain (Mvumi, 2001) and during sample sieving in the laboratory (personal experience) can result in the pest commonly being underscored in grain samples. Other researchers suggest that the effect of increased temperature could be either positive or negative as the effect on insecticides will depend on the mode of action, target insect species, method of application and quantity of insecticide ingested or contacted (Demissie and Rajamani, 2014). Others suggest that increased temperature or decreased relative humidity may lead to lower effectiveness of natural plant products and bio-pesticides (Sharma and Prabhakar, 2014). A study by Neven (2000) demonstrated that changes in temperature affected the metabolism of insects but that insects showed some adaptability to thermally challenging environments.

In addition to the storage technology such as hermetic storage facilities, the multiplication of storage insect pests such as *P. truncatus* and *Sitophilus* spp. and their natural enemies are greatly affected by storage conditions (temperature and RH) where an increase or decrease in each of the two affects the multiplication and development rates of the pests (Lachenicht *et al*., 2010). It was observed that during the later stages of the study (24 and 32 weeks storage), the number per kg of the main primary pests *S. zeamais* and *P. truncatus* were similar between the treatments.

Various reports suggest that global warming is likely to affect populations of stored product insect pests such as *P. truncatus* (Stathers *et al*., 2013; Delcour *et al*., 2015a). The mean weekly temperature ranges recorded within the stores in the 2015/2016 season of the current study, were higher at 25.3 to 38.1 °C than the ambient temperatures of 25.1 to 32.1 °C. However, further studies are needed to determine how temperatures within the stored grain as opposed to the store room compare to ambient temperatures. During the current study, the mean ambient temperatures (Dwale 26.3 ^{o}C and Livunzu 25.5 ^{o}C) were very similar to the annual mean temperatures recorded in the last 10 to 20 years (Dwale 26.5 °C and Livunzu 25.7 °C) (Sehatzadeh, 2011).

The presence of humid conditions during transportation and temporary storage prior to the setting up of the trials caused the increase in grain MC from the initial 13.4 % to 13.7 %. The current study has shown that storage of grain at above 13.5 % MC in hermetic storage facilities (PICS, MS and SGB) in Shire Valley is possible for smallholder farmers under the current prevailing climatic conditions (temperature and RH) in the area. Woven polypropylene bags have sufficient openings to enable further drying of grain of 13.7 % MC to occur during storage if the ambient conditions are warm and dry, but this is not the case in hermetic storage facilities. Further research should investigate the temperature and RH patterns inside hermetic storage facilities (MS, PICS and SGB) throughout storage period when stored in smallholder farmers stores. The ZFB cannot be recommended for use by smallholder farmers in Malawi due to its poor efficacy unless used with fumigated grain, which is impractical as smallholder farmers are prohibited by law from fumigating their grain in Malawi and many other SSA countries.

5.5 Conclusion

In conclusion, the study showed that the hermetic storage bags (PICS and SGB) effectively kept insect damage low during up to 32 weeks of smallholder farmer-managed maize grain storage in the Shire Valley of Malawi. The metal silos, traditionally used neem leaf powder materials, Actellic Super dust pesticide, and the ZeroFly® storage bag were not effective in preventing insect grain damage during the 32 weeks of storage. Given the prevailing storage conditions in Shire Valley and projected increasing temperatures, farmers in Shire Valley could use Neem leaf powder in protecting stored grain for less than 8 weeks, while ASD and ZFB for less than 16 weeks.

Based on the current study, it is recommended that the two hermetic storage bags (PICS and SGB) are promoted to smallholder farmers for long-term maize storage for up to 32 weeks in Shire Valley and other climate change prone areas of SSA. However, given that climate change projections suggest southern Africa will experience warmer mean temperatures and more variable rainfall amounts and timings. It is important that the efficacy of hermetic bags for smallholder farmer grain storage continues to be assessed over time, as higher storage temperatures combined with more risky grain drying situations may result in challenging conditions. The promotion of effective grain storage technologies should be integrated into practical training on good postharvest management to help ensure postharvest grain losses are minimised and the quality of the grain is maintained. The study hypothesis was rejected based on the results obtained from the two trial storage seasons

CHAPTER 6: EFFECT OF INCREASING AMBIENT TEMPERATURE ON THE EFFICACY OF GRAIN PROTECTANTS AND GRAIN STORAGE FACILITIES IN SMALLHOLDER MAIZE PRODUCTION SYSTEMS[3]

6.1 Introduction

Climate change and variability, have serious implications for insect pest damage, agri-food value chains and livelihood security (Deutsch *et al*., 2008). The increased incidence of droughts and floods is worsening poverty in some areas of sub-Saharan Africa (SSA) (Jayanthi *et al*., 2013). In addition to insect pests which damage crops during their field growth period, postharvest insect pests, such as the larger grain borer (LGB), *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) are also a major threat to food and nutrition security in Africa (Tefera, 2012). This pest was accidentally introduced to East Africa in the late 1970s from Central America and Mexico (Hodges, 1994), and has since spread throughout SSA (Hodges, 2002). It is one of the most destructive insect pests of dried maize and cassava during storage.

Postharvest losses (PHLs) are expected to worsen under global warming (Stathers *et al*., 2013), as it is expected to lead to more rapid insect development, increased generations and thus an abundance of problematic insects, including common storage pests such as, *P. truncatus* and the maize weevil, *Sitophilus zeamais*, Motschulsky (Coleoptera:

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[3] Modified and published as: Singano, C. D., Mvumi, B. M., Stathers, T. E., Machekano, H. and Nyamukondiwa, C. (2019). What does global warming mean for stored-grain protection? Options for Prostephanus truncatus (Horn) control at increased temperatures. *Journal of Stored Products Research*, https://doi.org/10.1016/j.jspr.2019.101532

Curculionidae) (Arthur, 1996). A more rapid increase in insect pest populations could exacerbate maize storage losses if the grain is inadequately protected. Moreover, increased temperatures may simultaneously lead to increased insecticide biodegradation (Stathers *et al*., 2013; Delcour *et al*., 2014). Investigation of the effects of these factors on stored product pest management is therefore important.

Temperature projections for some parts of SSA including Shire Valley in southern Malawi suggest an increase of >6 °C by the year 2065 if mitigation measures fail (IPCC, 2014), with monthly mean temperatures of above 32 °C expected in the Shire Valley (Matiya *et al*., 2011). Furthermore, an already dry southern Africa is expected to get drier and rainfall reduction will surpass 30 %, with more cases of extreme weather events should mitigation measures fail to cushion the changes (Matiya *et al*., 2011; IPCC, 2014; Serdeczny *et al*., 2017).

Various methods exist for protecting smallholder farmer stored grain against insect pest attack. These include hermetic storage bags, metal silos, synthetic residual pesticides, and traditional practices. Hermetic storage bags are made of high density polyethylene which has a low permeability to atmospheric gases. When grain is sealed tightly inside a hermetic storage bag, a hostile environment for insect pest survival is created within the hermetic bag due to the respiration of the enclosed grain, insects and fungi, which deplete the oxygen and release carbon dioxide (Murdock *et al*., 2012). Grain can be stored in hermetic bags without applying synthetic pesticides or other grain protectants as the insect pests die from suffocation (Murdock *et al*., 2012). Hermetic metal silos have also been found to be effective for smallholder grain storage. They prevent grain from being damaged by insects, mites, rodents and birds (Tefera *et al*., 2011; Chigoverah and Mvumi, 2016). In SSA, metal silos for household use typically range in size from 100 to 3000 kg capacity. A 1000 kg silo can conserve enough grain to feed a family of five adults for one year (World Bank, 2011). Many smallholder farmers admix synthetic pesticide dusts with their maize grain to protect it from insect attack during storage (Singano *et al*., 2019).

Some resource-constrained farming households that cannot afford modern storage technologies will often use locally-available pesticidal plant powders to protect their grain (Abass *et al.*, 2018a). Since the introduction of the neem tree in SSA, farmers have used the leaves as a grain protectant during storage. Whole leaves may be placed on the floor of the storage structure before loading the grain crops, or mixed with the grain in fresh, dried or ground forms. Various modes of action for neem have been documented. These include inhibition of moulting and feeding, reduction of fertility and fecundity (Tofel *et al.*, 2017). All these are associated with the plant's active secondary metabolites such as alkaloids, phenolics and terpenoids (González-Rodríguez *et al*., 2011).

Given the projected climate changes, the efficacy of existing storage containers and grain protectants may be significantly reduced. We hypothesise that increased ambient mean temperatures will accelerate storage insect pest development and increase grain losses in hermetic bags, metal silos or after admixing with synthetic pesticides or pesticidal plant powders. The current study examined the effect of increasing mean ambient temperatures on the efficacy of a range of grain protectants and storage containers used in developing countries for storing shelled maize grain.

Climate change risks, such as more frequent and prolonged dry spells, droughts, floods and higher temperatures, have negatively affected the livelihoods of many smallholder farming HHs resulting in increased food insecurity in the Shire Valley of Southern Malawi. The expectation is that climate change, particularly higher temperatures, will affect the development of some storage insect pests such as the larger grain borer (LGB), *P. truncatus* and the maize weevil, *S. zeamais*. Further, global warming is likely to increase degradation rates of storage insecticides or botanicals on stored maize and negatively affect the performance of storage technologies such as hermetic bags.

The overall objective of this study was to investigate and test the role of different grain protectants and storage facilities in assisting farming communities in Shire Valley to adapt to climatic changes through improving their food security.

The specific objectives were to;

1. Determine the effectiveness of grain protectants in controlling storage insect pests under increased temperature conditions,
2. Evaluate the performance of grain storage facilities under increased temperature conditions in protecting stored maize grain,
3. Determine the effect of increasing temperature on the survival of *Prostephanus truncatus* and quantify maize storage losses.

6.2 Materials and methods

6.2.1 Site and laboratory trials

The experiments were conducted in the Entomology Laboratory at Botswana International University of Science and Technology, Palapye, Botswana. Clean untreated yellow shelled maize, harvested in the 2017/2018 growing season was procured from the Botswana Agricultural Marketing Board for the experiments. To ensure the maize was free from insect infestation, the grain was fumigated using Aluminium Phosphide (56% a.i.) (Degesch Limited, Transvaal, South Africa) at the rate of 1.5 g per m^3. Aeration of the phosphine gas from the maize grain was done on the seventh day of fumigation for the recommended 8 hour period. The grain was thoroughly mixed to homogenise it.

The moisture content (MC) of the grain was determined using the oven method (Adler *et al*., 2018). This involved grinding the grain with a coffee blender (Kambrook Coffee Grinder, KCG201S, South Africa) to produce 0.46 to 0.55 mm grit sizes. The maize grit samples were weighed into ~15 g sub samples using a RADWAG microbalance (RADWAG® Wagi Elektroczne, Model AS200.R2, Poland) and placed in metal dishes of 5 cm diameter and covered with lids. The maize grit samples were then dried in a Memmert oven (UF160, Memmert GmbH + Co.KG, Germany) at 115 °C. Every three hours during the oven-drying process, the metal dishes were removed from the oven, left to cool to laboratory temperature (between 20 °C and 25 °C) in the desiccator for 30 to 45 minutes then re-weighed (Adler *et al*., 2018). The drying and re-weighing process continued until the total weight of the samples remained constant. Following fumigation and aeration, the grain had a moisture content of 10.6 %, meeting grain moisture content recommendations for safe storage of maize grain of less than 13 % (Chayaprasert *et al*., 2009).

6.2.2 Experimental conditions and approach

Two experiments were conducted simultaneously in two separate climate chambers (HPP 26.00, Memmert GmbH + Co.KG, Germany). Each experiment involved three different temperatures and RH conditions; 32°C and 60% RH; 38°C and 60% RH; and ambient conditions of 26˚C and 30.8% RH. Subsequently in this paper, these experimental conditions will be referred to as 32˚C, 38˚C and 26˚C (ambient).

One climate chamber was set at 32 ˚C and the other at 38 ˚C. These temperatures were selected based on the mean weekly temperatures recorded in store rooms during grain storage trials in the Shire Valley between November 2015 and May 2016. The lowest and highest mean weekly temperatures were 27 ˚C and 38 ˚C, respectively (Singano *et al*., 2019). Considering the anticipated mean increase in temperature of 3 ˚C in Shire Valley due to climate change (Matiya *et al*., 2011), the average lowest mean weekly temperature value was adjusted by increasing it by 5 ˚C to 32 ˚C. For the second climate chamber, the recorded highest mean weekly temperature value of 38 ˚C was used because preliminary observations showed insects struggled to survive at temperatures above 35 ˚C. As a result, a temperature of 38 ˚C was thus maintained. Furthermore for experimental purposes, it was also important to test the storage facilities at much higher temperature given the severity and unpredicted nature of climate change in SSA. The selected RH of 60 % was based on the mean RH reported during grain storage trials conducted in Dwale and Livunzu Extension Planning Areas in Shire Valley in the 2015/2016 storage season (Singano *et al.*, 2019).

The two chambers were pre-conditioned until the set conditions were attained, then the treatments (see Section 3.2.3 for details) were introduced and laid out in a completely randomised design (CRD) on the climate chamber shelves. For the ambient conditions, treatments were also placed in a CRD on the bench within the laboratory where the climate chambers were located. Each treatment was replicated three times in both experiments. The treatments in each experiment were multi-replicated making a total of 12 replicates enough to cater for the four destructive samplings.

The temperature and RH inside the two climate chambers, and the ambient temperature and RH (outside the chambers) were confirmed using a thermocron i-Buttons (model DS 1923, Maxim, Sunnyvale, CA, USA), set to record readings at 30 minute-intervals throughout the 12-week storage period (Fig. 6.1).

Figure 6.1: The thermocron i-Button used for recording temperature and RH inside the two climate chambers, and the ambient temperature and RH (outside the chambers), and inside the tested storage facilities (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

The temperature and RH data collected using the i-Buttons enabled the triangulation of the set climate chamber temperature and RH conditions. Temperature and RH data from inside the storage containers were also recorded for 12 weeks in some of the treatments including: the Metal silo (MS) and polypropylene (PP) bag in the 32°C chamber and the MS, Purdue Improved Crop Storage (PICS) bag, and PP in the 38°C chamber.

6.2.3 Test insects and seeding

An adult *P. truncatus* (Fig. 6.2) colony, originally collected from grain stores in Zimbabwe in March 2016, was reared on maize grain in glass jars fitted with perforated lids and kept under ambient laboratory temperature and relative humidity. The insects were introduced into the treatments at the start of the experiments at 10 adults per treatment replicate.

Figure 6.2: Lateral view of adult beetle of larger grain borer, *Prostephanus truncatus* used in the laboratory experiments (Source: Georg Goergen /IITA Insect Museum, Cotonou, Benin).

The insects were of unknown sex and age. The insect infestation rate of 10 insects per replicate was used in both grain protectants and storage containers experiments regardless of the differences in the quantity of grain used (i.e. 10 insects per 100g of grain for Experiment I on grain protectants, and 10 insects per 200g for Experiment II on storage containers). The infestation rate was chosen considering that the minimum number of insects (*P*. truncatus) per kg of grain is 10 insects if the insects are not sexed and known age, hence the use of the same rate for 100 g and 200 g maize replicate samples where all were below a kg of maize. The insects were placed on the top surface of the maize grain in both experiments.

6.2.4 Treatments

6.2.4.1 Experiment I: Evaluation of grain protectants at increased temperatures

The effect of increased temperatures on six grain protectant treatments included synthetic-pesticides, botanical grain protectants and an untreated control (see Table 6.1) was studied. The selection of the grain protectants was informed by a profiling study in which farmers in Shire Valley of southern Malawi listed the grain protectant products they used (Singano et al.

in prep.). All the synthetic-pesticide grain protectants were procured from Agricultural Trading Company and Chemical Plus in Lilongwe, Malawi. For each treatment, 2,700 g of grain was admixed with the respective protectant as specified in Table 1. The grain for each treatment was then divided into 27 sub-samples of 100 g each and placed into clean 250 ml glass jars (Fig. 6.3).

Figure 6.3: Treatments on grain protectants in 250 ml glass jars containing 100 g maize each and storage facilities containing 200 g maize each placed outside the climate chambers.

Each treatment had 12 replicates to cater for four samplings. Three replicate baseline samples were collected from each treatment initially. The remaining nine replicate samples were for each treatment and were placed under each temperature and RH conditions (32°C, 38°C and 26°C (ambient)). This translate to 27 replicates for each treatment and cater for the three trial conditions (32°C, 38°C and 26°C (ambient)). This translate to 27 replicates for each treatment and cater for the three trial conditions (32°C, 38°C and 26°C (ambient)). In the grain protectant treatments, test insects were added to each jar and then covered with a wire mesh cover (0.8 mm aperture) to allow adequate aeration while preventing the insects from escaping. At each of the four sampling periods (0, 4, 8 and 12 weeks), three replicates of each treatment were destructively sampled (3 temperature and RH conditions × 3 replicates = 9 replicates per sampling per treatment).

Table 6.1: Experiment I: grain protectant treatment materials and their active ingredients, sources and application rates

Name of pesticide	Active ingredients	Supplier of the pesticide	Application rate	Source of pesticide application rate
Dried Neem leaf powder (NM)	Not available	Shire Valley farmers	153g per 50kg of maize grain (or 0.31 % w/w)	Derived from local farmer practice in Shire-Valley
Actellic Gold dust (AGD)	1.6% Pirimiphos methyl + 0.36% Thiamethoxam	Farmers Organisation	25g per 50kg of maize grain (or 0.05% w/w)	Manufacturer's recommendations on the label
Wivokil Super dust (WSD)	1.0% Fenitrothion + 0.12% Deltamethrin	Agricultural Trading Company	25g per 50kg of maize grain (or 0.05 % w/w)	Manufacturer's recommendations on the label
Shumba Super dust (SSD)	1.0% Fenitrothion + 0.13% Deltamethrin	Farmers Organisation	25g per 50kg of maize grain (or 0.05% w/w)	Manufacturer's recommendations on the label
Wood ash of Mopane trees (WA)	Not available	Botswana in Palapye area	15kg per 50kg of maize grain (or 0.3% w/w)	Derived from farmers' practice in Shire Valley

6.2.4.2 Experiment II: Evaluation of grain storage containers at a range of temperatures

The effect of increased temperatures on grain stored using four different storage containers was studied (Table 6.3). An earlier postharvest profiling study in Shire Valley (Singano *et al*., in prep.) and a review of the literature (Tefera *et al*., 2011; Baban and Bingham, 2014; Abass *et al*., 2018) were used to identify and select the storage containers for Experiment II (Table 6.3).

The upper sections of the Purdue Improved Crop Storage (PICS) bag and Super Grain bag (SGB) were cut off to ensure the hermetic bags fitted into the available climate chamber space. The bottom (~15 cm height) part of each bag was retained, which provided sufficient capacity for 200g of grain for use in Experiment II (Fig. 6.3). The empty PICS and SGB mini-bags were tested for airtightness by filling with air and squeezing before loading the maize grain according to the respective manufacturers' recommendations. After loading the PICS and SGB mini-bags with maize, the bags were squeezed to remove as much air within each bag as possible to help deprive any insects present within the bag of oxygen. The polypropylene bags were also cut to produce mini-bags.

The miniature MSs were fabricated using galvanized iron sheet gauge number 24 (0.6 mm), to create a bottom and a top part which fitted into each other (Fig. 6.4). The miniature MSs did not have the usual inlet and outlet features characteristic of real-size metal silos used by farmers as described by Kimani *et al*., 2018. Rubber tubing was used to seal the mini metal silos (Fig. 6.4). The miniature MSs were tested for airtightness by introducing a burning candle inside the silo and sealing the two pieces with the rubber tubing, if the candle went out, then the metal silo was airtight and vice versa.

After the grain was loaded into the miniature MSs during set-up, a 5 cm long burning candle was placed inside each MS before closing and sealing the lids with the rubber tubing to deplete oxygen in the MS (Tefera *et al*., 2011b; Zachary *et al.*, 2015).

Table 6.2: Experiment II: Grain storage containers used, supplier and grain holding capacity

Grain storage container	**Supplier of container**	***Holding capacity (g) of container**
Purdue Improved Crop Storage (PICS) bag	Polypack in Malawi	200
Super Grain bag (SGB)	Chemicals and Marketing Company	200
Metal silo (MS)	Fabricated by artisans in Malawi	200
Polypropylene (PP) bag	Agricultural Trading Company	200

****The containers were modified into mini-bags and mini-silos for experimental purposes***

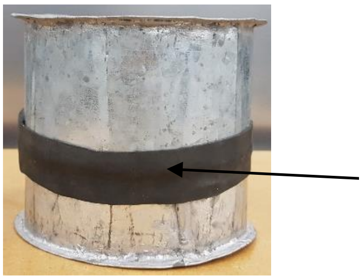


Figure 6.4: A miniature metal silo with a 12 cm diameter and 15 cm height (200 g maize grain holding capacity) as used in Experiment II.

Under the ambient temperature and RH conditions the MS treatment was excluded because there were insufficient numbers of them to cater for the three sets of storage conditions and the required sampling frequencies. This made it an unbalanced experimental design.

6.2.5 Grain sampling and sample analyses

Baseline grain samples were collected from Experiment I (grain protectants) and II (storage containers) at week 0, the start of the experiments. Three subsequent samplings were conducted at 4, 8 and 12 weeks storage from the three storage conditions (32°C, 38°C and 26°C (ambient)) for both experiments using a destructive sampling method. At each sampling, the whole treatment replicate (100 g for Experiment I, 200g for Experiment II) was collected from each of the climate chambers and the ambient storage set for analysis, and were not returned to the chambers or ambient condition location after sample analysis.

At each sampling period, each of the three treatment from each of the three storage temperature and RH conditions (32°C, 38°C and 26°C (ambient)), was weighed and the weight recorded. The sample was then sieved using 2.8 to 3.35 mm aperture nested sieves to separate insects, trash, flour dust and grains. The insects were separated into live and dead and counted and the data recorded. The sieved grains were separated into insect damaged and undamaged, and each category was counted and weighed. Grains with holes or tunnels created by insects as opposed to by mechanical damage, were categorised as insect damaged grains.

Each of the empty storage containers (glass jars, MS, PP, SGB and PICS) were weighed separately using the electronic microbalance and their weights recorded. The grain MC of every treatment replicate was determined as previously described (see Section 2.1). The maize grain weight loss for each treatment replicate was calculated using the count and weigh method (Compton *et al*., 1998).

$$Grain\ weight\ loss\ (\%) = \frac{[(Wu\ x\ Nd) - (Wd\ x\ Nu)]}{Wu\ x\ (Nd + Nu)}\ x\ 100$$

Where: W_u = Weight of undamaged grain

N_u = Number of undamaged grain

W_d = Weight of damaged grain

N_d = Number of damaged grain.

6.2.6 Data analyses

The mean treatment data for percentage number of insect damaged grains, grain weight loss, number of live, dead and total *P. truncatus* per kg and grain MC parameters were tested for normality using the Shapiro-Wilk test and found to satisfy the linear model assumptions of constant variance and normal errors. A multi-variate analysis of variance (MANOVA) was run using R version 3.5.1 (R Core Team, 2018) to simultaneously examine the multiple response variables (percentage damaged grain, percentage weight loss, total *P. truncatus* numbers, percentage grain moisture content) using storage conditions, treatments and storage durations as explanatory variables. Separate MANOVAs were run for Experiment I (grain protectants) and Experiment II (storage facilities). Data were then subjected to one-way analysis of variance (ANOVA) in GENSTAT version 14. Statistically significant differences among treatment means were separated using Tukey-Kramer HSD test at the 0.05 level. A bivariate correlation test was carried out on related parameters to check for relationships using Pearson's correlation. The climate data recorded from inside treatments and chambers were graphically analysed.

6.3 Results

6.3.1 Experiment I: Evaluation of grain protectants at increased temperatures

6.3.1.1 Main effects of storage condition, grain protectant and storage duration

The MANOVA results showed that the storage conditions, grain protectants, and storage duration all had a significant effect on the combined dependent variables (Table 6.3; Appendix E). Significant interaction effects were found between: storage conditions and grain protectants; storage conditions and storage duration; grain protectants and storage duration; and storage conditions, grain protectants and storage duration (Table 6.3; Appendix E).

Table 6.3 Multivariate analysis of variance (MANOVA) of the main effects of storage condition, grain protectant and storage duration on the combined dependent variables

	DF	**Pillai**	**Approx. F**	**DF**	**Den DF**	**p-value**
Storage condition	2	1.1700	37.355	8	212	< 0.0001
Grain protectant	5	1.2912	10.296	20	432	< 0.0001
Storage period	2	1.5130	82.335	8	212	< 0.0001
Storage condition*grain protectant	10	0.5850	1.850	40	432	< 0.0001
Storage condition*storage period	4	0.9507	8.418	16	432	< 0.0001
Grain protectant*storage period	10	1.3067	5.240	40	432	< 0.0001
Storage condition*grain protectant*storage period	20	0.8483	1.453	80	432	< 0.0001

6.3.1.2 Insect grain damage

At baseline (0 weeks storage), the % number of damaged grains was 2.5 ± 0.1 %. Under all three storage conditions (32 $^{\circ}$C, 38 $^{\circ}$C and 26 $^{\circ}$C (ambient)), insect damage remained lower (<8.5 % in the synthetic-pesticide grain protectants during the 4, 8 and 12 weeks of storage (Figs. 6.5a-c). The percentage damaged grains was significantly affected by the storage conditions ($F_{2, 144}$ = 13.158; p < 0.001), the treatments ($F_{5, 144}$ = 254.517; p < 0.001) and the storage duration ($F_{2, 144}$ = 657.841; p < 0.001). There were significant interaction effects (p<0.05) between each pair of these variables, most significantly between treatments and storage duration ($F_{10, 144}$ = 1.963; p <0.01), storage condition and storage duration ($F_{6, 144}$ = 4.559; p < 0.001) (Appendix E).

Of the three storage conditions, the untreated grain at ambient conditions after 12 weeks storage had the highest number of insect damaged grains (26.8 ± 0.9%) followed by the untreated grain kept at 32°C and 38°C at 4, 8 and 12 week storage periods (Figs. 6.5a-c).

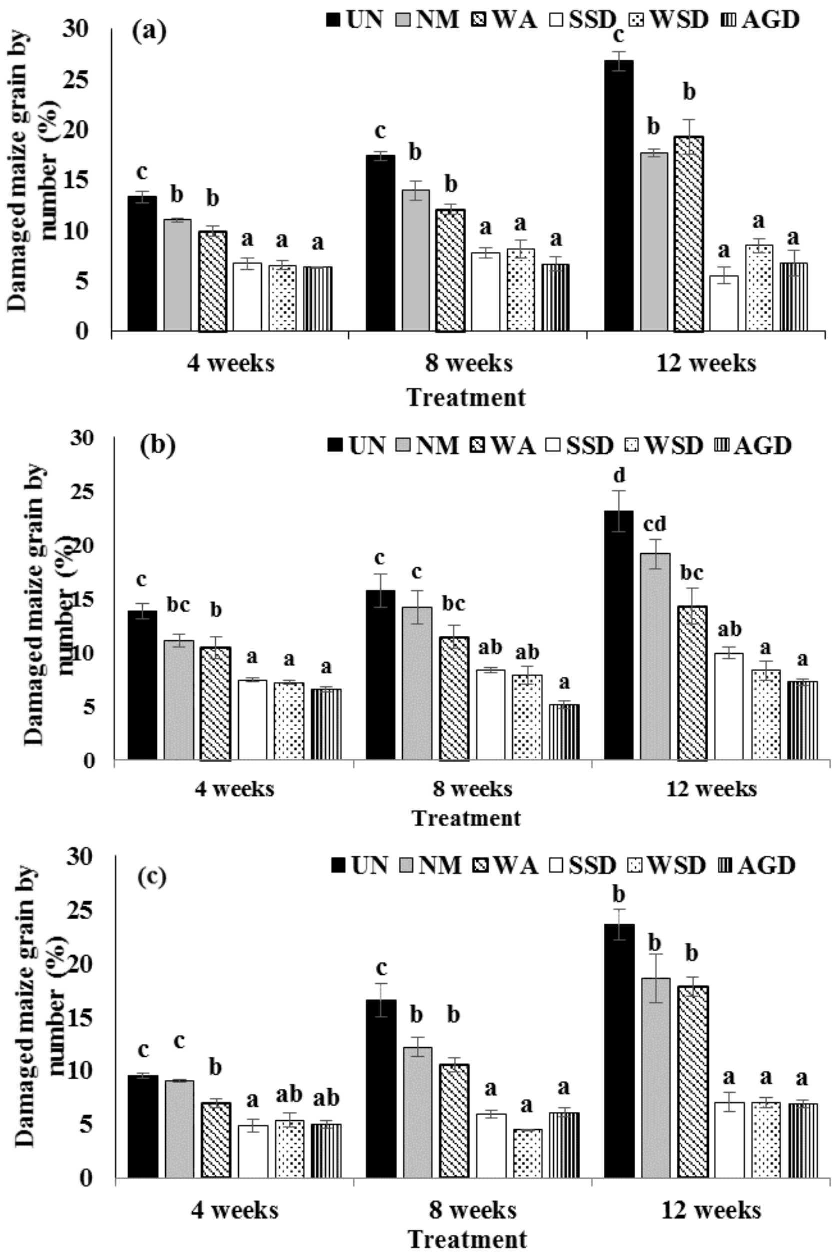


Figure 6.5: Mean (± SEM) insect damaged grain by number (%) from a range of grain protectant treatments when 100 g of maize grain was infested with 10 adult *P. truncatus* and stored for up to 12 weeks under different environmental conditions: (a) 26 ˚C and 30.8% RH (ambient); (b) 32 ˚C and 60% RH, and (c) 38 ˚C and 60% RH (n = 3). Comparisons were made across treatments at each time interval and treatment means were separated using Tukey's test. Legend: UN = Untreated grain, NM = Neem powder, WA = Wood Ash, SSD = Shumba Super dust (1.0% Fenitrothion + 0.13% Deltamethrin), WSD = Wivokil Super dust (1.0% Fenitrothion + 0.12% Deltamethrin) and AGD = Actellic Gold dust (1.6% Pirimiphos methyl + 0.36% Thiamethoxam). SEM = Standard Error of the Mean

6.3.1.3 Maize grain weight loss

After 12 weeks of storage, no significant differences in grain weight losses were observed between non-synthetic (NM and WA) and synthetic (WSD and AGD) grain protectants kept at 38°C (Fig. 6.6c). However, significant differences were observed between non-synthetic and synthetic grain protectants kept at 32°C and 38°C during the 12 week of storage (Fig. 6.6a-b). The grain protectant treatments had a significant effect on the grain weight loss ($F_{5, 144} = 19.268$; $p < 0.001$), and storage duration had also effect on grain weight loss ($F_{3, 144} = 26.509$; $p < 0.001$) (Appendix E). Storage conditions and storage duration did not, nor was there any significant interaction effect between any or all of these three variables (Appendix E).

6.3.1.4 Adult *P. truncatus* counts

The total number of *P. truncatus* adults was significantly affected by the storage conditions ($F_{2, 144} = 8.966$; $p < 0.001$), the treatments ($F_{5, 144} = 7.444$; $p < 0.001$) and the storage duration ($F_{3, 144} = 396.937$; $p < 0.001$), and there were significant interaction effects between all combinations of these three variables ($F_{30, 144} = 3.364$; $p < 0.001$) (Appendix F). At all three temperature and RH conditions (32 °C, 38 °C and 26 °C (ambient)), the highest total *P. truncatus* numbers were recorded from the untreated control at 12 weeks storage (Table 6.4).

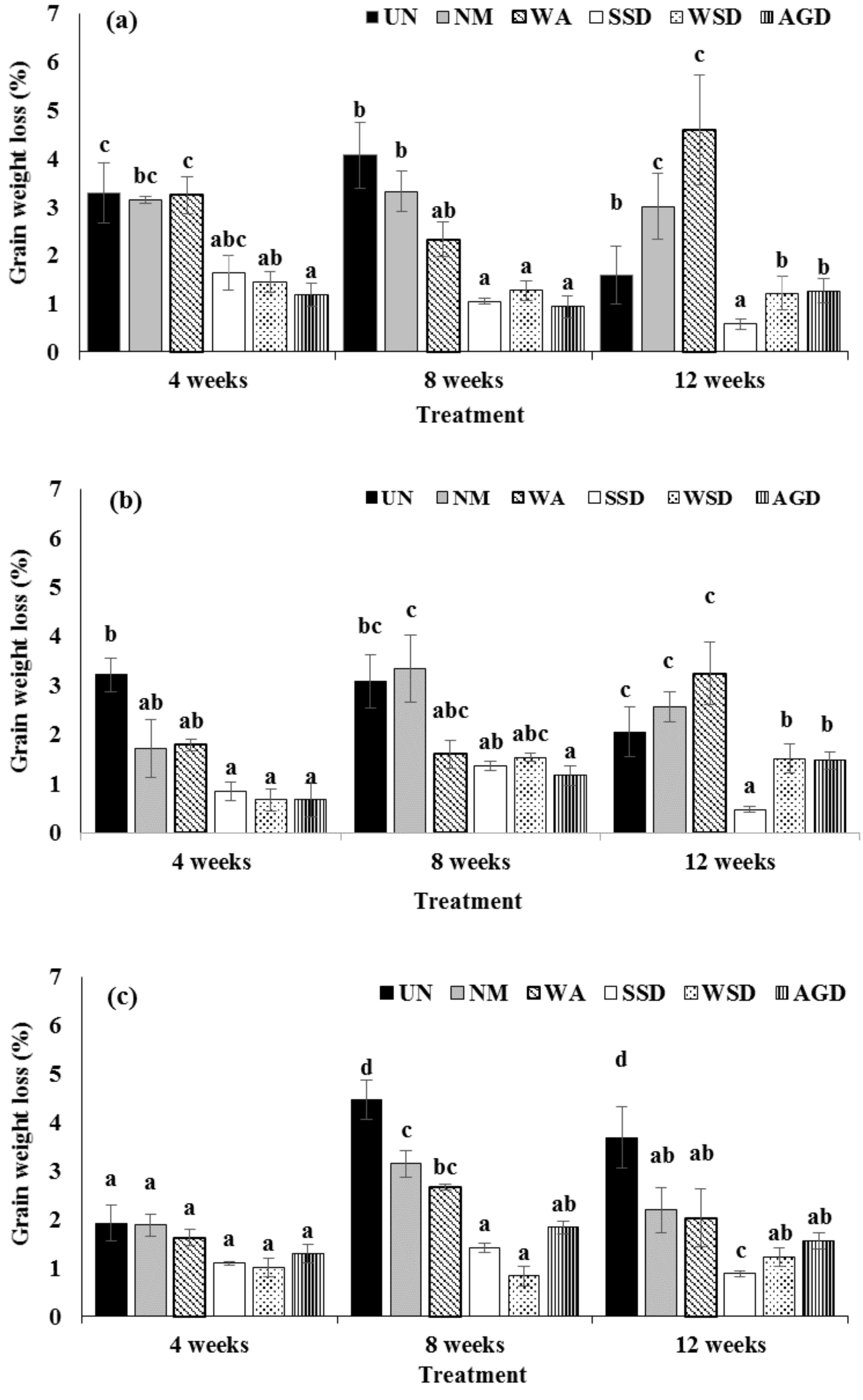


Figure 6.6: Mean (± SEM) maize grain weight loss (%) from a range of grain protectants treatments when 100 g of maize grain was infested with 10 adult *P. truncatus* and stored for up to 12 weeks under: (a) ambient 26 ˚C and 30.8% relative humidity; (b) 32 ˚C and 60% relative humidity, and (c) 38 ˚C and 60% relative humidity (n = 3). Comparisons were made across treatments at each time interval and treatment means were separated using Tukey's HSD test. Legend: UN = Untreated grain, NM = Neem powder, WA = Wood Ash, SSD = Shumba Super dust (1.0% Fenitrothion + 0.13% Deltamethrin), WSD = Wivokil Super dust (1.0% Fenitrothion + 0.12% Deltamethrin) and AGD = Actellic Gold dust (1.6% Pirimiphos methyl + 0.36% Thiamethoxam). SEM = Standard Error of the Mean

In the Wivokil Super dust, Shumba Super dust and Actellic Gold dust treatments, no or <5 live *P. truncatus* adults were observed at the 4-, 8- and 12-weeks storage samplings (Table 6.4).

Higher numbers of above 68 dead *P. truncatus* per kg of maize were recorded in the synthetic grain protectants throughout the 12 week storage period at all temperature regimes. However, in all the non-synthetic grain protectants recorded less than 67 dead *P. truncatus* per kg of maize except untreated control during 12 week of storage at ambient and 32°C storage conditions (Table 6.4). The difference between synthetic and non-synthetic grain protectants on numbers of dead *P. truncatus* was not statistically significant under all three storage conditions at 4-, 8- and 12-week storage periods (Table 6.4). The number of live *P. truncatus* were affected by storage condition ($F_{2, 144} = 13.152$; $p < 0.001$), treatment ($F_{5, 144} = 61.552$; $p < 0.001$) and storage duration ($F_{3, 144} = 155.694$; $p < 0.001$) (Appendix E). A much higher number of live *P. truncatus* (282.7 ± 32.7 per kg of maize) was recorded at 12 weeks storage in the untreated grain kept at ambient conditions than in the other treatments kept at 32°C and 38°C (Table 6.4). At 12 weeks storage, significantly higher numbers of live *P. truncatus* were present in the untreated grain compared to the synthetic pesticide treatments at ambient and 38°C, and compared to the neem powder and wood ash at ambient and 38 °C (Table 6.4).

6.3.1.5 Maize grain moisture content

At ambient conditions (26 °C and 30.8 % RH), the grain MC decreased from an initial 10.7 ± 0.1 % at 0 weeks storage to 8.5 ± 0.1 % by 4 weeks storage and remained below 10 % for the remainder of the 12 week storage trial (Fig. 6.7a). At 32 °C and 38 °C, the MC of all treatments increased from week 0 to week 4, then decreased at week 8, never exceeding 12.3 % in any treatment throughout the 12 week trial period nor differing significantly between treatments (Figs. 6.7b and c). Moisture content was significantly affected by the storage conditions ($F_{2, 144} = 2500.025$; $p < 0.001$), storage duration ($F_{3, 144} = 79.945$; $p < 0.001$) and the interaction of storage condition and storage duration ($F_{6, 144} = 315.994$; $p < 0.001$) (Appendix E). However, the treatment, interaction of storage condition and treatment, treatment and storage duration, and interaction of the three factors had no effect on the grain moisture content throughout the 12 weeks of storage period (Appendix E). At 12 weeks of storage under ambient conditions, grain MC was significantly higher in the Actellic Gold dust treatment than the wood ash or untreated control, but was not significantly different from the other treatments.

Table 6.4: Mean (± SEM) number of adult *Prostephanus truncatus* per kg of maize from a range of grain protectant treatments (following infestation of 100 g of maize with 10 adult P. truncatus) during 12 weeks' storage under different temperature and relative humidity conditions (n = 3)

	Experimental conditions→	26 ºC and 30.8 % RH (ambient conditions)			32 ºC and 60 % RH			38 ºC and 60 % RH		
Insects	Treatment	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks
Live	Actellic Gold dust	0a	0a	0a	0a	0a	0a	3.3 ± 3.26a	0a	0a
	Shumba Super dust	0a	0a	3.4 ± 3.39a	0a	0a	0a	3.3 ± 3.25a	0a	0a
	Wivokil Super dust	0a	0a	0a	3.3 ± 3.27a	0a	0a	0a	0a	0a
	Neem powder	20.2± 5.81ab	0a	131.5 ± 35.02b	9.8 ± 5.65a	9.8 ± 5.64a	68.4 ± 20.34ab	13.0 ± 8.55a	0a	61.7 ± 17.32a
	Wood ash	7.8 ± 4.53ab	0a	114.9 ± 14.78b	12.7 ± 6.73a	0a	45.5 ± 21.28ab	9.8 ± 5.67a	3.3 ± 3.33a	68.3 ± 14.95a
	Untreated control	23.5 ± 8.88b	10.2 ± 5.86b	282.7 ± 32.70c	22.9 ± 8.59a	6.5 ± 6.53a	81.7 ± 22.92b	19.5 ± 5.64a	6.3 ± 6.33a	169.3 ± 31.22b
Dead	Actellic Gold dust	97.3 ± 3.39c	91.2 ± 5.81b	84.0 ± 9.01a	94.6 ± 3.92c	97.8 ± 0.11c	94.5 ± 3.25ab	68.3 ± 11.24b	91.0 ± 6.47c	91.1 ± 3.13b
	Shumba Super dust	90.5 ± 5.80c	81.1 ± 5.86b	70.9 ± 5.93a	88.1 ± 5.64c	88.1 ± 5.67c	88.0 ± 0.12ab	87.8 ± 5.81b	94.3 ± 3.16c	91.2 ± 3.25b
	Wivokil Super dust	87.6 ± 8.88c	71.2 ± 11.75b	87.8 ± 6.69a	78.2 ± 5.63c	81.5 ± 3.32c	94.5 ± 3.33ab	87.8 ± 5.79b	81.3 ± 6.40bc	68.5 ± 5.77ab
	Neem powder	47.2 ± 3.33b	67.7 ± 13.48b	60.7 ± 5.83a	45.7 ± 8.65b	42.4 ± 8.62b	42.3 ± 14.21a	29.3 ± 5.71a	61.9 ± 8.73bc	45.6 ± 17.18ab
	Wood ash	15.7 ± 4.54a	66.9 ± 4.58b	60.8 ± 11.70a	22.8 ± 4.40ab	25.9 ± 8.47ab	58.5 ± 11.28ab	3.2 ± 3.22a	48.7 ± 9.64ab	39.0 ± 11.34a
	Untreated control	6.7 ± 6.70a	10.2 ± 5.87a	90.8 ± 11.58a	9.8 ± 5.63a	6.5 ± 6.51a	107.9 ± 26.26b	19.5 ± 5.64a	19.5 ± 5.68a	52.1 ± 14.18ab
Total	Actellic Gold dust	97.3 ± 3.39c	91.2 ± 5.81b	84.0 ± 9.01ab	94.6 ± 3.92c	97.8 ± 0.11c	94.5 ± 3.25a	71.6 ± 8.60bc	97.5 ± 0.22d	91.1 ± 3.13b
	Shumba Super dust	90.5 ± 5.80 bc	81.1 ± 5.86b	74.3 ± 9.04a	88.1 ± 5.64c	88.1 ± 5.67c	88.0 ± 0.12a	91.1 ± 6.64c	94.3 ± 3.16d	91.2 ± 3.25b
	Wivokil Super dust	87.7 ± 8.88bc	71.2 ± 11.75b	87.8 ± 6.69ab	81.5 ± 3.29bc	81.5 ± 3.32c	94.5 ± 3.33a	87.8 ± 5.79c	81.3 ± 6.40cd	68.5 ± 5.77ab
	Neem powder	67.4 ± 6.65b	67.7 ± 13.48b	192.2 ± 38.27c	55.4 ± 14.24abc	52.2 ± 3.25b	110.7 ± 19.84ab	42.3 ± 3.12ab	61.9 ± 8.74bc	107.5 ± 22.43a
	Wood ash	23.6 ± 4.53a	66.9 ± 4.58b	175.7 ± 14.83bc	35.5 ± 10.18ab	25.9 ± 8.47a	104.0 ± 14.13ab	13.0 ± 6.51a	51.9 ± 8.51ab	107.2 ± 20.52a
	Untreated control	30.2 ± 5.81a	20.3 ± 10.16a	373.6 ± 21.27d	32.5 ± 14.16a	13.0 ± 6.52a	189.6 ± 42.12b	39.4 ± 11.63ab	26.0 ± 3.23a	221.6 ± 38.59b

Means in each of the live, dead and total categories followed by the same letter in the same column are not significantly different at $p < 0.05$. The means were compared and separated using Tukey's HSD test at $p < 0.05$

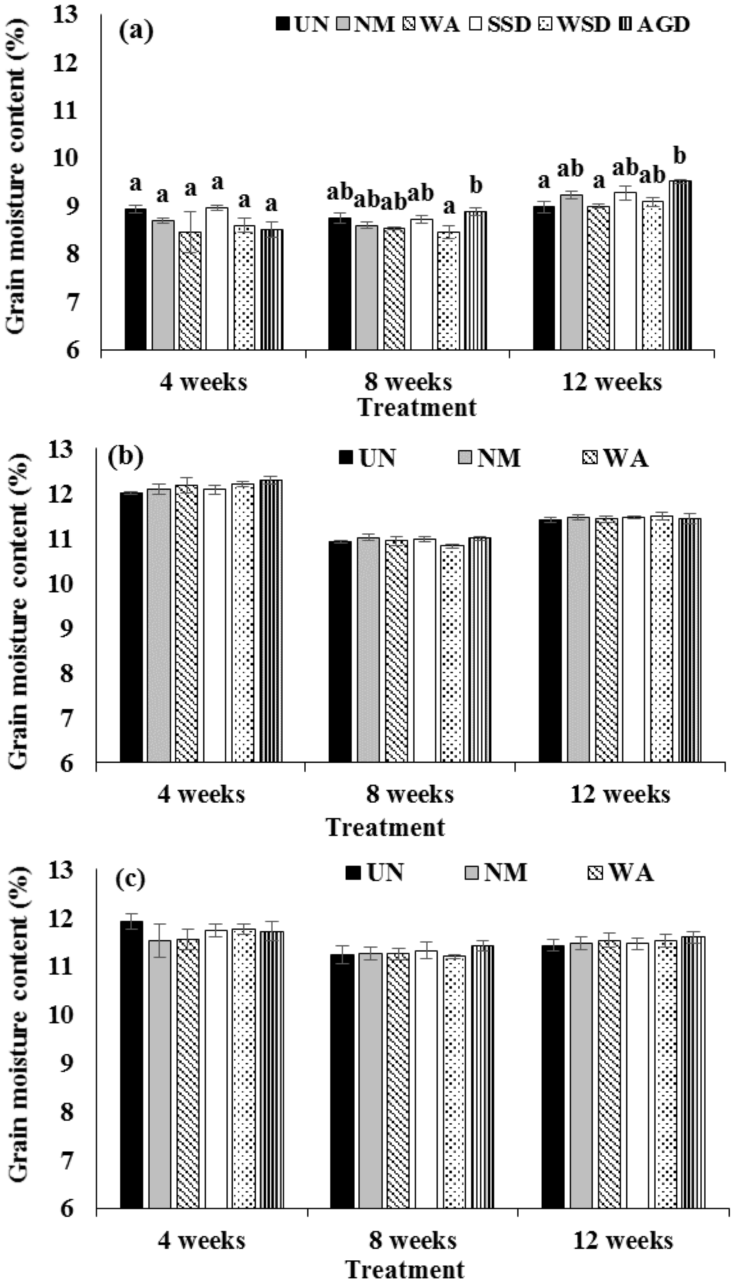


Figure 6.7: Mean (± SEM) percent grain moisture content from a range of grain protectants treatments when 100 g of maize grain was infested with 10 adult *P. truncatus* and stored for up to 12 weeks under: (a) ambient 26 ˚C and 30.8% relative humidity; (b) 32 ˚C and 60% relative humidity, and (c) 38 ˚C and 60% relative humidity (n = 3). Comparisons were made across treatments at each time interval and treatment means were separated using Tukey's HSD test at p=0.05 where significant differences were found. Legend: UN = Untreated grain, NM = Neem powder, WA = Wood Ash, SSD = Shumba Super dust (1.0% Fenitrothion + 0.13% Deltamethrin), WSD = Wivokil Super dust (1.0% Fenitrothion + 0.12% Deltamethrin) and AGD = Actellic Gold dust (1.6% Pirimiphos methyl + 0.36% Thiamethoxam). SEM = Standard Error of the Mean

6.3.2 Experiment II: Evaluation of grain storage containers at a range of temperatures

6.3.2.1 Main effects of storage condition, storage facilities and storage duration

The MANOVA results showed that the storage conditions, storage containers, and storage duration all had a significant effect on the combined dependent variables (Table 6.5; Appendix F). Significant interaction effects were found between: storage conditions and storage containers; storage conditions and storage duration; storage containers and storage duration; and storage conditions, storage containers and storage duration (Table 6.5; Appendix F).

Table 6.5: Multivariate analysis of variance (MANOVA) of the main effects of storage condition, storage facilities and storage duration on the combined dependent variables

	DF	Pillai	Approx. F	DF	Den DF	p-value
Storage condition	2	1.3470	33.006	8	128	< 0.0001
Storage facilities	3	1.1130	9.584	12	195	< 0.0001
Storage period	2	1.2365	25.909	8	128	< 0.0001
Storage condition*storage facility	5	1.4253	7.307	20	264	< 0.0001
Storage condition*storage period	4	0.5796	2.796	16	264	< 0.0001
Storage facility*Storage period	6	1.4415	6.197	24	264	< 0.0001
Storage condition*storage facility*storage period	10	0.7889	1.622	40	264	0.014

6.3.2.2 Insect grain damage

The percentage insect damaged grains was significantly affected by the storage conditions ($F_{2, 88} = 46.782$; $p < 0.001$), treatments ($F_{3, 88} = 635.461$; $p < 0.001$) and storage duration ($F_{3, 88}$ =

344.184; $p < 0.001$). There were significant interaction effects by storage conditions and treatments ($F_{5, 88} = 16.660$; $p < 0.001$), storage condition and storage duration ($F_{6, 88} = 6.411$; $p < 0.001$), treatment and storage duration ($F_{9, 88} = 120.357$; $p < 0.001$), and storage condition, treatment and storage duration ($F_{5, 88} = 16.660$; $p < 0.001$), on the insect damaged grain (Appendix F). The baseline mean number of insect damaged grains was < 2.4 ± 0.1 % and this increased to 28.9 % in the polypropylene bag treatment by 12 weeks storage, recorded from all the three different storage conditions (Figs. 6.8a-c).

6.3.2.3 Grain weight loss

The storage conditions ($F_{2, 88} = 11.614$; $p < 0.001$), treatments ($F_{3, 88} = 105.405$; $p < 0.001$) and storage duration ($F_{3, 88} = 59.468$; $p < 0.001$) had significant effects on grain weight loss. There were interaction effects of storage condition and treatment ($F_{5, 88} = 8.313$; $p < 0.001$), storage condition and storage duration ($F_{6, 88} = 4.444$; $p < 0.01$), treatment and storage duration ($F_{9, 88} = 16.433$; $p < 0.001$), and storage condition, treatment and storage duration ($F_{15, 88} = 3.964$; $p < 0.001$) on the grain weight loss (Appendix F). High percentage grain weight losses occurred in the polypropylene bags from 4 week of storage kept at 32°C and under ambient conditions (Fig. 6.9a-b) except during the 12 week of storage kept at 38 $^{\circ}$C (Figs. 6.9c).

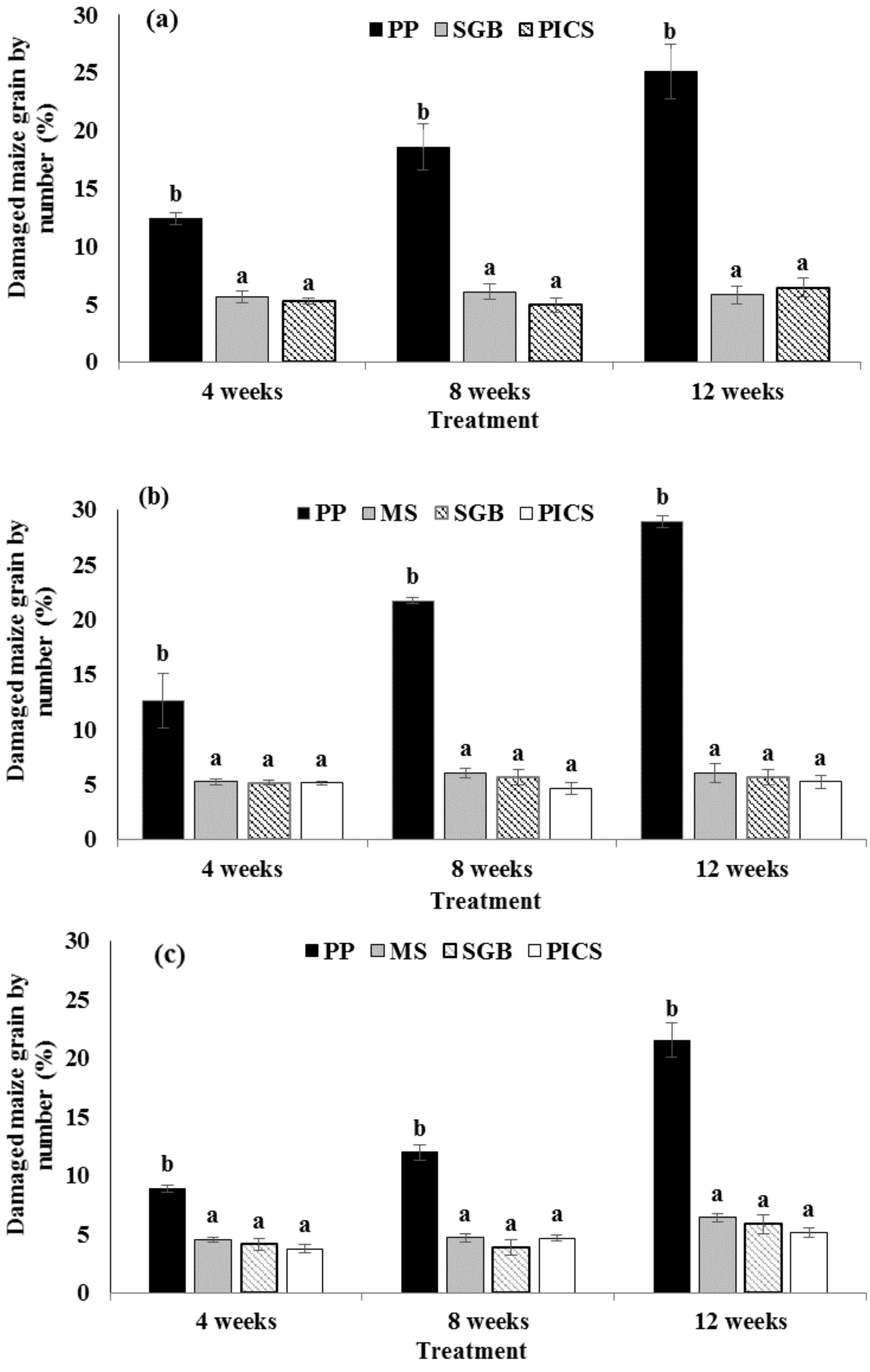


Figure 6.8: Mean grain damage (%) from a range of storage facility treatments when 200g of maize grain was infested with 10 adult *P. truncatus* and stored for up to 12 weeks under: (a) ambient 26 ˚C and 30.8% relative humidity (the metal silo treatment was excluded because there were insufficient numbers of them to cater for the three sets of storage conditions and the required sampling frequencies); (b) 32 ˚C and 60% relative humidity, and (c) 38 ˚C and 60% relative humidity (n = 3). Comparisons were made across treatments at each time interval and treatment means were separated using Tukey's HSD test. PP = Polypropylene bag, MS = Metal silo, SGB = Super Grain bag and PICS = Purdue Improved Crop Storage

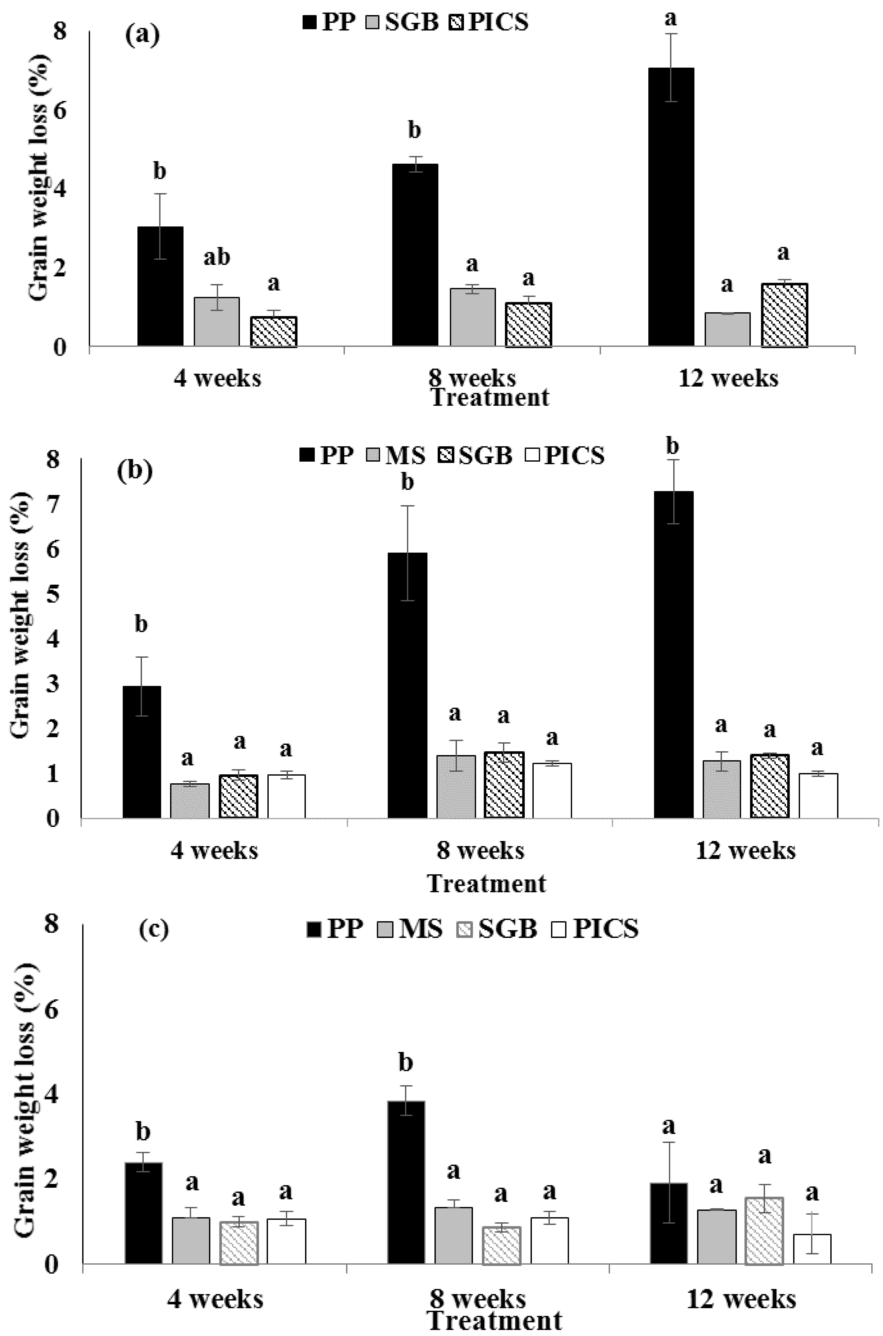


Figure 6.9: Mean (+ SEM) maize grain weight loss (%) from a range of different storage facilities when 200 g of maize grain was infested with 10 adult *P. truncatus* and stored for up to 12 weeks under: (a) ambient 26 ˚C and 30.8% relative humidity (the metal silo treatment was excluded because there were insufficient numbers of them to cater for the three sets of storage conditions and the required sampling frequencies); (b) 32 ˚C and 60% relative humidity, and (c) 38 ˚C and 60% relative humidity (n = 3). Comparisons were made across treatments at each time interval and treatment means were separated using Tukey's HSD test. PP = Polypropylene bag, MS = Metal silo, SGB = Super Grain bag and PICS = Purdue Improved Crop Storage. SEM = Standard Error of the Mean

6.3.2.4 Adult *P. truncatus* counts

At 12 weeks storage, higher total adult *P. truncatus* numbers were recorded in the grain stored in the polypropylene bag than in the hermetic storage containers (Table 6.6). Storage duration had significant effect on the total *P. truncatus* ($F_{3, 88} = 150.404$; $p < 0.001$), while storage conditions or treatments had no significant effect on the total *P. truncatus* (Appendix F). The total *P. truncatus* numbers was affected by the interaction of treatment and storage duration ($F_{9, 88} = 25.273$; $p < 0.001$). The interaction of storage condition and treatment, storage condition and storage duration, and storage condition, treatment and storage duration had no effect on the total *P. truncatus* (Appendix F).

The number of live *P. truncatus* was not affected by the storage condition, but was affected by the treatment ($F_{3, 88} = 31.678$; $p < 0.001$) and storage duration ($F_{3, 88} = 32.063$; $p < 0.001$). The interaction effect of treatment and storage duration ($F_{9, 88} = 25.273$; $p < 0.001$) affected the number of live *P. truncatus* (Appendix F). The number of dead *P. truncatus* was affected by treatment ($F_{3, 88} = 134.480$; $p < 0.001$), and storage duration ($F_{3, 88} = 379.501$; $p < 0.001$), but was not affected by storage condition. The interaction of treatment and storage duration affected the number of dead *P. truncatus* ($F_{9, 88} = 30.113$; $p < 0.001$) The interaction of storage condition and treatment, storage condition and storage duration, and storage condition, treatment and storage duration had no effect on the number of dead *P. truncatus* (Appendix F). The results showed a weak non-significant positive correlation between grain MC and total adult *P. truncatus* per kg of maize ($r = 0.052$; $p = 0.555$).

6.3.2.5 Grain moisture content

The grain moisture content was affected by storage condition ($F_{2, 88}$ = 160.620; $p < 0.001$), treatment ($F_{3, 88}$ = 6.656; $p < 0.001$), and storage duration ($F_{3, 88}$ = 37.994; $p < 0.001$) (Appendix F). The interaction of storage condition and treatment ($F_{5, 88}$ = 138.933; $p < 0.001$), storage condition and storage duration ($F_{6, 88}$ = 23.048; $p < 0.001$), treatment and storage duration ($F_{9, 88}$ = 2.655; $p < 0.01$), and storage condition, treatment and storage duration ($F_{15, 88}$ = 5.253; $p < 0.001$) significantly affected the grain MC (Appendix F). The grain moisture content remained below 12% in all treatments throughout the 12 week of storage (Figs. 6.10a-c). However, under ambient conditions it dropped in the polypropylene bag treatment to 8.36% by 4 weeks and remained below 9% throughout the 12 weeks of storage (Fig. 6.10a).

Table 6.6: Mean (± SEM) number of adult *Prostephanus truncatus* per kg of maize from a range of storage containers treatments (following infestation of 200 g of maize with 10 adult *P. truncatus*) during 12 weeks' storage under different experimental conditions (n = 3).

	Experimental conditions→	26ºC and 30.8% RH (ambient conditions)			32ºC and 60 % RH			38ºC and 60 % RH		
Insect	Treatment	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks	4 weeks	8 weeks	12 weeks
Live	Purdue Improved Crop Storage bag	0a	0a	0a	0a	0a	0a	0a	0a	0a
	Super Grain bag	0a	0a	0a	0a	0a	0a	0a	0a	0a
	Metal silo				0a	0a	0a	0a	0a	0a
	Polypropylene bag	10.2 ± 2.93b	5.1 ± 2.94a	57.8 ± 12.21b	11.4 ± 1.64b	4.9 ± 2.83a	79.6 ± 12.05b	8.3 ± 4.41a	3.3 ± 3.33a	71.9 ± 17.03b
Dead	Purdue Improved Crop Storage bag	50.0 ± 0.01b	48.3 ± 1.69b	45.0 ± 5.02a	41.6 ± 5.99b	48.2 ± 1.66b	46.2 ± 1.39a	36.6 ± 6.00b	44.9 + 5.01b	47.9 ± 1.69a
	Super Grain bag	45.0 ± 2.90b	40.1 ± 5.79b	40.1 ± 2.88a	41.4 ± 4.22b	44.8 ± 2.86b	44.7 ± 2.86a	36.5 ± 4.43b	46.4 ± 1.66b	48.1 ± 1.68a
	Metal silo				36.4 ± 4.41b	41.2 ± 4.44b	41.0 ± 4.42a	39.7 ± 2.86b	42.7 ± 4.40b	47.5 ± 1.59a
	Polypropylene bag	1.7 ± 1.69a	1.7 ± 1.71a	47.6 ± 4.53a	1.7 ± 1.63a	1.6 ± 1.63a	30.9 ± 4.37a	5.0 ± 2.88a	11.4 + 1.61a	32.6 ± 7.09a
Total	Purdue Improved Crop Storage bag	50.0 ± 0.01b	48.3 ± 1.69b	45.0 ± 5.02a	41.6 ± 5.99b	48.2 ± 1.66b	46.2 ± 1.39a	36.6 ± 6.00b	44.9 + 5.01b	47.9 ± 1.69a
	Super Grain bag	45.0 ± 2.90b	40.1 ± 5.79b	71.8 ± 31.92a	41.4 ± 4.22b	44.8 ± 2.86b	44.7 ± 2.86a	36.5 ± 4.43b	46.4 ± 1.66b	48.1 ± 1.68a
	Metal silo				36.4 ± 4.41b	41.2 ± 4.44b	41.0 ± 4.42a	39.7 ± 2.86b	42.7 ± 4.40b	47.5 ± 1.59a
	Polypropylene bag	11.9 ± 3.39a	6.8 ± 1.69a	105.4 ± 13.22a	13.1 ± 3.27a	6.5 ± 1.64a	110.5 ± 15.92b	13.3 ± 1.66a	14.7 ± 4.87a	104.3 ± 21.40b

Means in each of the live, dead and total categories followed by the same letter in the same column are not significantly different from each other at $p < 0.05$. The means were compared and separated using Tukey's HSD test at $p < 0.05$. Note: metal silo treatment was excluded at 26 °C (ambient) and 30.8 % relative humidity because there were insufficient numbers of them to cater for the three sets of storage conditions and the required sampling frequencies

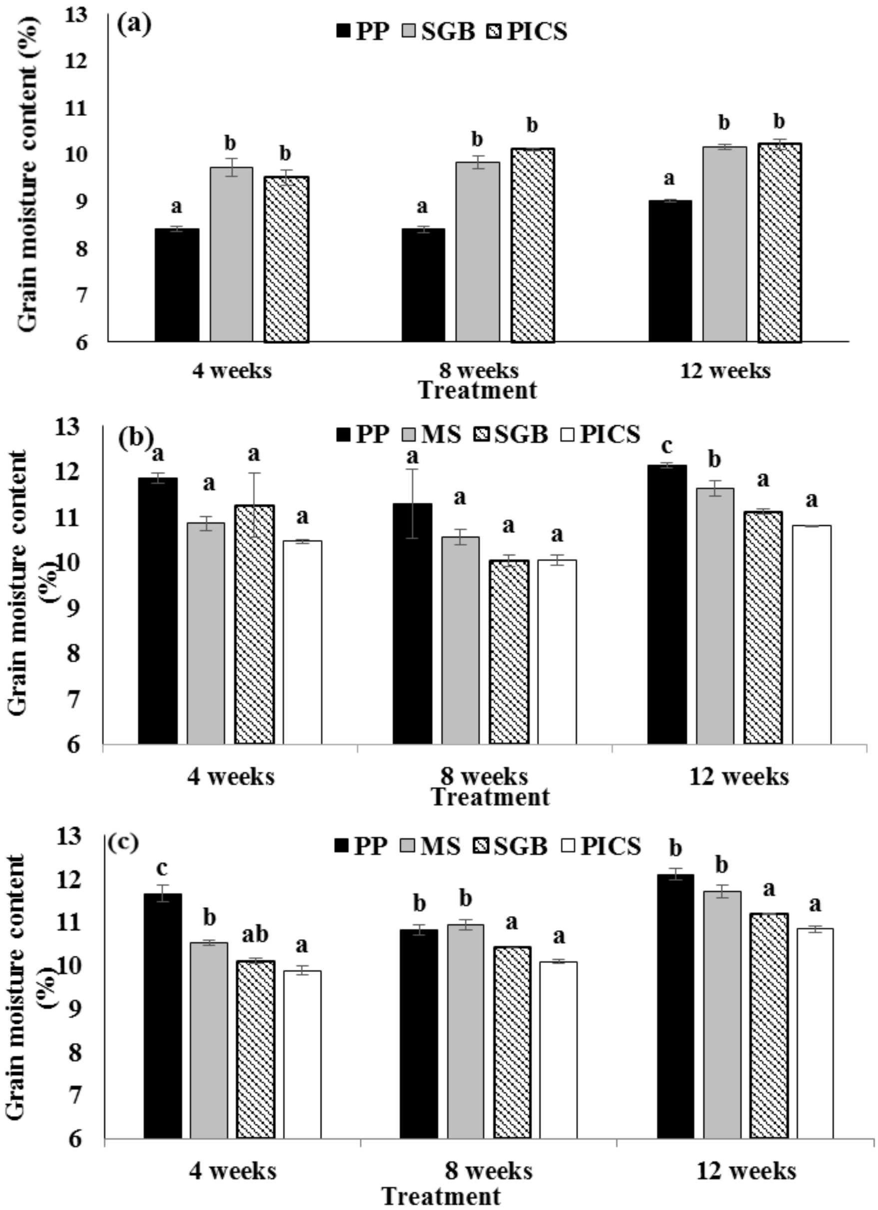


Figure 6.10: Mean (+ SEM) grain moisture content (%) from a range of storage facilities treatments when 200 g of maize grain was infested with 10 adult *P. truncatus* and stored for up to 12 weeks under: (a) ambient 26 ˚C and 30.8% relative humidity (the metal silo treatment was excluded because there were insufficient numbers of them to cater for the three sets of storage conditions and the required sampling frequencies); (b) 32 ˚C and 60% relative humidity, and (c) 38 ˚C and 60% relative humidity (n = 3). Comparisons were made across treatments at each time interval and treatment means were separated using Tukey's HSD test. PP = Polypropylene bag, MS = Metal silo, SGB = Super Grain bag and PICS = Purdue Improved Crop Storage. SEM = Standard Error of the Mean

6.3.3 Temperature and relative humidity recorded inside and outside climate chambers

The internal temperature of the climate chamber set at 32 ˚C fluctuated between 31 ˚C and 35.6 ˚C with a mean of 33.1 ˚C, while the climate chamber set at 38 ˚C fluctuated between

35.8 °C and 38.2 °C throughout the 12 week storage period, with a mean of 37.8 °C (Fig. 6.11). Outside the climate chambers, at ambient conditions, wide temperature fluctuations (ranging between 20.1 °C and 31.3 °C) with a mean temperature of 26 °C were recorded throughout the 12 week storage period, with higher fluctuations occurred from week 7 to 12 (Fig. 6.11). The mean RH inside both of the climate chambers (one set at 32 °C and 60 % RH and the other at 38 °C and 60 % RH) were 62.1 % and 63.8 % respectively (Fig. 6.11), while the external ambient RH fluctuated between 16.7 % and 48.2 % with a mean of 30.8% during the 12 week storage period (Fig. 6.11). The correlation of temperature recorded inside the climate chambers and storage duration were positive and the strength of the relationship were 19.9%; chamber at 32°C (R^2 = 0.199) and 43.2%; chamber at 38°C (R^2 = 0.432), while the recorded temperature at ambient (R^2 = 0.054) showed a relationship strength of only 5.3% (Fig. 6.11). However, the strength of the relationship between relative humidity within the chambers and storage duration were 35.5% for chamber set at 32°C (R^2 = 0.355) and 38.7% for the chamber set at 38°C (R^2 = 0.387), ad for relative humidity at ambient recorded (R^2 = 0.52) (Fig. 6.11).

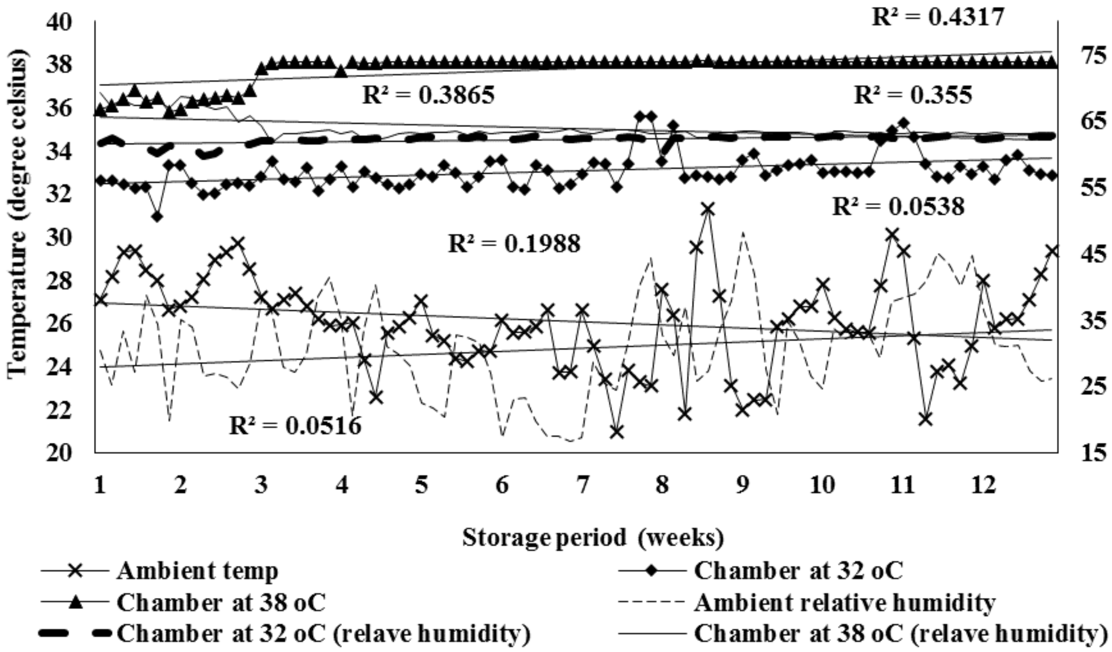
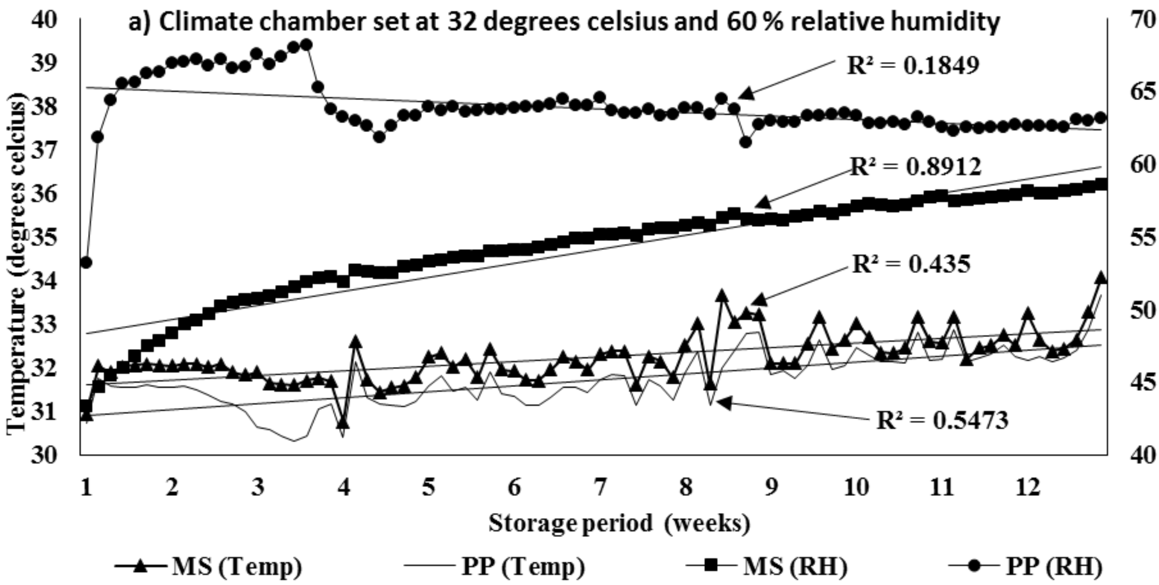


Figure 6.11: Mean daily temperatures and relative humidity recorded inside two climate chambers set at 32ºC and 38 ˚C and both at 60 % RH, and outside the climate chambers during the 12 weeks storage period. Legend; Ambient = 26 ˚C and 30.8 % RH, Chamber at 32 ˚C = 32 ˚C and 60 % RH and Chamber at 38 ˚C = 38 ˚C and 60 % RH.

6.3.4 Temperature and relative humidity recorded inside a metal silo, a Purdue Improved Crop Storage bag and a polypropylene bag

Inside the storage containers, a slightly higher mean internal temperature 32 ˚C ($F_{1,\ 170}$ = 18.29; P ≤ 0.001) occurred in the MS than the polypropylene bag (31.8 ˚C) kept in the climate chamber set at 32 ˚C during the 12 week storage (Fig. 6.12a). The correlation of storage duration and the temperature inside the MS was strong (R^2 = 0.435) but the relationship was very strong and positive (R^2 = 0.8912) between storage duration and relative humidity within the MS kept in climate chamber set at 32˚C (Fig. 6.12a). The weakest relationship between storage duration and the relative humidity was observed in PP (R^2 = 0.184), while storage duration and temperature was strong (R^2 = 0.547) in PP kept in climate chamber set at 32˚C (Fig. 6.12a).

At week 4, 8 and 12 samplings, inside temperatures in the MS and polypropylene bag were less than 30.4 °C in the climate chamber set at 32 °C. A lower mean internal RH (54.1 %) was recorded in the MS than that recorded in the PP (63.8 %) during the 12 week storage period (Fig. 6.12b). Mean internal temperature of between 37.5 °C and 38.7 °C were recorded in the hermetic storage containers (MS and PICS) and PP kept inside the climate chamber set at 38 °C during the 12 week storage period (Fig. 6.12b). While low internal RH (between 43.4 % and 58.7 %) were registered from the hermetic storage containers (PICS and MS) compared to the polypropylene bag (between 52.2 % and 64.9 %) kept in the climate chamber set at 38 °C during the 12 week storage period (Fig. 6.12b). The temperature inside hermetic storage facilities kept in climate chamber set at 38°C had weak or no relationship with the storage period, MS (R^2 = 0.078) and PICS (R^2 = 0.067). While the relationship was very strong between RH and storage duration MS (R^2 = 0.944) and PICS (R^2 = 0.948) (Fig. 6.12b). Furthermore, in PP kept in climate chamber kept at 38°C, there was a very weak positive relationship between temperature and storage duration (R^2 = 0.159) (Fig. 6.12b).



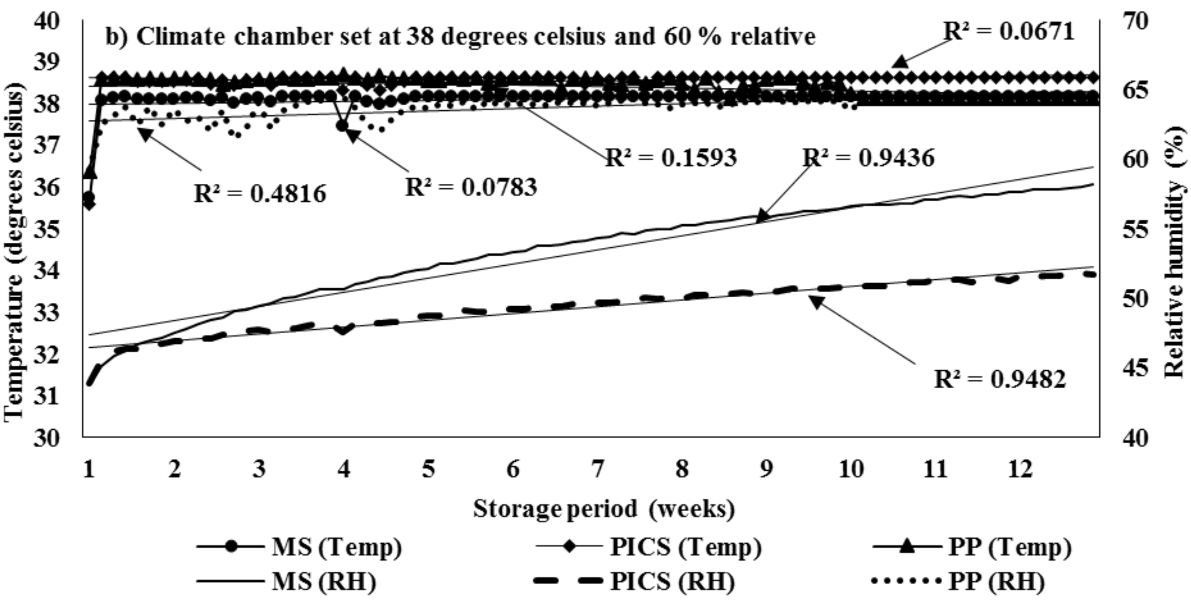


Figure 6.12: Mean daily temperatures inside the different grain storage facilities (Purdue Improved Crop Storage, Metal silo and Polypropylene bag kept in a) climate chamber set at 32 ˚C temperature and 60 % relative humidity b) climate chamber set at 38 ˚C temperature and 60 % relative humidity during a 12 week storage period. Legend; Temp = Temperature, RH = Relative humidity, MS = Metal silo, PICS = Purdue Improved Crop Storage and PP = Polypropylene bag

6.4 Discussion

Maize grain treated with synthetic-pesticides (ASD, SSD and WSD) and stored at ambient conditions (26 ˚C and 30.8 % RH) suffered lower insect damage than maize grain left untreated or admixed with either WA or NM (Fig. 6.5a). The current findings concur with study results in Zimbabwe where insect damaged grain of below 20 % was recorded from synthetic grain protectants (comprising organophosphates and pyrethroids) under natural infestation, under hot ambient field temperatures and RH during a 40 weeks storage period (Mlambo *et al*., 2018). Further, at higher storage temperatures of 32 °C and 38 °C, grain had low insect damage, suggesting the efficacy of these grain storage pesticides is not negatively impacted on by mean storage temperatures of up to 38 °C (Fig. 6.5b-c). Previous studies on cereal grains found temperature increases from 20 °C to 30 °C to have a positive effect on the efficacy of synthetic protectants and of spinosad and spinetoram (Fields *et al*., 1998; Athanassiou *et al*., 2007).

The number of live *P. truncatus* were higher in the non-synthetic compared to synthetic grain protectants (Table 6.4). Neem leaf powder and wood ash, based on the application rates as commonly used by smallholder farmers, were ineffective as grain protectants against *P. truncatus*. Similarly in Zimbabwean field trials, farmers' traditional grain protection methods, i.e. *Eleusine coracana* and *Eucalyptus* sp. leaves were ineffective (Machekano *et al*., 2019). This finding is also consistent with a previous study in Kenya under ambient temperature and RH (associated with warm and dry, and cooler humid) conditions (Njoroge *et al*., 2014). *Prostephanus truncatus* lays its eggs inside rather than outside the grain, making it unlikely that the internally developing larva and pupa come into contact with the botanical pesticides. Previous studies found that non-synthetic grain protectants, including Neem seed oil were more effective in controlling storage insect pests which lay eggs outside than inside grain (Bett *et al*., 2017). Although ethanolic extracts of mopane bark and leaves have been reported to contain antimicrobial activity against *Pseudomonas aeruginosa*, *Bacillus subtilis* and *Staphylococcus aureus*; data on the same plant materials for the control of stored insect pests is scanty (Iyambo *et al*., 2017). The presence of tannins, saponins, flavonoids and cardiac glycosides in the leaf and bark aqueous extracts of mopane tree was reported by Iyambo *et al*. (2017). Mopane leaves possess chemicals including tannin and phenols, mainly during the wet season, which seem to deter some herbivore feeding (Makhado *et al*., 2019).

Application rates and methods influence the efficacy of synthetic and non-synthetic grain protectants. Murdock *et al*. (2003) pointed out that spreading a layer of ash on top of stored grain may prevent weevils from penetrating into the stored grain. As ash comprises fine dust particles, it tends to accumulate at the bottom of the bagged grain (Alonso-Amelot and Avila-Núñez, 2011), which then renders it less available for contact action with the insect pests feeding on grain in other parts of the bag. However, Murdock *et al*. (2003) concluded that wood ash was effective in controlling cowpea bruchids, *Callosobruchus maculatus* (F.) in stored cowpea grain due to the abrasive effect of the ash on the insect cuticle which cause desiccation and death of the insect.

The number of *P. truncatus* that were inside the untreated grains could not be easily determined during the sample analyses at 4, 8 and 12 week sampling periods while the beetles introduced in other treatments (synthetic and traditional grain protectants, and hermetic storage facilities) were killed before entering the grains due to the effect of the treatments resulting in higher total *P. truncatus* being recorded. The internal feeding behaviour of *P. truncatus* adults (Kiobia *et al*., 2015) contributed to the low numbers of total *P. truncatus* reported from the untreated controls in the two experiments compared to the other treatments. The seeded *P. truncatus* insects survived the first 4 weeks of storage in grain treated with the synthetic protectants (AGD and SSD) at a storage temperature of 38°C, but none survived beyond 4 weeks (Table 6.4). Similar investigations reported that combinations of synthetic grain protectants and temperatures of 50 °C resulted in a significant increase in adult mortality of *Sitophilus oryzae* (100 %) due to the increase in chemical reactions and the continuous exposure to high temperatures (Delcour *et al*., 2015b; Lü and Zhang, 2016). In the grain treated with non-synthetic protectants, half of the artificially introduced *P. truncatus* were dead at 32 °C, 38 °C and ambient conditions by 12 weeks (Table 6.4). However, temperatures of >50 °C for periods of 24 to 36 h, are used as heat treatment methods in storage and processing facilities, for controlling stored product insects without the need for any additional pesticides (Mahroof *et al*., 2005).

The grain storage container experiment showed that hermetic containers (PICS, SGB and MS) led to lower insect damaged grain (Fig. 6.8c) and grain weight losses (Fig. 6.9c) even at high temperatures (38 °C) than in the PP bags. Hermetic bags are reported to slow down the growth of stored grain insect populations already in the stored grain, while simultaneously preventing cross-infestation, whereas in PP bags, insects can enter, multiply and feed or exit (Baoua *et al*., 2014). Grain damage levels were low and similar (2.5 ± 0.1 to 6.4 ± 0.4) across the three different hermetic containers tested throughout the 12 week storage period, while higher damage levels of >20 % occurred in the PP bags stored at all temperature conditions (Fig. 6.8a-c). A study in Kenya, reported 73.9 % and 2.0% insect-damaged grain stored in PP bags and PICS bags, respectively, which were artificially infested with *P. truncatus* at ambient temperature and RH (January to July associated with warm and dry, and cooler humid conditions), for a six month storage period (Njoroge *et al*., 2014).

In the current study, the mean insect damage of the grain stored in all the hermetic storage containers (< 6.4%) was slightly lower than that in the grain treated with the synthetic protectants (< 7.0%) (Fig. 6.8). This could be attributed to the fact that 1) the rate of initial artificial infestation with *P. truncatus* was lower in the storage containers (50/kg) than in the grain protectant treatments (100/kg) and 2) the hermetic environment caused reduction in insect activities due to oxygen exclusion. As a result of hypoxia, the insects' feeding, reproduction and migration ceases and they eventually die due to asphyxiation (Hell *et al*., 2014). Overall, at 38 °C, grain MC in the PP kept at ambient conditions decreased, while that in the MS increased at week 12 of storage (Fig. 6.10c). This finding is similar to those of Williams *et al*. (2017) and Ng'ang'a *et al*. (2016) who reported an increase in maize grain MC stored in PICS bags and a reduction in grain MC stored in PP and jute bags during storage. Studies on paddy rice stored in the International Rice Research Institute (IRRI) hermetic bags also reported a slight increase in grain MC from 12.7 % to 13.3 % and this increase was higher than the grain MC recorded in grain stored in PP bags (Prasantha *et al*., 2014).

In the current study, the temperatures recorded inside both hermetic storage containers and PP were slightly higher (up to 38.7°C) than those from inside the two climate chambers set at 32°C and 38°C (Fig. 6.12). Similarly, another study found higher internal temperature inside hermetic IRRI bags than in PP bags during a 12 week storage period (Prasantha *et al*., 2014). Baoua *et al*. (2018) also reported an increase in the internal RH in the PICS bags compared to PP bags. Temperature in PP bags was also significantly higher than in PICS bags during a 12 week study by Njoroge *et al*. (2014), while RH remained stable in PICS bags and fluctuated in PP bags. Njoroge *et al*. (2014) concluded that as long as grain is sufficiently dried (12.46 $\pm$ 0.33 %) prior to storage, PICS bags can ably maintain the MC of stored produce. On the other hand, non-synthetic grain protectants (NM and WA) in combination with increased temperatures (32 °C and 38 °C) were less effective in reducing maize grain weight losses than the synthetic grain protectants (AGD, SSD and WSD) within a 12 week storage period. Even at ambient conditions the effect of the NM and WA treatments were very variable. However, the increased temperature is potentially harmful to *P. truncatus* as evidenced by the higher damage recorded in grain stored in PP bags maintained at 32 ˚C compared to that`12 PP bags kept at 38 ˚C. Condensation has been reported on the lids of MSs and the upper inner-layer of PICS bags due to grain and insect respiration in field studies where stored grain had an initial MC of 12.5 ± 0.2 % and increased to 13.5 ± 0.2 % within 30 weeks of storage (Abass *et al*., 2018).

6.5 Conclusion

In conclusion, the increased temperatures of 32 ˚C and 38 ˚C, representing two projected climate change-related temperature scenarios for southern Malawi, did not negatively affect the performance of the tested storage containers (SGB, PICS and MS) or synthetic grain protectants (AGD, SSD and WSD) in preventing stored grain damage by *P. truncatus*. Smallholder farmers should therefore be able to continue to use these options for stored maize protection as temperatures increase in climate change-prone SSA countries.

Further exploration of how higher temperatures might differentially affect the long-term insect survival, dynamics, and competition among commonly occurring and co-existing species would be informative. This would also influence selection of the pest management strategies. However, close field monitoring should be conducted as mean temperatures rise to ensure other changes to elements of the postharvest system do not lead to variable or reduced efficiency of these grain storage options. As temperature tolerance varies across insect life-stages and species, further studies should look at ontogenetic effects of higher temperatures on different species, as well as diurnally varying temperatures and RH on *P. truncatus* survival and damage to stored grain. Based on the study results, the null hypothesis was rejected.

CHAPTER 7: ASSESSMENT OF TECHNICAL AND INSTITUTIONAL PERFORMANCE OF THE WAREHOUSE RECEIPT SYSTEMS AND COMMUNITY GRAIN BANKS AS ADAPTIVE STRATEGIES FOR MANAGING MAIZE POSTHARVEST LOSSES IN SHIRE VALLEY, SOUTHERN MALAWI

7.1 Introduction

Grain storage losses contribute to food insecurity among smallholder farmers in Africa, with storage losses estimated to be at 8 % of all the cereals grain produced in Malawi (Kaminski and Christiaensen, 2014), and losses of maize across all the postharvest stages estimated to be at 17.5 % in sub-Saharan Africa (SSA) (Hodges *et al*., 2011). One of the major causes of crop storage losses is damage by storage insect pests such as *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), a destructive pest of stored maize in many African countries including Malawi (Golob and Hanks, 1990). Furthermore, the types of storage facilities used by some smallholder farmers may contribute to high PHLs. This perceived high risk of loss during storage together with households' (HHs) urgent need for cash to repay existing debts, leads some HHs' to sell their crop immediately after harvest, when sale prices are typically low (Florkowski and Xi-Ling, 1990). Farmers commonly sell this grain to vendors at low prices compared to the Agricultural Development Marketing and Cooperation (ADMARC) prices, due to frequent delays in them launching the buying season (Gondwe and Baulch, 2017). The ADMARC used to be the only public organisation with a market network across Malawi, with 10 depots, 24 parents and 343 unit markets, and 411 seasonal markets. Additionally, ADMARC has 220 warehouses with a total storage capacity of 137,000 mt (Gondwe and Baulch, 2017).

Climate change may lead to more variable and unpredictable weather conditions, such as cloudy conditions during the drying period making it difficult to dry crops which may lead to increased PHLs (Hodges *et al.,* 2011). When droughts or floods occur, governments typically intervene and relief food and is distributed to the affected HHs (Wilby and Keenan, 2012). However, to assist farmers in adapting to the greater climate variability anticipated in the future, it is important to understand and start developing adaptation strategies (Thomas and Twyman, 2005). While mitigation addresses the causes of climate change, adaptation addresses the effects (Lamboll *et al*., 2011).

Some climate-risk prone communities, including those in the Shire Valley of Malawi, have adopted coping strategies such as casual labouring, charcoal making and sales, and running of small businesses within their communities (Matiya *et al*., 2011). New technologies, institutional arrangements and farming innovations are some of the agricultural adaptations which communities need to respond to the effects of climate change (Lamboll *et al*., 2011). Climate change increases the need for good postharvest, in addition to pre-harvest, crop management by smallholder farming HHs to reduce losses and conserve the harvests in anticipation of poor subsequent harvests (Stathers *et al*., 2013). Adaptation to climate change is the adjustment of a system to moderate the impacts of climate change, to take advantage of new opportunities or to cope with the consequences (IPCC, 2014). A wide range of interventions have been introduced to help farmers maintain the quality of their postharvest produce and access good market prices. One such intervention is called the warehouse receipt system (WRS). A warehouse receipt is a document that provides proof of ownership of a commodity that is stored in a certified warehouse (Coulter and Onumah, 2002). The receipt shows the depositor's personal information, the warehouse's details and commodity specifications such as tonnage, moisture level, variety and grade. The WRSs are managed by professional grain handling and storage experts and the quality and quantity of the deposit is guaranteed (Coulter and Onumah, 2002). The depositor can use their warehouse receipt, to obtain a loan of up to 70 % of the receipts value, with the deposited commodity acting as collateral (Pal and Wadhwa, 2007).

Community grain banks (CGBs) are collective crop grain storage systems which typically involve grain deposits by farmers producing agricultural commodities at a small-scale for household consumption and surplus for sale (Coulter, 2007). A number of community grain banks started operating between 1990 and 2003 as collective storage systems using storage warehouses with capacities of 5 to 120 mt per CGB (World Bank, 2011). However, many older examples of traditional community grain bank arrangements exist across SSA such as Zunde raMambo in Zimbabwe. According to Mararike (2001), Zunde raMambo is a practice where community members produce crops mainly staples from a communal field provided by the traditional leaders. After harvesting the crops, are stored in strategic grain reserves for assisting vulnerable groups such as widows, orphans, the sick, the elderly and people affected by disasters such as drought (Mararike, 2001). However, a study by Mapfumo *et al*. (2013) reported that the Zunde raMambo system is now failing to serve this purpose due to the lack of social cohesion among community members in Zimbabwe

According to Coulter (2007), the later CGB were developed and established with the sole aim of preventing farmers from selling surplus grains at low prices and buying later at high prices. Commonly, the CGB storage systems aimed to protect farmers from exploitation by middlemen who offer low prices to the farmers for their surplus produce (Mahanta, 2012). However, several studies have reported grain losses during storage, market competition with local traders and management challenges as some of the contributing factors to the poor performance of CGBs in Africa especially in SSA (Mahanta, 2012). A study in Ghana reported that collective storage systems were effective with regard to staple crops but challenges arose with higher value cash crops (Coulter and Onumah, 2002).

Community-level collective food storage systems can play a role in improving food security as well as helping communities to access better markets for their stored grain (Florkowski and Xi-Ling, 1990). Collective grain storage schemes, such as WRS and CGBs are being introduced to smallholder farmers in Malawi by various development agencies. The Agricultural Commodity Exchange (ACE) started operating a WRS in Malawi in 2006, focusing its operations in three complementing spheres: trade facilitation, implementation of a WRS, and market information dissemination (Gondwe and Baulch, 2017). The ACE registered the first storage facility and issued its first warehouse receipt in 2006, with individual farmers depositing a total of 14.5 and 44 metric tons (mt) of maize grain in the first and second year respectively (Hernandez, 2012). Some farmers' associations reported that unfavourable experiences with WRS loans, mainly for pigeon pea storage, deterred farmers from using the WRS due to market delays, high storage costs, and payment of withholding tax (Baulch *et al*., 2018). Farmers and small traders might also be tempted to use the WRS for grain storage, without linking them to commercial banks. Additionally, commercial banks would benefit from developing limits and prices for the WRS-backed loans (Baulch *et al.*, 2018).

The CGBs were first introduced in Malawi in 2008 by the Food and Agriculture Organisation of the United Nations. The first six CGBs were constructed in six districts namely Mzimba in Northern region, Salima, Mchinji and Lilongwe in the Central region, and Chiradzulu and Zomba in the Southern region, each with a grain holding capacity ranging from 1,000 to 1,500 mt. They worked with farmer groups to provide storage space for the surplus grain and promote collective marketing. However, before the CGBs were handed over to the communities, the FAO procured fumigation equipment for each of the CGBs, and organised fumigation and grain management training courses for two to three members per CGB.

The current study was carried out to assess the feasibility of using warehouse receipt systems (WRS) or community grain banks (CGB) as adaptation strategies for reducing crop storage losses in Shire Valley.

Specifically the study aimed to:

1) Assess the technical and institutional performance of the warehouse receipt systems and community grain banks;
2) Quantify grain storage weight losses occurring at selected WRSs and CGBs, in southern Malawi;
3) Critically assess applicability of the WRS and CGB as adaptive strategies in reducing storage losses in a CC prone area of Shire Valley in Malawi.

7.2 Materials and methods

7.2.1 Sampling of study areas

The study was conducted in the October 2016 storage season in six districts namely Balaka, Blantyre, Chiradzulu, Machinga, Phalombe and Zomba located in southern Malawi (Fig. 3.1). The districts were purposively selected as they had a WRS (Fig. 7.1) or a CGB (Fig. 7.2) and similar climatic conditions to the climate-risk prone Shire Valley, where to date no WRS or CGBs exist (Table 7.1).

Figure 7.1: Mwandama warehouse receipt system located in Zomba district, southern Malawi, with a grain holding capacity of 2,500 metric tonnes (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

Figure 7.2: Nkalo community grain bank with a grain holding capacity of 1500 metric tonnes, located in Chiradzulu district, southern Malawi (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

All the WRSs selected in the study were running with the technical support from the Agricultural Commodity Exchange (ACE), an institution that provides support to WRS management in Malawi while the CGB were under community management.

Table 7.1: Details of the targeted districts, location, agro-ecological zone, coordinates, altitude and mean annual rainfall

District	Location	Storage system	Agro-ecological zone	Coordinates	Altitude (masl)	Mean annual rainfall (mm)
Balaka	Balaka	WRS	Lakeshore, middle and upper Shire	14° 59′ S; 34° 57′ E	640	971
Machinga	Nsanama	WRS	"	14° 58′ S; 35° 30′ E	692	1146
Zomba	Mwandama	WRS	"	15° 30′ S; 35° 26′ E	710	1,335
Blantyre	Mdeka	CGB	"	15° 27′ S; 34° 56′ E	518	1,127
Phalombe	Gwirima	CGB	"	15° 50′ S; 35° 45′ E	726	1715
Zomba	Namangale	CGB	Mid elevation upland plateau	15° 24′ S; 35° 19′ E	894	1273
Chiradzulu	Nkalo	CGB	"	15° 44′ S; 35° 15′ E	882	1227

7.2.2 Study tools and grain sampling

Two structured questionnaires were developed and pre-tested followed by necessary adjustments to the questions for interviews with the management (Appendix G) and the beneficiary members (Appendix H) of the WRS and CGB collective storage systems, respectively. These structured questionnaires focused on the following thematic areas:

1) individual respondent's characteristics;
    - HH owner's gender, age, education level, and family size, income and employment, investments, food security and livelihoods.
2) crop production characteristics;
    - area of production,
    - quantity of harvest,

- access to extension services and credit,
- marketing.

3) information on membership;
    - membership requirements and fees,
    - general management of the storage systems,
    - opportunities and challenges of the storage systems.
4) storage structure and marketing information;
    - description of overall structure (capacity, materials, age and dimensions),
    - storage structure's physical features such as ventilation and type of roofing,
    - construction costs and payment arrangements,
    - grain holding capacity and location of the storage system,
    - stock of equipment including pest control equipment,
    - ownership and grain management of the storage system,
    - market outlets and commodity prices,
    - timing of sales for the commodities.
5) general information;
    - impact of the WRS and CGB on the communities,
    - understanding or perception of farmers regards WRS and CGB,
    - storage period, beneficiaries and sustainability,
    - period the storage system has been in operational,
    - role of storage system in building resilience to climate-related shocks or other kinds of shocks amongst members of the community.

The management team members included members involved in the daily running of the collective storage systems and were purposively selected, while the beneficiaries were randomly sampled from the list of active members at the time of the study. The management team members interviewed were the managers, chairperson, secretaries, treasurers and committee members at both WRSs and CGBs. The beneficiaries in this study were considered to be those farmers who deposited grain in the collective storage systems. The questionnaires were administered by a team of four trained enumerators through individual interviews. The student supervised the whole exercise of administering the questionnaires so that correct data was collected according to the plan. At each of the WRSs and CGBs, management and beneficiary members were interviewed. This gave a total of 38 management interviews (17 WRS and 21 CGB interviewees) and 34 beneficiaries interviews (13 WRS and 21 CGB) respectively.

Additionally, grain samples were collected from the available stocks in the WRSs and CGBs. The weight loss of these grain samples were then analysed using a rapid loss assessment method based on visual scales and standard graphs as described in sub-section below.

7.2.2.1 Grain sample collection and loss assessment analyses

Data on the level of PHLs occurring in the stored grain in the different collective storage systems was also collected and analysed in addition to the questionnaire data. Where stocks were available, grain samples were collected from the WRSs and CGBs. The weight loss that had occurred in these grain samples was analysed using a rapid loss assessment method based on visual scales and standard graphs on pigeon peas and maize as described in the sub-sections 7.3.3.2 and 7.3.3.3 below. Pigeon pea and maize were selected as they were the only crop grains in stock in the storage systems at the time of the study. The visual scales and standard graphs were developed at Chitedze Agricultural Research Station, Lilongwe, Malawi in 2015 and 2008, using the method described by Compton and Sherington (1999).

The grain damage and weight loss sample assessment commenced in October 2016 at the time of administering the questionnaire, and continued at 8-week intervals for 24 weeks (until May 2017) when all the stored grain had been withdrawn from the storage systems. The grain samples (maize and pigeon peas) were collected using a multi-compartmented sampling spear to obtain representative samples. Samples were collected from 5 to 11 points depending on the quantity of each crop in the stack. For stacks of up to 15 mt, grain sub-samples were taken from 5 different points across the stack and collated to provide a representative sample of ~1kg. While for stacks of 16 to 30 tonnes, sub-samples were taken from 8 points, and for stacks of 31 to 50 tons sub-samples were taken from 11 points (Jewers *et al*., 1989).

7.2.2.2 Visual scales for estimation of pigeon peas weight losses

The visual scales were developed using samples of pigeon pea grains that were classified into five classes based on the level of damaged grains. Principally, class 1 had 0 % damaged grain, class 2 had 20 % damaged grains, class 3 had 40 % damaged grains, class 4 had 60 % damaged grains while class 5 had 90 % damaged grains (Fig. 7.3). Grain in each class was mixed thoroughly and spread on a laboratory working table and photos were taken using a high resolution camera (Fujifilm Digital camera, FinePix S5700/FinePix S700, Fujifilm Corporation, Tokyo, Japan). Percent grain weight loss of each class was obtained using ‘count and weight method’ (Compton and Sherington, 1999), and the grain weight losses were assigned to each corresponding classes. A photo of each class, labelled with the class number, percentage of damage grain and the grain weight loss, was printed on A4 size paper using colour printer for easy comparison during sample weight loss assessment (Fig. 7.3). The visual scale was used to estimate pigeon pea grain weight loss by matching the damage in the sample to that of the damage category on the visual scales (photographs). Using this method, grain damage and weight loss of stored pigeon peas samples at all the three WRSs were assessed. Unfortunately, at the time of the study there was no stored grain in any of the four CGBs, as the grain that was deposited from the month of June had already been withdrawn.

7.2.2.3 Standard graph for estimation of maize weight losses

A standard graph was developed based on damaged and undamaged maize grain. Only damage on the maize grain was caused by storage insect pests namely *S. zeamais* and *P. truncatus* was considered. These insects were artificially introduced in the grain. The two species were selected being the most destructive storage insect pests of maize. The maize was separated into damaged and undamaged grains, then the damaged and undamaged grains were counted into groups of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100. The two categories of damaged and undamaged grain samples were mixed in proportion making a total of 100 grains in each set, for instance 10 damaged grains and 90 undamaged grains to make a total of 100 grains for the 10 % damaged grain category. Grain weight losses for each set were calculated using the count and weigh method (Compton *et al.*, 1998). The estimated grain weight losses were calculated using the following equation:

$$Weight\ loss\ (\%) = \frac{((\mathrm{Wu} \times \mathrm{Nd}) - (\mathrm{Wd} \times \mathrm{Nu})) \times 100}{\mathrm{Wu} \times (\mathrm{Nd} + \mathrm{Nu})}$$

Where: W_u = Weight of undamaged grain, N_u = Number of undamaged grains

W_d = Weight of damaged grain, N_d = Number of damaged grains.

A graph was developed where the recorded percent grain weight losses (y-axis) were plotted against the percent damaged grains (x-axis) in Microsoft Excel. The standard graph was printed on A4 size paper and laminated, and was used in this study (Fig. 7.4).

The maize sample collected from the WRS was placed in a plastic tray and mixed thoroughly. The sample was divided using the coning and quartering method into four sub samples. Two diagonally opposite sub samples were combined, while the remaining opposite sub samples were discarded. A 100 grain sample was randomly selected from the retained combined sample. The 100 grains were physically assessed and categorised into damaged (grains with holes arising from insect pest infestation) and undamaged grains. The percentage of damaged grain, was then used with the standard graph on the x-axis to obtain an estimated % of grain weight loss on the y-axis (Figure 7.4). After assessing the grain weight losses for all the samples collected, the mean grain weight loss was calculated and recorded to represent the weight loss at that particular sampling session. The maize weight losses were assessed at Balaka WRS only because the other two WRS had no maize stocks at the time of the study. The grain used to estimate the weight losses were a mixture of hybrid and composite varieties as farmers typically grow different maize varieties which are commonly mixed during storage.

Class 1: No damaged grains

(0% Weight loss)

Class 2: 20% damaged grains

(5.6% Weight loss)

Class 3: 40% damaged grains

(14.3% Weight loss)

Class 4: 60% damaged grains

(22.3% Weight loss)

Class 5: 90% damaged grains

(33.2% Weight loss)

Figure 7.3: Visual scales for estimation of pigeon pea weight losses at Balaka, Nsanama and Mwandama warehouse receipt systems in the 2016/2017 storage season.

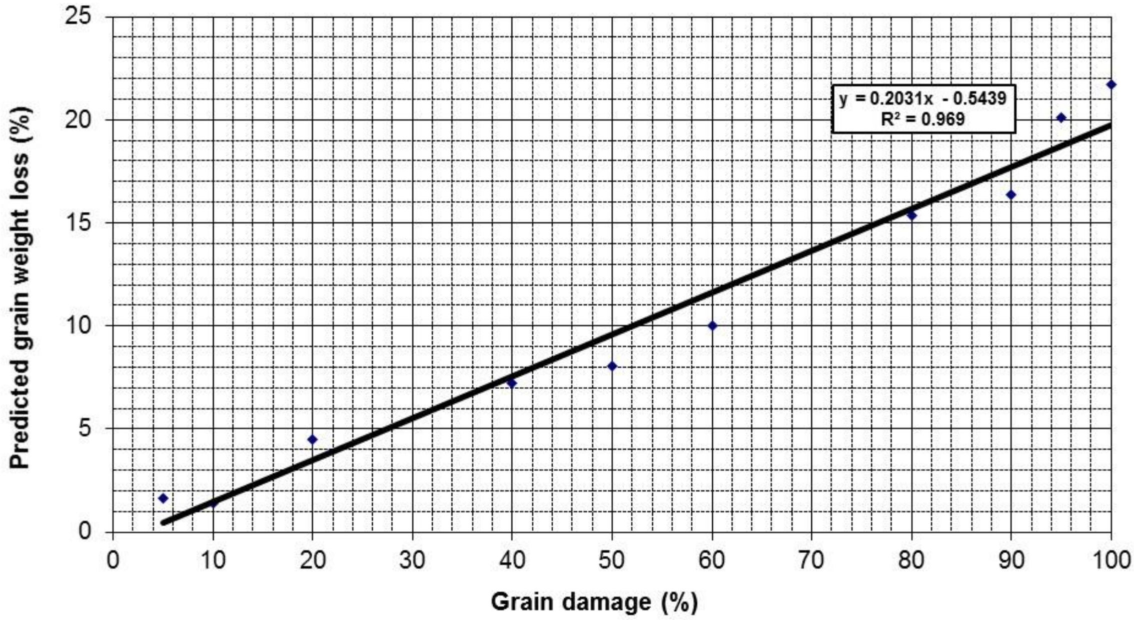


Figure 7.4: Standard graph for estimation of maize weight losses at Balaka warehouse receipt system in the 2016/2017 storage season (n = 3)

7.2.3 **Data analyses**

Data from the interviews with the management and the beneficiaries were analysed using the Statistical Package for Social Scientists (SPSS) version 19.0 (Gamble, 2001) to provide descriptive statistics and cross-tabulations. The Chi-square was used to test the independence of the categorical variables in the data sets. Correlations and regressions were conducted on the quantity of grain produced, deposited grain and storage period at the storage systems to check if there were any relationships. Descriptive statistics in Microsoft Excel was used to analyse grain weight loss data obtained from the visual scales and the standard graph on pigeon pea and maize respectively.

7.3 Results

7.3.1 Management member interviews

7.3.1.1 Demographic and social characteristics of the interviewees

Out of the management team members interviewed, six of the 17 WRS respondents were male (35 %) and 11 were female (65 %), while 12 of the 21 CGB respondents were male and nine were female (57 %). The breakdown of those interviewed by role in the organizations is shown in (Table 7.2).

Table 7.2: Gender and position of the management team respondents from warehouse receipt systems and community grain banks (numbers in parenthesis are percent of respondents)

Storage system	Sex	Member	Chairperson	Secretary	Treasurer	Committee Member	Manager	ACE	Sub total
WRS	Male	0 (0)	2 (11.6)	0 (0)	1 (5.9)	1 (5.9)	1 (5.9)	1 (5.9)	6 (35.2)
	Female	2 (11.8)	1 (5.9)	1 (5.9)	2 (11.8)	1 (5.9)	4 (23.5)	0 (0)	11 (64.8)
CGB	Male	0 (0)	2 (9.5)	2 (9.5)	2 (9.5)	1 (4.8)	5 (23.8)	0 (0)	12 (57.1)
	Female	1 (4.8)	0 (0)	1 (4.8)	2 (9.5)	3 (14.3)	2 (9.5)	0 (0)	9 (42.9)

Note: WRS = warehouse receipt system, CGB = community grain bank and ACE = Agricultural Commodity Exchange.

The majority of respondents, 12 of the 17 WRS (71 %) and 11 of the 21 CGB (53 %) respondents were aged between 36-56 years (Table 7.3). A mix of education levels existed among those interviewed at both the WRS and the CGBS (Table 7.3). Out of the respondents interviewed from WRS, three managers had primary, one had secondary and one had tertiary education, while from CGBs, one and six respondents had primary and secondary education, respectively (Table 7.3).

Table 7.3: The age category and education of the management team respondents from the Warehouse receipt systems and Community grain banks

		Age (years)			**Education**			
Position of respondent	Storage system	15 - 35	36 - 56	57 - 77	Never attended	Primary	Secondary	Tertiary
Member	WRS	0	2 (11.8)	0	2 (11.8)	0	0	0
	CGB	0	1 (4.8)	0	0	1 (4.8)	0	0
Chairperson	WRS	1 (5.9)	2 (11.8)	0	0	2 (11.8)	0	1 (5.9)
	CGB	0	2 (9.5)	0	0	1 (4.8)	1 (4.8)	0
Secretary	WRS	0	0	5.9 (1)	0	1 (5.9)	0	0
	CGB	2 (9.5)	1 (4.8)	0	0	0.0	3 (14.3)	0
Treasurer	WRS	1 (5.9)	2 (11.8)	0	0	1 (5.9)	2 (11.8)	0
	CGB	1 (4.8)	3 (14.3)	0	0	4 (19.0)	0	0
Committee	WRS	1 (5.9)	1 (5.9)	0	0	1 (5.9)	1 (5.9)	0
Member	CGB	1 (4.8)	3 (14.3)	0	0	4 (19.0)	0	0
Manager	WRS	3 (17.6)	2 (11.8)	0	0	3 (17.6)	1 (5.9)	1 (5.9)
	CGB	1 (4.8)	6 (28.6)	0	0	1 (4.8)	6 (28.6)	0
ACE	WRS	1 (5.9)	0	0	0	0	0	1 (5.9)

Note: WRS = warehouse receipt system, CGB = community grain bank and ACE = Agricultural Commodity Exchange. The figures in parenthesis are percent of respondents interviewed

Of those interviewed, 5 out of 17 WRS (31 %) and 9 of the 21 CGB (44 %) respondents, reported a monthly income of less than MK5000, and between MK5000 to MK10000 respectively. Managers featured in all the monthly income brackets (Fig. 7.5). A chi-square test showed there was no significant difference (X^2 = 5.61, p = 0.346) in monthly income of the members between the two storage systems (WRS and CGB).

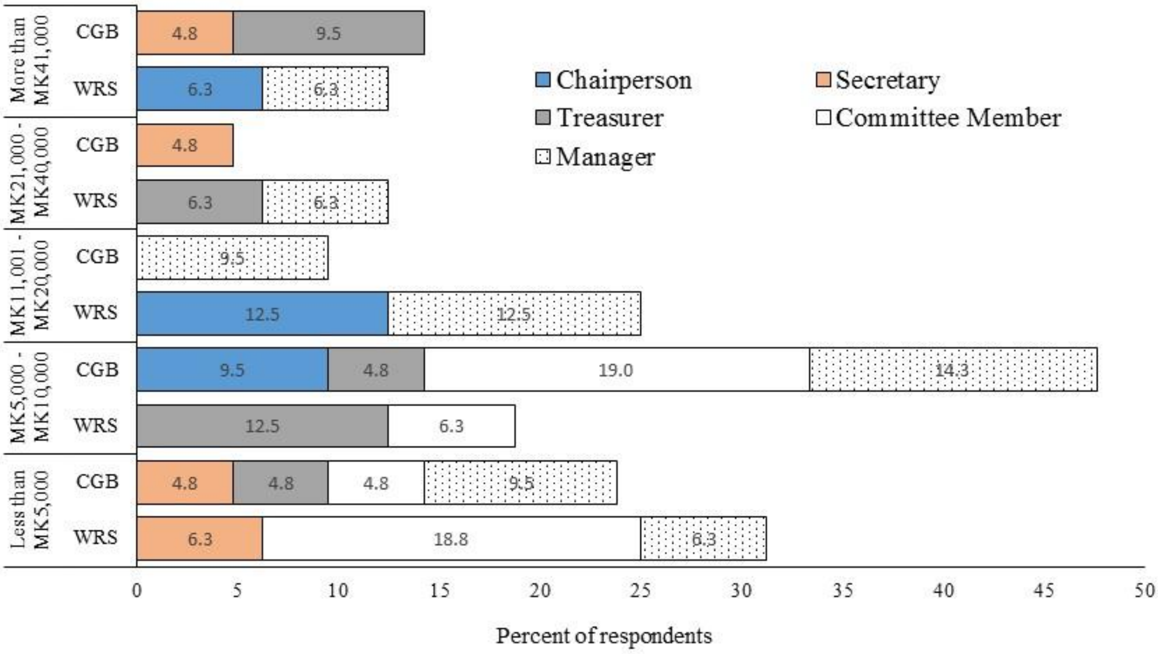


Figure 7.5: The average monthly income of the management team interviewed from the warehouse receipt systems and community grain banks (n = 37) Legend: WRS = Warehouse receipt system, CGB = Community grain bank and MK = Malawi Kwacha. Note: Exchange rate at the time of the study was MK721.502 to 1 United States Dollar

7.3.1.2 Grain deposits, management of and perceived aims of collective storage systems

Four of the 17 WRS (24 %) and six out of 21 CGB respondents (29 %), were managers who produced between 1 and 3 mt of maize, while one CGB manager had produced 22 mt of maize in the 2015/2016 growing season. Further, only one WRS respondent (secretary) and no CGB respondents had produced less than 1 mt of maize in the 2015/2016 growing season. However, the 12 out of 17 WRS (71 %) and 14 of the 21 CGB respondents (67 %) (chairpersons, secretaries, treasurers, committee members and ordinary members) produced between 1 and 3 mt of maize in the 2015/2016 growing season.

Nine of the 17 WRS (54 %) and three out of 21 CGB (15 %) respondents did not deposit any maize during the 2015/2016 growing season. However, seven out of 17 WRS (41 %) and 11 of the 21 CGB respondents (52 %) deposited maize, while four of the 17 WRS respondents (24 %) deposited pigeon peas during the 2015/2016 storage season. Additionally, one chairman and one secretary among those interviewed deposited sorghum at WRS and CGB, while a manager and committee member deposited cowpeas. The quantity of grain deposited by the depositors interviewed ranged between 1 and 3 mt (Fig. 7.6). There was a positive moderate correlation between quantities of maize produced and deposited during the 2015/16 growing season and was significant ($r = 0.491$; $p = 0.002$).

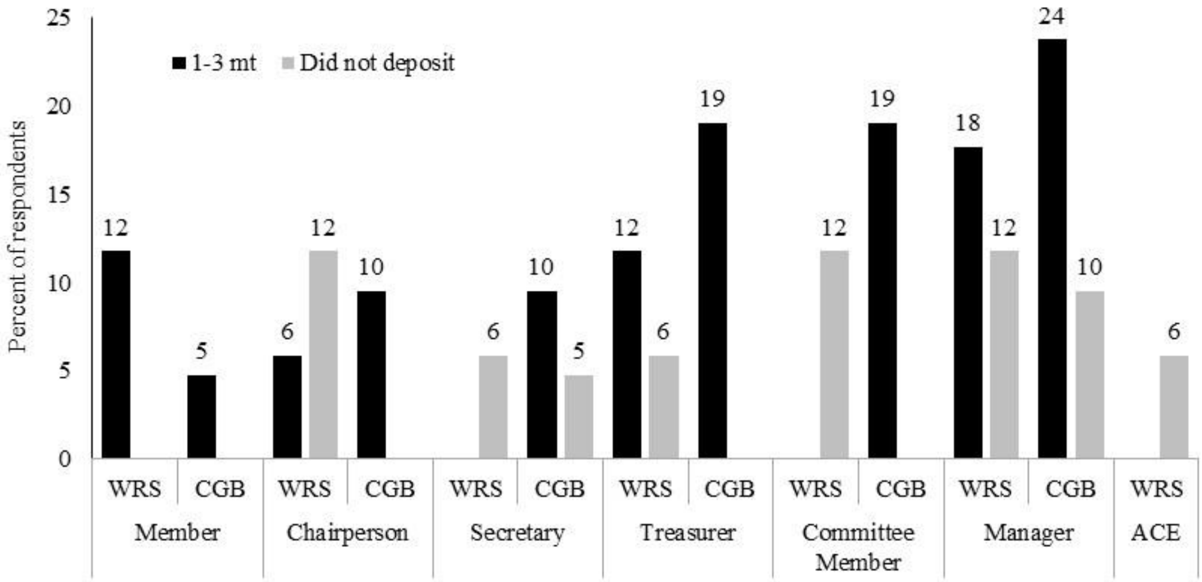


Figure 7.6: The quantity of maize grain (mt) deposited by management team respondents at the warehouse receipt systems and community grain banks in the 2015/2016 growing season (n = 38) Legend: ACE = Agricultural exchange commodity, WRS = Warehouse receipt system and CGB = Community grain bank

Several respondents reported that the storage systems were established to provide better market access for their grain (WRS: four managers and CGB: four managers and four treasurers). Only one of the respondents could not explain why the CGB was established. According to three chairpersons and three treasurers WRS respondents (35 %), the WRSs belong to non-governmental organisations (NGOs). When asked about ownership of the CGB, most of the CGB respondents thought it was owned by the community members, a cooperative or a farmer organisation; four of the 21 CGB respondents (24 %) did not know who the CGB was owned by (Fig. 7.7). Fourteen of the 17 WRS respondents (82 %) said the WRS was owned by an NGO, while two respondents (12 %) thought it was a cooperative and one did not know who owned it.

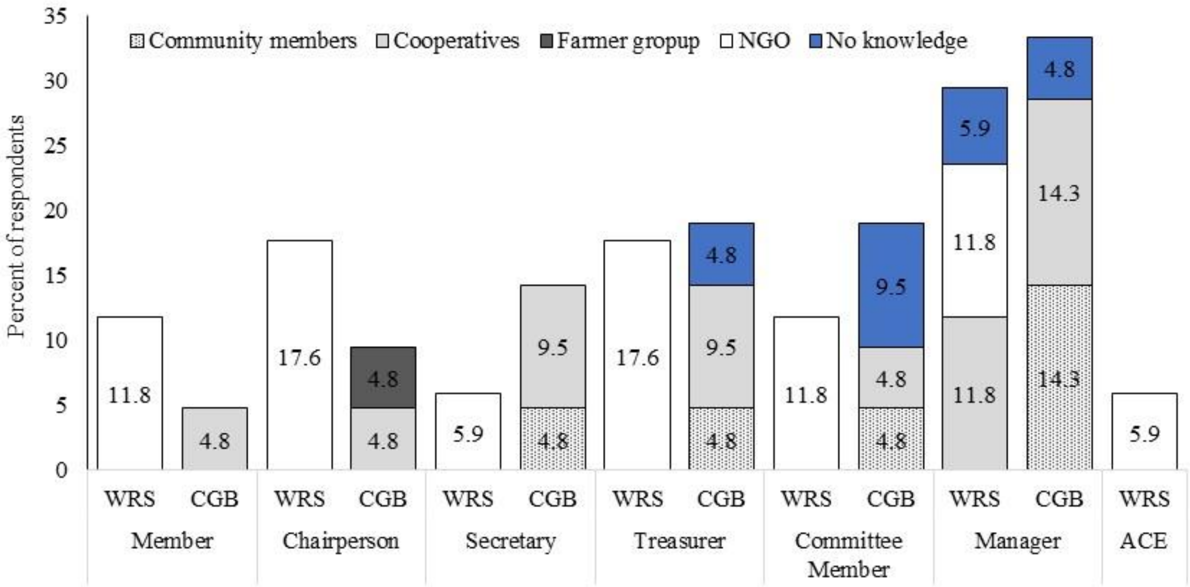


Figure 7.7: Knowledge of ownership of warehouse receipt systems and community grain bank by management team members (n = 38). Legend: ACE = Agricultural exchange commodity, WRS = Warehouse receipt system, CGB = Community grain bank and NGO = Non-Governmental Organisation

Understanding of membership criteria varied amongst respondents. Most respondents, nine of the 21 CGB interviewed (43 %) stated that one has to be a community member before joining the CGB. Further, two of the 21 respondents (both of whom were managers) (10 %) said they had no knowledge of the criteria used to accept new members. Among the 17 WRS respondents, two respondents (12 %) reported that there was a requirement to pay to become a member, another two respondents (12 %) reported that one had to be a community member to become a WRS member. However, one of the 17 WRS (6 %) and one of the 21 CGB respondents (5 %) reported that the quantity of grain is one of the criteria for accepting new members.

Among the seven focal collective storage systems, Mwandama WRS had the biggest grain holding capacity at 2,500 mt, although at the time of the study it only contained 1 mt of pigeon pea. Although the combined grain storage capacity of the seven collective storage systems is 6,500 mt (Balaka 500 mt, Nsanama 700 mt, Mwandama 2500 mt, Gwirima 300 mt, Mdeka 500 mt, Nkalo 1500 mt and Namangale 400 mt), less than 1000 mt (<15 %) of the total storage capacity was under use at the time of the study. The respondents explained that these storage facilities used to be filled to their full capacity prior to the phase out of the projects which had supported the establishment of these storage systems.

7.3.1.3 Reasons for depositing grain and involvement of commercial banks

Twelve of the 17 WRS respondents (71 %) said the reason for depositing grain at the warehouse receipt system was for cash after grain sales, while four WRS respondents (24 %) the reasons were for cash and consumption. There was only one WRS respondent (6 %) who the reason for depositing as for food security (Fig. 7.8). Amongst the CGB respondents, nine of the 21 (43 %) indicated it was for both cash and consumption reasons, while eight (38 %) viewed it as for cash, and one viewed (5 %) it as being just for consumption (Fig. 7.8). The majority of the respondents (12 out of 17 WRS [71 %]) indicated that the First Merchant Bank (FMB) is involved in the WRS activities, while a few (4 WRS [24 %]) reported that the Opportunity International Bank of Malawi (OIBM) is involved in the WRS activities. While 16 out of 21 (76 %) CGB respondents reported having no knowledge of the involvement of banks in the CGB activities, three of the 21 CGB respondents (14 %) reported the involvement of the OIBM.

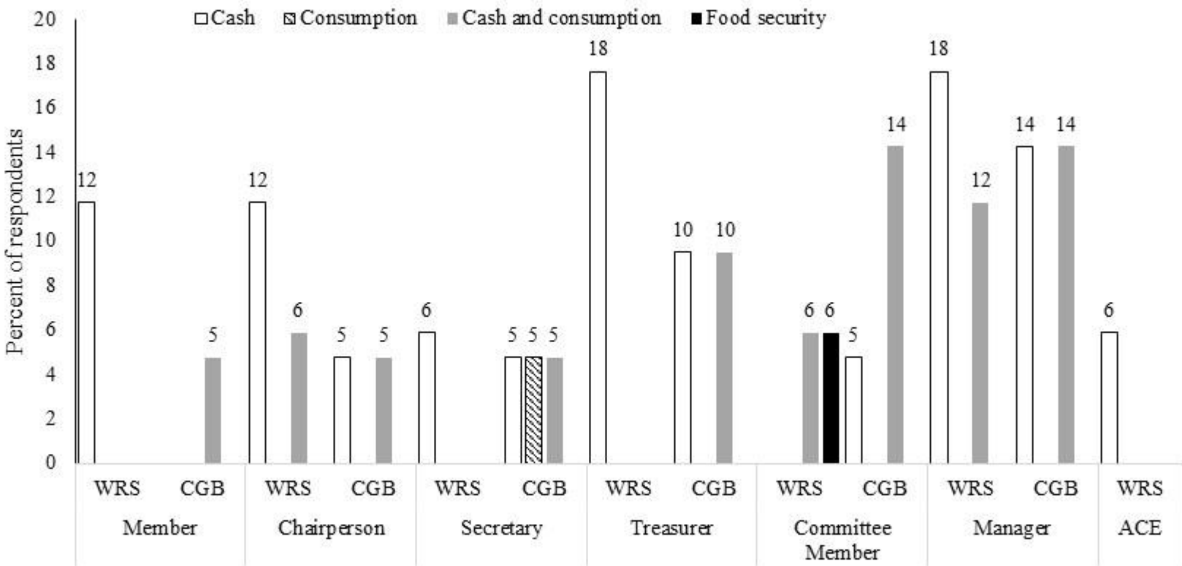


Figure 7.8: The reasons for depositing grain at the warehouse receipt system and community grain bank by the management team (n = 38). Legend: ACE = Agricultural exchange commodity, WRS = Warehouse receipt system and CGB = Community grain bank

Two respondents at the CGB (10 %) reported that National Bank (NB) and FDH Bank are involved in the CGB activities.

7.3.1.4 Grain withdrawal frequency and reasons

The majority of the respondents, 10 of the 17 WRS (59 %) and 15 out of 21 CGB (71 %) reported that they withdraw grain only annually (Fig. 7.9). Seven WRS (40 %) and four CGB (20 %) respondents reported that the reason for grain withdrawal was payment of school fees for their kids after selling the grain. It was also reported by 13 CGB (60 %) respondents that some members withdraw grain because of HH level hunger. However, five

WRS (30 %) and four CGB (20 %) respondents had no idea of the reasons why grain was withdrawn from the WRS or CGB (Fig. 7.9).

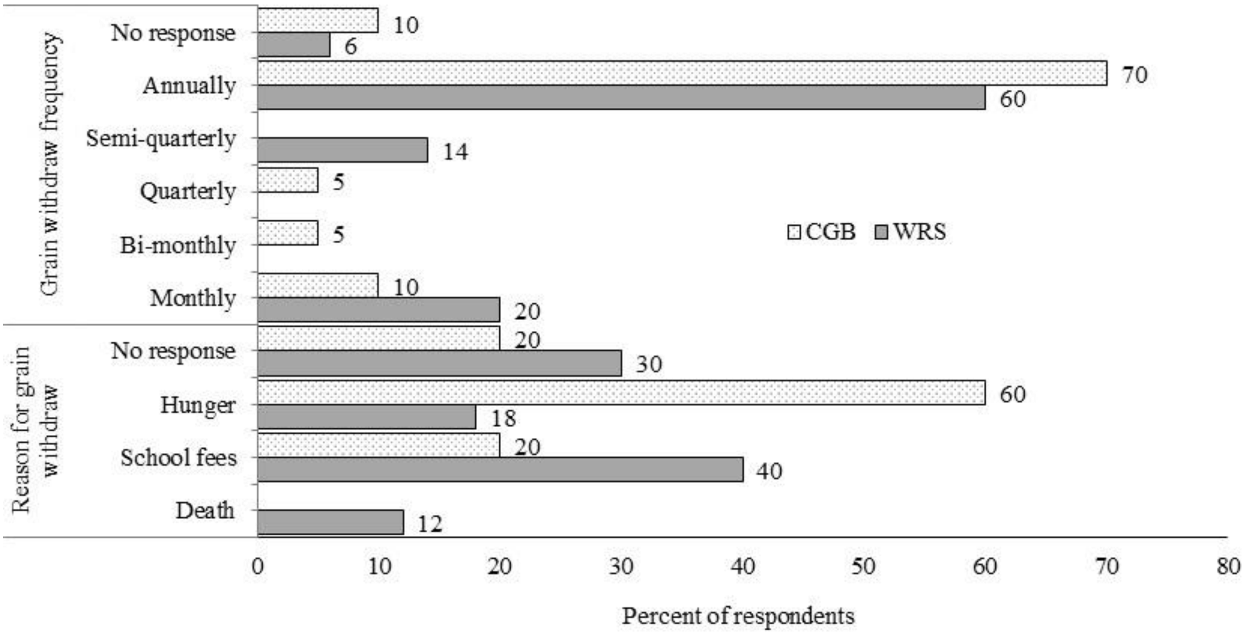


Figure 7.9: Grain withdraw frequency and reasons for grain withdrawals at warehouse receipt systems and community grain bank (n = 38). Legend; WRS = Warehouse receipt system and CGB = Community grain bank

7.3.1.5 Perceived buyers of grain from WRS and CGBs

Eight of the 17 WRS respondents (47 %) reported that NGOs are the main buyers of the grain stored in the WRS, while 9 of the 21 CGB respondents (43 %) indicated local farmers were the main grain buyers at the CGBs. However, CGB respondents also indicated other buyers of the CGB stored grain, such as traders, producers and NGOs.

7.3.1.6 Pest management of stored grain at the WRS and CGBs

The respondents reported a range of pest management methods used by the WRS and CGB to protect the stored grains. Five of the 17 WRS respondents (29 %) and 13 of the 21 CGB respondents (62 %), said the use of liquid or dust insecticide formulations was common, while 9 and 7 respondents from the WRSs (53 %) and CGBs (33 %) respectively said fumigants were used for pest control activities (Fig. 7.10).

The dust and liquid formulations of grain protectants reported by WRS and CGB respondents included Actellic Super (Pirimiphos methyl + Permethrin), Shumba Super (Fenitrothion + Deltamethrin), Wivokil Super (Fenitrothion + Deltamethrin) and Novactellic Super (Pirimiphos – methyl + Permethrin). Twenty of the 21 CGB (95 %) and three of the 17 WRS (18 %) respondents, said pest control activities were usually conducted by members of the CGB and WRS, respectively. The majority of the WRS (67 %) respondents (14 of the 21) reported pest control activities mainly being carried out by hired pest control companies or individuals (Fig. 7.10). The main source of pesticides for pest control activities was reported to be AGORA Malawi according to 47 % and 52 % of the respondents at the WRS and CGB respectively. Agrochemicals & Marketing was another source of pesticides reported by 24 % WRS and 29 % CGB respondents (Fig. 7.10). The fumigation and spraying equipment were mainly sourced from recommended shops such as AGORA Malawi, Agricultural Trading Company and Chemicals and Marketing Company. Pest control equipment used at the WRSs and CGBs was reported to include shovels, sprayers, tarpaulins, moisture meters, pallets and weighing scales, which were mainly supplied through the projects that led to the establishment of WRS and CGB.

7.3.1.7 Perceived causes of postharvest losses in the WRS and CGBs

Mould was reported to be among the main causes of crop PHLs at the two storage systems, by 5 of the 17 WRS (29 %) and 9 out of 21 CGB (43 %) respondents. While 10 WRS (59 %) and 8 CGB (38 %) respondents reported rodents as the cause of stored grain PHLs.

Some of the causes of PHLs highlighted by respondents included termites by 1 WRS (6 %) and 1 CGB (5 %) respondent), *S. zeamais* (1 WRS; none from CGBs) and *P. truncatus* (none WRS; 1 CGB).

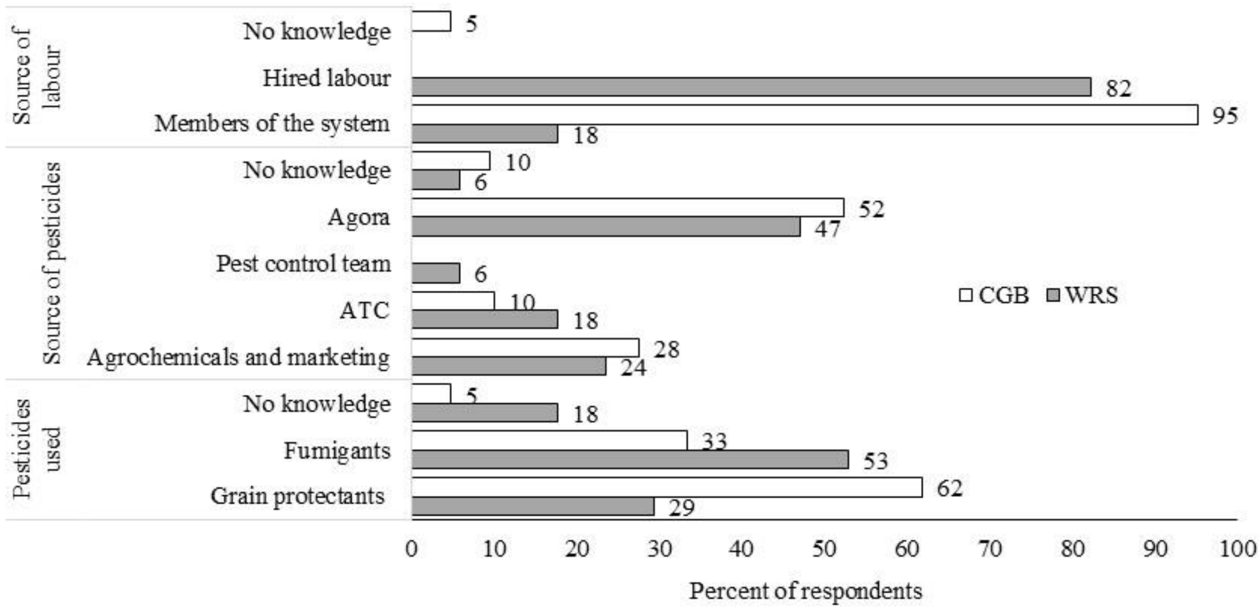


Figure 7.10: Type of pesticides used, source of pesticides and source of labour for the pest control activities at the warehouse receipt systems and community grain banks (n = 35). Legend; WRS = Warehouse receipt system and CGB = Community grain bank

7.3.1.8 Training topics at WRS and CGBS

The majority of respondents, 15 of the 17 WRS (88 %); 16 of the 21 CGB (76 %), reported that management members had undergone training regarding the collective storage systems but the rest of the members had not been trained. Most respondents, 76 % (13 WRS) and 43 % (9 CGB), indicated that major training areas focused on storage pest management, while other respondents 12 % (2 WRS) and 29 % (6 CGB) reported that the training focused on grain management. Furthermore, one CGB respondent (5 %) reported that the training tackled storage pesticide management, but none of the WRS respondents (6 %) reported it. However, 2 WRS (12 %) and 5 CGB (24 %) respondents reported that they had no knowledge of the topics covered at the trainings. A Chi-Square test showed that the number of days of training was not significantly different (p = 0.310) between the WRS and CGB storage systems ($x^2 = 10.51$, df = 9).

7.3.1.9 Perception of climatic changes

A few of the management members interviewed, 8 of the 17 WRS (47 %) and 2 of the 21 CGB (10 %) reported that there had been changes in frequency on the occurrence of climate-related risks over the last 20 to 30 years, while the majority 9 WRS (53 %) and 19 CGB (90 %) indicated there had been no change. Many of the respondents (10 WRS (59 %); 8 CGB 38 %)) felt the collective storage systems did have an impact on climate-related risks. One of the impacts of storage systems on climate-related risks reported by two WRS (12 %) and one CGB (5 %) respondent, was the supply of grain during hunger periods.

7.3.2 Beneficiary member interviews

7.3.2.1 Crop production, postharvest grain management and deposits

The results showed all WRS beneficiaries interviewed had land holding sizes between 0.3 and 8 ha, while for CGB beneficiaries, it ranged between 0.08 and 3.2 ha. The reported maize crop harvests ranged between 0.15 and 1.7 mt per HH (WRS), and 0.05 and 1.25 mt per HH (CGB) during the 2015/2016 growing season. Some of the crops grown by the respondents at both WRS and CGB include maize, pigeon peas, groundnuts, rice, beans, soya beans, cowpeas, sorghum and bambara nuts. The majority of 8 of the 13 WRS (62 %) and 9 of the 21 CGB (43 %) respondents had deposited pigeon peas, although one WRS (8 %) and four CGB (19 %) respondents, did not deposit grain during the 2014/2015 storage season. Six WRS (46 %) and six CGB (29 %) respondents, reported that grain deposits were made by cooperatives. According to 4 WRS (31 %) and 13 CGB (62 %) respondents, grain deposits were made by individuals, while one of the 13 WRS (8 %) and 2 of the 21 CGB (10 %) respondents reported that grain deposits were done by farmer groups. The quantities of maize grain deposited by individuals, farmer groups or cooperatives to the WRSs and CGBs ranged between 0.32 and 15 mt (WRS), and 0.1 to 0.6 mt (CGB). However, at the time of the study (October 2016), Balaka (WRS) had grain stocks of both maize and pigeon peas, while Mwandama and Machinga had pigeon peas only, and none of the CGBs had grain stocks.

The majority 8 out of 13 WRS (62 %) and 16 of the 21 CGB (76 %) respondents reported that maize grain deposits commonly commence in April, while July or September are the commencement months of grain deposits especially rice and pigeon peas, according to 5 WRS 38 %) and 5 CGB (24 %) respondents interviewed. According to 12 WRS (92 %) and 11 CGB (52 %) of the respondents, the grain deposits are done for cash, while four CGB (19 %) respondents reported that grain deposits are made for the purpose of maintaining food security at household level. However, some grain deposits are done due to a lack of storage space at the homestead, according to 1 WRS (8 %) and 6 CGB (29 %) respondents interviewed.

7.3.2.2 Management of deposited grain

The respondents, 5 of the 13 WRS (38 %) and 11 of the 21 CGB (52 %) mentioned that grading is one of the major activities carried out on the deposited grain, while seven WRS (54 %) and nine CGB (43 %) respondents reported that determination of grain moisture content was one of the key activities which occurs at the time of depositing grain. Other activities reported include weighing, cleaning, grain drying, grain bagging, bag stacking and pest control.

The majority, 8 of the 13 WRS (62 %) and 11 of the 21 CGB (52 %) of the respondents reported that deposited grain normally remains in stores for between 4 to 6 months before it is withdrawn for consumption or sold. Four WRS (31 %) and four CGB (19 %) respondents suggested 1 to 3 months was the maximum storage period occurring before the grain was withdrawn or sold. While one of the 13 WRS (8 %) and six of the 21 CGB (29 %) respondents interviewed, said the maximum grain storage period range between 7 and 12 months.

It was reported that the grain selling season in all the storage systems commences in June up to January the following year depending on the volume of the grain stocks. However, during the current study, all grain stocks had been withdrawn or sold by May 2017 and the delay in selling out the grain stocks was due to poor market prices offered on the two commodities (maize and pigeon peas).

7.3.2.3 Grain stored pests and control

The two collective storage systems face storage problems. The main one being grain PHLs which are caused by storage pests such as rodents, *S. zeamais* and *P. truncatus*. Two of the 13 WRS (15 %) and eight of the 21 CGB (38 %) respondents, reported that rodents and *S. zeamais* are the main causes of grain storage losses. While three WRS (23 %) and six CGB (29 %) respondents said rodents and *P. truncatus* are the cause of grain storage losses.

One of the control measures used against the reported stored product pests is fumigation, according to one WRS respondent. Although the individual could not recall the trade names of the fumigant used. The majority of respondents, 8 WRS (60 %) and 14 CGB (67 %) reported that synthetic grain protectants in the form of dusts and liquid formulation were used for the control of storage pests. While four WRS (33 %) and six CGB (30 %) respondents had no idea about the type of pest control measures used at collective storage systems (Fig. 7.11).

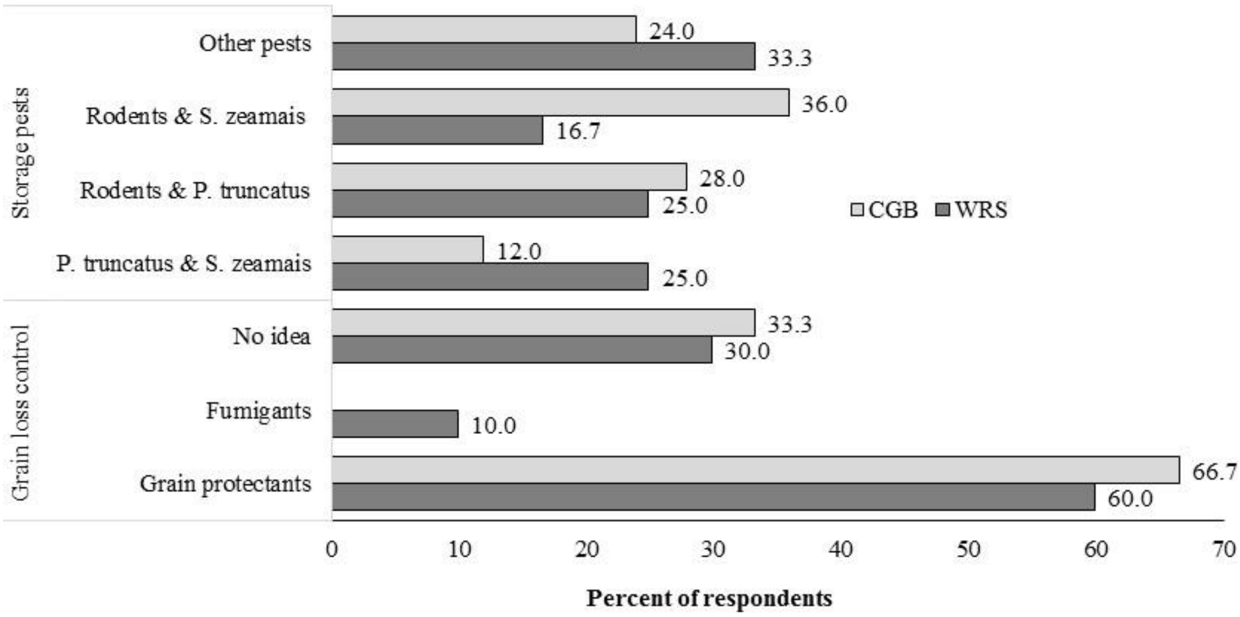


Figure 7.11: Grain storage pests and the control measures employed for the control of storage pests (n = 34). Legend; WRS = Warehouse receipt system and CGB = Community grain bank.

Most WRS respondents, 16 of the 17 (94 %) believe the costs associated with grain losses at the WRSs are settled by the WRS operators, while the other respondent did not know. The majority of respondents at the CGBs, 16 of the 21 (76 %), believe that the management team running the CGB are responsible for the costs of the storage losses, although four out of 21 CGB respondents (19 %) thought that the depositors were the ones who covered the cost of grain losses.

7.3.2.4 Challenges faced in using the WRSs and CGBs

The majority of respondents, five of the 13 WRS (38 %) and seven of the 21 CGB (33 %), reported that lack of reliable markets for the deposited grain was the main challenge. However, they further said lack of storage space for example Nsanama WRS had no free space and ended up storing some grain at Balaka WRS. Storage pest infestation, lack of training and droughts are some of the challenges faced by the WRSs and CGBs members. However, five WRS (38 %) and four CGB (19 %) respondents reported that there were no challenges (Fig. 7.12).

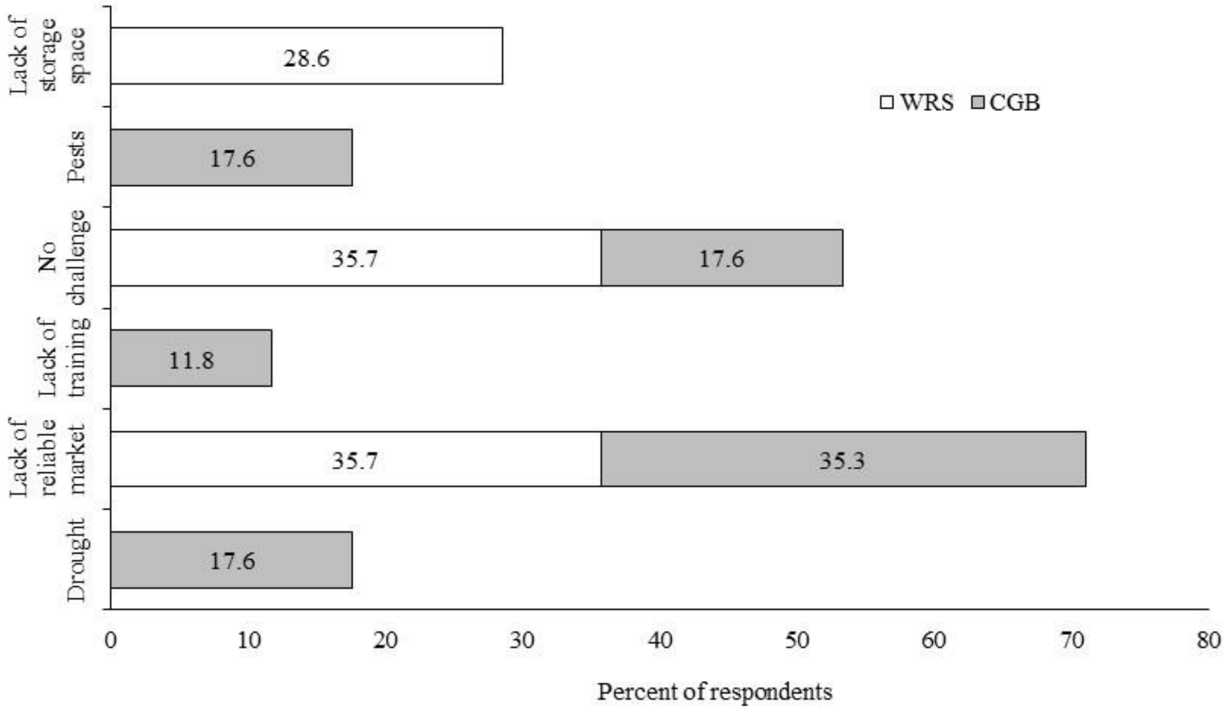


Figure 7.12: Challenges faced at the warehouse receipt system and community grain banks (n = 34). Legend; WRS = Warehouse receipt system and CGB = Community grain bank.

7.3.2.5 Climate change and associated risks

7.3.2.5.1 Perceptions of climate-related risks

Respondents felt the climate-related risks facing the collective storage systems included late on-set and early termination of rains according to six of the 13 WRS (44 %) and 11 of the 21 CGB (53 %) respondents); heavy rains and increased temperature (4 WRS (31 %); 4 CGB (19 %)); floods and droughts (3 WRS (23 %); 6 CGB (29 %)) (Fig. 7.13). The majority of the respondents (8 WRS (62 %); 12 CGB (57 %)) reported that they had observed the impact of the two collective storage systems on climate-related risks in their communities (Fig. 7.13).

The climate-related risks were reported to contribute to low crop production and increased PHLs resulting in hunger among the community members. According to the respondents, the frequency of these climate-related risks has changed over time and they commonly occur every 2 to 3 years. The respondents reported that the area used to receive rains in October but that the season had changed, and that at the time of the study (October 2016) the rains had not yet started nowadays almost every year, farmers would plant more than once and end up not harvesting enough grain for their families. Although in the previous growing season (2015/2016), they had received good rains, they anticipated less rain in the current season (2016/2017). Respondents also reported that in the previous two years a shortage of rains had resulted in low crop productivity. The reported impact of the CGBs on climate-related risks included the easy access to food grains by members and non-members during food shortage periods. The storage system members have a greater advantage of accessing the grain than non-members. The prices are fixed for both storage system members and non-members.

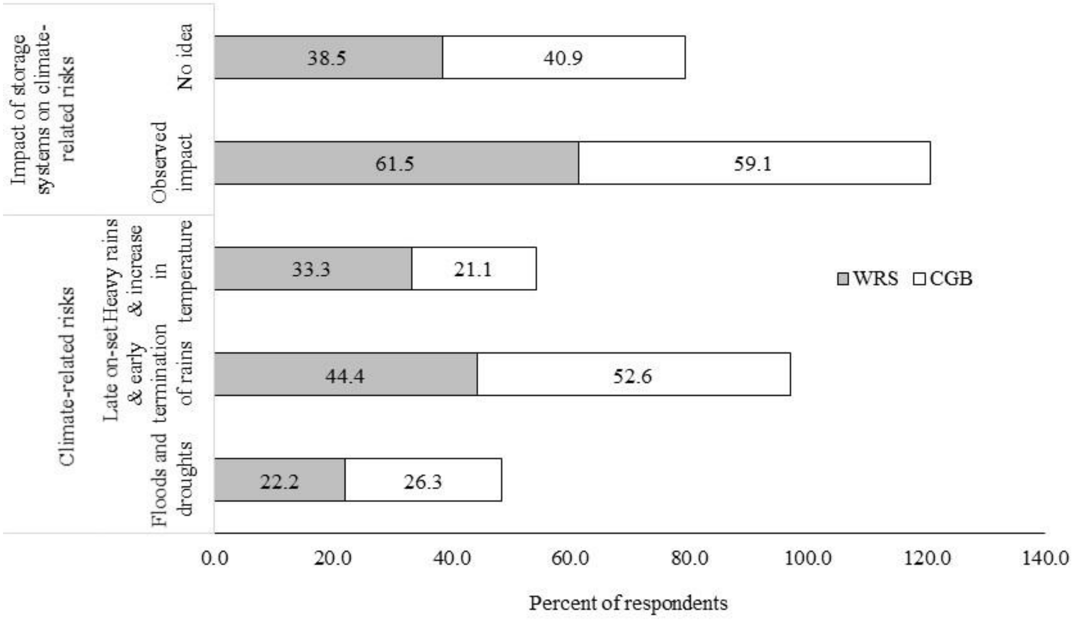


Figure 7.13: Climate-related risks and the perceived impact of warehouse receipt systems and community grain banks to the local communities (n = 37). Legend; WRS = Warehouse receipt system and CGB = Community grain bank.

7.3.2.5.2 Perceived benefits to collective storage system members

It was reported that at the CGB, members could withdraw grain at opportune times when grain was scarce. Sometimes collective storage system members would donate grain to the orphanages in their communities as part of their social responsibility, although this would typically be less than 1 % of the grain in store and did not occur frequently. The majority of respondents, 10 of the 13 WRS (77 %); 9 of the 21 CGB (43 %) reported that provision of loans to members in the form of cash, and pay back in the form of grain was one of the benefits to the members of the collective storage systems. Furthermore, respondents 23 % (3 WRS); 19 % (4 CGB) reported that community members are also allowed to buy grain from the collective storage systems. It was reported that the collective storage systems have improved the living standards of the beneficiaries as they now receive better prices for their grain and at the same time access the grain easily when grain is scarce in the area.

7.3.2.6 Suggestions for improving the management of collective storage systems

The majority of respondents, 9 of the 13 WRS (69 %); 11 of the 21 CGB (52 %) offered suggestions aimed at improving the management of collective storage systems to better help communities become more resilient to climate-related risks. Some of the suggestions include training on better management of the WRS and CGB, crop diversification and establishment of more cooperatives. In addition to these, promotion of re-afforestation programmes and renting out of the warehouses during the off-season when the WRSs and CGBs are empty. The warehouses are sometimes empty for 6 months and organisations such as World Food Programme rent them.

7.3.3 Grain damage and loss assessment

Sampling of the maize that had been deposited at Balaka WRS in August 2016 showed 4 $\pm$ 1.3 % mean damaged maize grain at the initial grain sampling done in the 2016/2017 storage season. The highest mean damaged grain level of 20 $\pm$ 3.2 % was recorded 24 weeks later. The mean number of damaged maize grains increased from 9.6 $\pm$ 2.9 % to 19.6 $\pm$ 2.9 % between week 8 and week 16, with a further increase of 0.4 % between week 16 to week 24. Some of the storage insect pests which were observed during sampling included *P. truncatus* and *S. zeamais,* mainly at the start of the sampling period, week 0 (Fig. 7.14). A significant positive relationship between the percent damaged grain percent and storage duration ($R^2 = 0.910$, $p = 0.046$), wa found (Fig. 7.14).

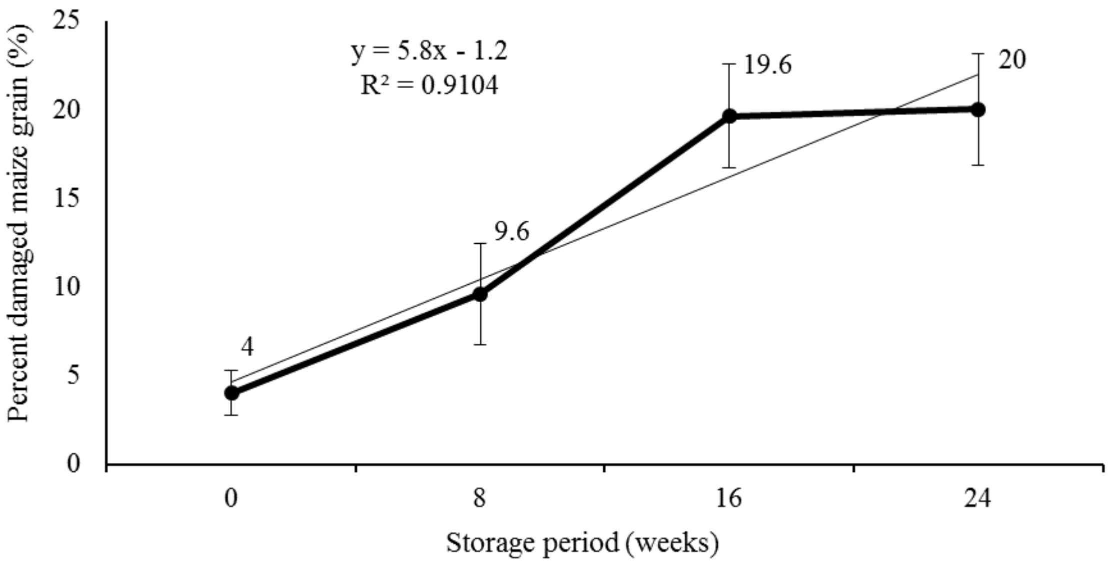


Figure 7.14: Mean (+ SEM) percent damaged maize grain recorded from grain samples collected at week 0, week 8, week 16 and week 24 from Balaka warehouse receipt system in the 2016/2017 storage season (n = 3). SEM = standard error of the mean

The initial maize sampling at Balaka WRS at week 0 recorded 0.6 + 0.2 % grain weight loss. This increased to 4 + 0.6 % by week 24 (Fig. 7.15). The maize weight losses and percentage damaged grain followed similar trends across the storage period. The relationship of storage duration and the grain weight loss percent was positive and significant (R^2 = 0.928, p = 0.037) and this translate that 93 % was the strength of the relationship (Fig. 7.15).

The regression analysis indicated that there was a postive significant relationship between the the level of damaged pigeon pea grains and the storage duration (R^2 = 0.970, p = 0.03) in Balak WRS (Fig. 7.16). Similarly at Mwandama WRS, there was a positive relationship between storage duration and level of damaged pigeon peas (R^2 = 0.983, p = 0.017). At the beginning of the study, all three WRSs had pigeon peas in stock. Samples of the pigeon pea at week 0 found 4.3 + 2.3 %, 5.7 + 2.5 % and 8 + 4.9 % mean damaged grain at Balaka, Nsanama and Mwandama WRSs respectively.

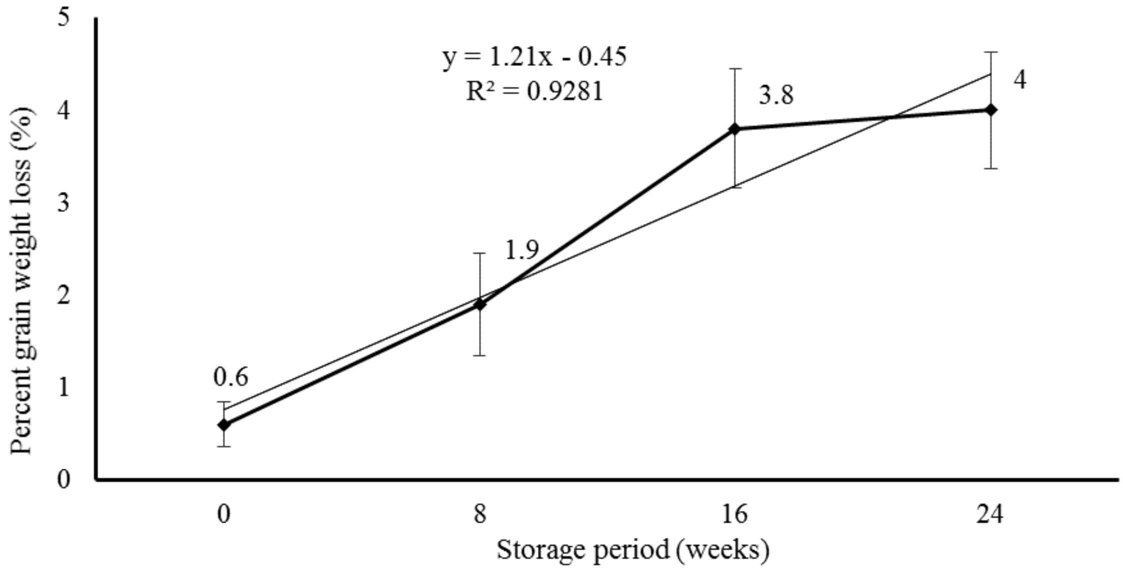


Figure 7.15: Mean (+ SEM) percent maize grain weight losses recorded at week 0, week 8, week 16 and week 24 from Balaka warehouse receipt system in the 2016/2017 storage season (n = 3). SEM = standard error of the mean

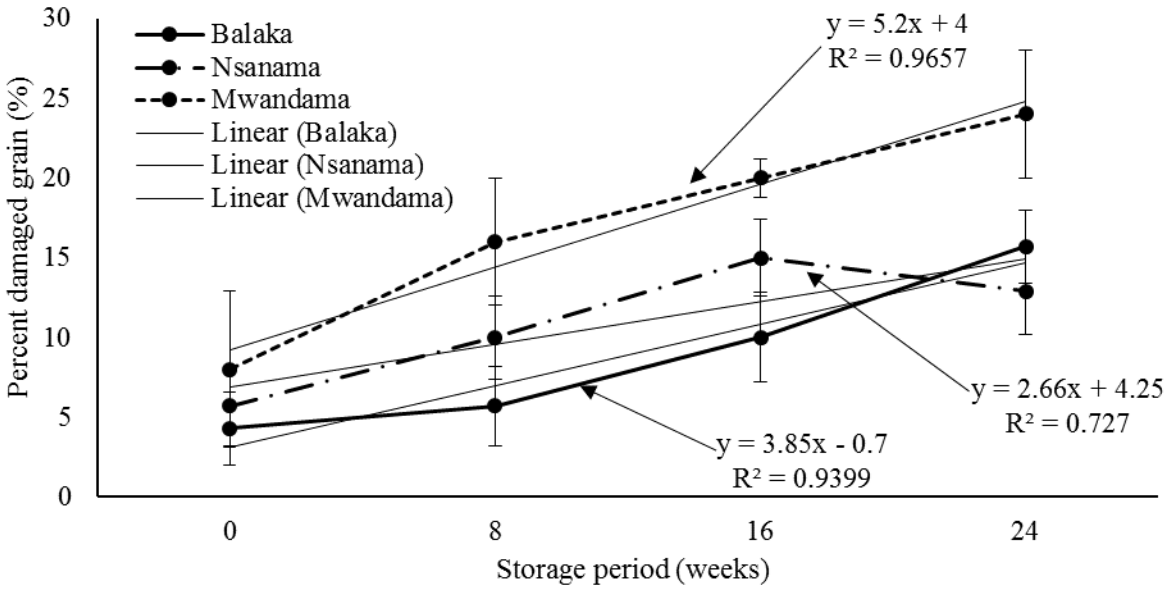


Figure 7.16: Mean (+ SEM) damaged pigeon pea grains recorded from pigeon pea samples collected at week 0, week 8, week 16 and week 24 from Balaka, Nsanama and Mwandama warehouse receipt systems in the 2016/2017 storage season (n = 3). SEM = standard error of the mean

The highest grain damage recorded from the pigeon pea occurred at Mwandama WRS and was 24 + 4 % at week 24 (Fig. 7.16). Positive significant relationships between storage duration and level of pigeon pea grain weight were observed at Balaka WRS (R^2 =0.970, p = 0.030) and Mwandama WRS (R^2 =0.991, p = 0.009) (Fig. 7.17). A positive relationship at Nsanama was obtained but it was not significant (Fig. 7.17). For pigeon pea, the highest initial grain weight loss (2.2 + 0.7 %) occurred at Mwandama WRS, while Balaka and Nsanama recorded 1.2 + 0.7 % and 1.6 + 0.7 % respectively. By week 8, grain weight losses in all the three WRSs had increased. By week 24, the highest recorded pigeon pea grain weight loss was at Mwandama WRS (7.3 + 1.7 %). A slight decrease in the grain weight loss occurred at Nsanama WRS between weeks 16 and 24 (Fig. 7.17).

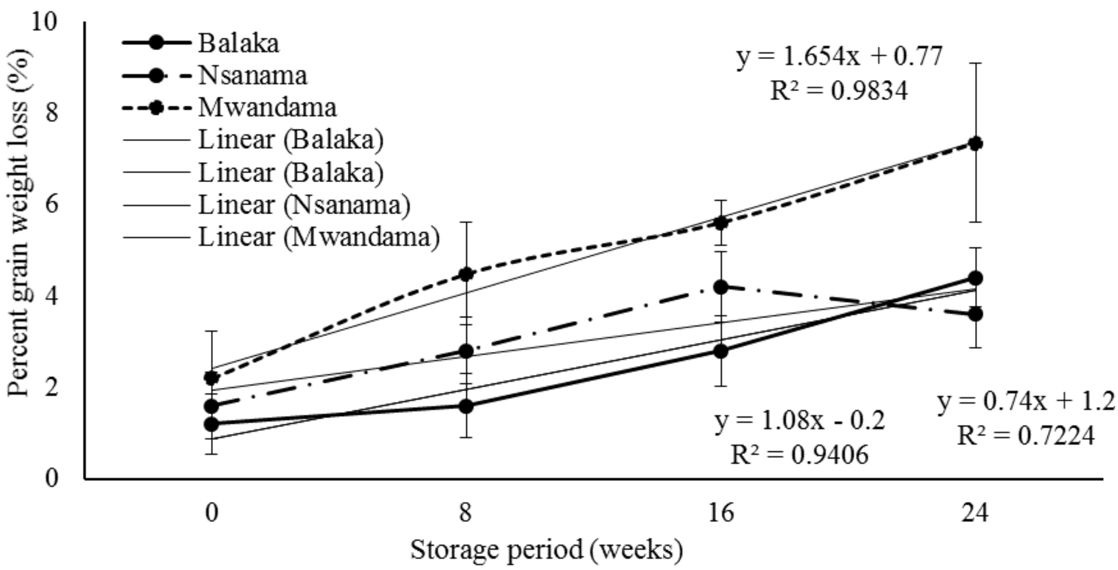


Figure 7.17: Mean (+ SEM) percent pigeon pea grain weight losses recorded at week 0, week 8, week 16 and week 24 from Balaka, Nsanama and Mwandama warehouse receipt systems on grain deposited in 2016 in the 2016/2017 storage season (n = 3). SEM = standard error of the mean.

At the start of the study, the stored grain had been in the warehouses (WRS) for less than six and seven months for maize and pigeon peas, respectively. Three WRSs namely Nsanama, Balaka and Mwandama had grain in store amounting to 678 mt, 440 mt and 2 mt, respectively.

7.4 Discussion

The majority of the members interviewed had at least a primary education level, and were between 36 to 57 years old, considering that some of them had not completed their primary education their understanding of training materials might be weak. Within the small sample of members interviewed there were more women than men in management positions at both WRS and CGB, and they played an active role in decision-making.

The establishment of CGBs by NGOs and governments was to help farmers resist the need to sell grain at low prices and prevent future famine, and this was in response to the famine that occurred in the 1970s and 1980s (Coulter, 2007). However, the construction of grain storage warehouses in the farmers' communities and provision of grain management trainings by the World Food Programme (WFP) improved smallholder farmers' grain management capabilities by reducing grain storage losses (Dorward *et al*., 2006). The current study listed WFP, Rab processors and Export trading company as the potential buyers of WRS and CGB stored grain. However, the significant problem of low crop production due to the small land size per HH, and its negative affect on the quantities of grain being deposited at the collective storage systems were also noted.

The WRS was perceived as one form of collective grain marketing that can accelerate the efficient removal of grain from farmers into safe centralized storage (Coulter and Shepherd, 1995). Storage facilities not only offer the opportunity to provide a supply of staple food between crop harvests but also improve farm incomes after grain sales at premium prices when demand outstrips supply later in the post-harvest period (Florkowski and Xi-Ling, 1990).

The present study found that long delays in securing better grain markets can confuse depositors and reduce interest in the depositing of grain at the WRS (Fig. 7.12). Further, some would then collect their grain from the WRSs without following the agreed procedures. In Ghana, rural traders developed a network of CGBs for grain assembling in a rural area then after sell to the Strategic Grain Reserves. This grain is mainly for the rural and urban populations, supporting community members market access for selling or buying of grain (Shepherd, 2009). One incident reported from Nsanama WRS, involved depositors withdrawing all their deposited grain from the WRS by force despite having collected a 70 % advance payment on the deposited grain (Fig. 7.12). In contrast to the current study, a Ghanaian study reported that one of the challenges contributing to low numbers of WRS members, was the high operational costs which are imposed on the depositors (Miranda *et al*., 2018). Further delays in securing better markets for the deposited grain led to this misunderstandings between the WRS management team and grain depositors. The current study found the potential buyers of grain from WRSs are typically agro-processors such as Rab processors that supply the urban areas. In addition to improving grain availability in rural areas, urban areas are also potential markets for grain stored in CGBs and WRSs in many SSA countries but lack of information and unreliable transportation system remain major challenges (Henson *et al*., 2008).

In Malawi, the Mwandama union opened a grocery shop, mill and bought a 3 ton lorry with funds from collective grain sales made to WFP. Furthermore, the Mwandama union still maintains 12 permanent employees originally hired under a UNDP funded project. One of the three WRSs, Mwandama is rented out to other organisations during the off-season when the facility is empty thus generating more revenue to support smoother running of the storage system. Bulking of staple food crops by smallholder farmers for collective marketing in Uganda was found to be more profitable than individual grain selling (Coulter, 2007). Besides provision of storage space and market access, CGBs play an important social role in assisting the most vulnerable groups in the community. Mdeka CGB members reported having donated 50 kg maize grain to each of the five HHs with orphans in the community. Although this could be easily expanded if the members adopted a "Zunde raMambo" type-system as practiced traditionally in Zimbabwe to cater for the wide range of vulnerable people within their communities (Mararike, 2001)

The study observed that Gwirima CGB was constructed at the Village headman's (VH) premises, who also chairs the management team. It was reported that many members had withdrawn their membership as the headman controlled the CGB as though it were his personal property. Defaults, corruption and inefficient management are often said to characterise CGBs, resulting in their failure to compete with private traders (Coulter, 2007). Despite the existing challenges, Gwirima CGB allows members to borrow money from the CGB account for purchase of 50 kg of fertilizer under the Farm Input Subsidy Programme (FISP) (Dorward and Chirwa, 2011). In return they are then expected to pay back the loan by depositing 50 kg of maize at the CGB, which is equivalent to the money borrowed. According to Shepherd (2009), farmers depositing grain at CGBs in SSA countries are fearful of losing their grain to government in the course of the storage period. A different situation was reported from Mdeka CGB, with some depositors being misled by some village headmen who informed their subjects that the CGB would rob them of their grain and the possible depositors in the area lost interest. Some studies conducted on village-level bulk granaries in Africa showed that the majority were empty, indicative of management problems (Shepherd, 2009), although in the current study low production was one of the contributing factors to low grain deposits by CGB members.

Despite CGBs offering a common storage site for multiple smallholder farmers for aggregation and distribution within the rural community set up and abundant grain storage space, the current study found that the CGB membership was low. A study in Malawi by Gondwe and Baulch (2017), reported that in 2016, ACE had facilitated the sale of about 66,000 mt of grain commodities. These grain commodities comprised of 70 % maize, 12 % soy beans and 10 % sunflower. A similar study in Ghana on WRS revealed that the Ghana Grain Council issued receipts for 46,942 mt of maize (Miranda *et al.*, 2018). Maize appears to be one of the most traded grains under the WRS in these countries. A similar study on community grain banks conducted in Sierra Leone indicated farmers' initial reluctance to use the facilities. Eventually the farmers accepted after observing that the system had reliable buyers and the grain sales were more profitable than when done as individual HHs (Shepherd, 2009). Some of the contributing factors to farmers' reluctance included a lack of confidence in the management system of the CGB, fear of losing the grain to government and an unwillingness to disclose their grain quantities to fellow farmers (Fafchamps, 2004). Provision of false information by the village headmen to their subjects in the current study contributed to a lack of grain deposits at the Mdeka CGB. The CGB was empty at the time of the study, although the low harvests which farmers experienced during the 2015/2016 growing season may also have contributed to this. High crop production was found to be associated with high crop storage losses in another study, suggesting increased crop production may develop farmers interest in purchasing technologies to minimise storage losses (Ambler *et al*., 2018).

The low maize storage losses recorded at Balaka WRS during the six months storage period was a clear indication of good pest control management despite the challenges the storage system was facing, the pest control at this WRS was managed by ACE. However, at Mwandama WRS, where ACE was not involved in pest control, higher storage losses were recorded than at Balaka and Nsanama WRSs (Fig. 7.17) which receive pest control services from ACE. This agrees with results of a study by Onumah (2010), which reported that viable WRSs may significantly minimise crop storage losses among smallholder farmers. The majority of the CGB pest control team members were trained with support from FAO and a few of the trained members continue practicing fumigation. However, some trained fumigators had withdrawn their membership from the study's focal CGBs. This led to the switch from using fumigants to dust and liquid formulated storage pesticides which are not recommended for bulk grain storage as they are too costly and labour intensive. Despite challenges at the CGBs, farmers continue depositing grain to reduce the long-term storage risks, although the storage period was less than five months in the current study (Fig. 7.8).

The WRS's heavy reliance on ACE central office pest control trained staff caused concerns as pest infestations continue to build-up while waiting for the pest control team. Greater farmer training could improve the effectiveness of grain loss prevention strategies (Ambler *et al*., 2018). Stathers *et al.* (2013) reported key research areas for less developed countries to help deal with the implications of climate change mainly on crop PHLs and adaptation to guide policy makers and the efficient use of resources.

Respondents felt the WRSs and CGBs studied in Malawi, could be alternative local suppliers of relief food grain, which normally comes from the strategic grain reserves located in the central region of Malawi to disaster prone areas such as Shire Valley. Coulter (2007) noted that CGBs can sometimes act as grain assembly points in times of distribution of relief food items commonly in climate risk prone areas. In addition to maintaining food security among communities, the storage systems could be a temporary mitigation strategy to climate change-related events such as floods. However, there is need for a holistic approach in creating public awareness, education and training about safety approaches towards natural hazards as proposed by Bendito and Twomlow (2015), following a study on crop and livestock conducted in Rwanda

7.5 Conclusion

The study demonstrated that smallholder farmers perceive these two collective storage systems models as useful if adopted by the communities and properly managed. The WRS and CGB can be part of adaptive strategies for farmers from areas frequently hit by climate-related disasters. Nevertheless, construction of these collective storage systems needs to be done on higher grounds to minimize flood risks, which can easily damage the structures rendering them unsuitable for their intended purpose.

Grains can be safely stored from storage pests and climate-related disasters for future use if deposited at the WRSs or CGBs. The introduction of the CGB or WRS in Shire Valley would also act as grain reserves for emergency relief food to the affected HHs due to climate-related events. In view of the results obtained from the study, the null hypothesis was accepted

CHAPTER 8: OVERALL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 General discussion

8.1.1 Existing and innovations for managing maize postharvest losses in Shire Valley area, southern, Malawi

Shire Valley is one of the most vulnerable areas to climate-related risks in Malawi. These risks, including dry spells, floods, heavy storms and hailstorms. These pose serious threats not only to crop production but also to postharvest management (PHM) of maize and other staple crops. Climate change (CC) effects on PHM are particularly poorly understood. To help build household and community resilience to these risks, it was necessary to better understand farmers and other stakeholders' experiences of the climate-related risks and changes, and their postharvest (PH) systems and linkages between CC and PH systems. Interviews of 203 households (HHs), 43 key informants and communities in seven focus group discussions (FGDs) illustrated that farmers perceive that they are now experiencing higher temperatures throughout the year compared to during the past 10-20 years when cooler temperatures were experienced during the rainfall season (Fig. 4.10), coupled with more frequent occurrences of floods compared to the same period in the past. Rainfall variations in Shire Valley are known to be associated with floods and prolonged dry spells (Potts and Wiley, 2006). Household interviews showed that the most common grain storage facilities used in the study area were woven polypropylene bags, mostly used in combination with synthetic grain protectants (Fig. 4.5b-c). FGDs indicated that the increased use of these storage bags since 10-20 years ago, is due to both their easy availability and accessibility, increasing food insecurity and alleged high incidences of maize theft in the southern region of Malawi if maize is stored outside the dwelling houses. The increase in maize theft cases was mainly a result of reduced maize production partly emanating from the reported CC in the study area and the high population density.

Key informant interviews indicated that there is limited PH knowledge and skills amongst extension agents, NGO staff and farmers which contributes to the mis-use of chemicals among some HHs (Fig. 4.9). A study by Stathers *et al.* (2013) highlighted the need to include PH topics in national agricultural curricula and training courses. There is a lack of studies, and understanding by technical staff and farmers, on adaptation strategies to CC issues regarding crop postharvest handling. Many studies focus on crop production. For example, studies in Botswana, Malawi and Swaziland reported by Stringer *et al*. (2009b), highlighted several adaptation strategies focused on crop production including the use of high yielding, drought and disease-tolerant seed varieties, and development of cost-effective production technologies, all aimed at increasing agricultural productivity. The majority of households (≈70%) currently use synthetic storage pesticides in the study area, corroborating findings by Ricker-Gilbert and Jones (2015), who reported an average of 50.6 % of HHs across Malawi having used subsidised storage insecticides between the 2008/2009 and 2012/2013 storage seasons. In the current study, respondents reported that neem leaf powder imparts a bitter taste on treated grain intended for consumption, although neem products may have more applications for use in protecting retained seed than grain intended for use as food (Sibale *et al*., 2013). The bamboo and timber used in the construction of traditional granaries are prone to attack by *P. truncatus* (Hodges, 2002). Now with the increased theft cases of stored maize in traditional granaries which are erected outside farmers' dwelling houses, farmers have opted to store in polypropylene bags using synthetic and non-synthetic pesticides (Hodges, 2002). This presents an opportunity for farmers to start using hermetic storage facilities and other pesticide-free technologies, currently preferred by many farmers in many locations (Subramanyam and Roesli, 2000; Kljajić *et al.*, 2010). Stathers *et al*. (2013) reviewed some PH CC adaptation options including prompt harvesting, use of recommended drying facilities, grain protection, good storage hygiene, repair and maintenance of storage structures and containers. Nevertheless, in the current study, understanding of CC and associated risks varied amongst HHs with some HHs unable to explain the existing problems on general PH handling of maize grain in relation to CC and variability. To prevent the mis-use of chemicals and to improve general grain PHM, the district key informants emphasised the need to increase understanding and skills in crop PHM such as storage hygiene, harvesting process and timing, drying, moisture content assessment, sorting, protection, storage and monitoring. Based on the findings and the observations from the community study, on-farm trials were proposed to understand and confirm the validity of the reported PHM options by farmers in Shire Valley.

8.1.2 Farmer participatory evaluation of existing and new PH innovations under on-farm conditions

The participatory on-farm storage trials compared seven different grain storage technologies namely Actellic Super dust, Super Grain bag, Purdue Improved Crop Storage, Metal silo, ZeroFly® bag, Neem leaf powder and Polypropylene bag. These trials in Shire Valley had high maize grain weight loss of up to 29.0 % in the synthetic and non-synthetic pesticide grain treatments at 32 weeks of storage in the 2014/2015 and 2015/2016 seasons. These results emphasised the need for alternative storage technologies. By contrast, in the 1978/79 storage season, maize grain weight losses of just 2 – 5 % in farmers' stores in Shire Valley were reported within a 10 months storage period (Golob, 1981). The increased weight losses in the current study were essentially due to insect pest damage largely by *P. truncatus* and the high susceptibility of the maize used.

Grain stored in hermetic bags (PICS, SGB) during the participatory on-farm trials, sustained significantly lower insect damage and weight loss compared to other treatments across sites and seasons. Previous studies on two hermetic bags in India, found that the PICS bag controlled storage insect pests better than the SGB within 6.7 months (Harish *et al*., 2014), while in the current study in Malawi there was no significant efficacy difference between the two brands of hermetic bags. Several similar studies in Kenya, Zimbabwe, Benin, Burkina Faso and Ghana have also reported reduced levels of grain weight losses in hermetic bags during storage periods of more than 6 months (Baoua *et al*., 2014; Njoroge *et al*., 2014; Baributsa *et al.*, 2017; Mlambo *et al.*, 2017). In the current study, perforations of three out of the 16 SGB and PICS bags by *P. truncatus* within 24 or 32 weeks storage, might have contributed to the loss of air tightness of the bags, and enabled insect pests to access and damage the stored grain. Hell *et al.* (2014) demonstrated that large air spaces between cassava chips stored in PICS bags, provided oxygen for *P. truncatus* to survive and perforate the inner plastic bag within 8 months of storage. Hence, great care should be exercised when handling hermetic bags to prevent punctures that can render the bags useless. Metal silos can play an important role in protecting farmers' stored grains (Tefera *et al.*, 2011; Chigoverah and Mvumi, 2016; Mlambo *et al*., 2017) although in the current study they did not protect the grain effectively from insect pests. The ineffectiveness of the metal silos was partly associated with the continuous loss of the air-tightness due to the rubber tubing that was used for sealing the MS detaching itself from the silos, possibly due to high temperatures. The ineffectiveness of ZFBs in controlling stored insect pests, was linked to the initial build-up of insects in the stored grain at the start of the study because the maize grain used was not fumigated, as smallholder farmers' typically do not fumigate their grain. However, Baban and Bingham (2014) reported ZFB being effective in controlling storage insect pests of cereal grains, pulses and oilseeds. In Zimbabwe, non-fumigated maize grain stored in ZFBs sustained high weight losses compared to the MS, SGB and PICS, and the ZFB and was therefore not recommended for grain storage under smallholder farmers' conditions (Mlambo *et al*., 2017). However, the success of technologies such as the hermetic containers and grain protectants will depend on their availability within the farming communities. A study by Govereh *et al*. (2019) observed that collaboration between manufacturers of hermetic bags and rural retailers, and bulk orders for delivery by retailers to cater for a specific community are important operational factors required if the technologies are to meet the intended objectives. These factors are also vital for the up-scaling of the technologies.

One climatic factor suspected to have contributed to the failure of the storage technologies was high temperature, and this led to the proposal to test the same technologies in the laboratory at increased temperatures. Correspondingly in the current study some field-tested storage technologies (protectants and facilities) such as ASD, MS and ZFB were negatively affected by the prevailing environmental conditions. According to Mubayiwa *et al*. (2018), climatic conditions influence the performance of grain protectants in storage.

8.1.3 Effect of increasing ambient temperature on the efficacy of grain protectants and grain storage facilities in smallholder maize production systems

Among the technologies tested (Actellic Gold dust (AGD), Shumba Super dust (SSD), Wivokil Super dust (WSD), Super Grain bag (SGB), Purdue Improved Crop Storage (PICS), Metal silo (MS), ZeroFly® bags (ZFB), Neem leaf powder (NM), wood ash (WA) and Polypropylene bags (PP)), the hermetic storage containers kept mean insect grain damage below 6.4 % in climate chambers set at 32 ˚C and 38 ˚C, and at ambient temperature (26 ˚C) throughout the 12-week storage period (Fig. 6.8a-c). The insect grain damage in these laboratory trials was caused by *P. truncatus*, the test insect used in the study, which is the most destructive storage insect of stored maize and dried cassava in SSA following its accidental introduction in the late 1970s (Hodges, 1994). In a Kenyan trial, maize grain kept in PICS bags at ambient temperature for six months recorded 2.0 % insect damage (Njoroge *et al*., 2014). An earlier study found temperature increases from 20 ˚C to 30 ˚C had a positive effect on the efficacy of synthetic protectants on cereal grains (Athanassiou and Kavallieratos, 2014). During the trial maximum temperatures of 38.7 ˚C and 38.1˚C were recorded from inside the hermetic containers and PP bags that had been placed inside climate chambers (set at 32 ˚C and 38 ˚C) respectively, these results were similar to those from a study on hermetic IRRI bags, in which higher internal temperatures were recorded than in PP bags during a 12 week storage period (Prasantha *et al.*, 2014).

In the laboratory trial, the hermetic storage containers kept mean insect grain damage below 6.4% compared to 24.5% in the untreated control at all the experimental conditions (Fig. 6.8a-c). Higher mortality of *P. truncatus* in the grain protectant treatments at the higher temperatures (32 ˚C and 38 ˚C) than at ambient temperature (26 ˚C mean) (Table 6.5), suggests that the combined negative effect of increased temperatures and pesticide treatment may result in synergistic control of *P. truncatus* in treated stored grain at these higher temperatures. Two projected climate change-related temperature scenarios for southern Malawi of 32 ˚C and 38 ˚C, did not negatively affect the performance of the tested storage containers (SGB, PICS and MS) or synthetic grain protectants (AGD, SSD and WSD) in preventing stored grain damage by *P. truncatus*. Possible effects of global warming on insects include changes in the number of generations, population growth rate, dispersal and migration, and these are based on existing studies on increased temperature on the biology of the insects (Papanikolaou *et al*., 2018; Papanikolaou, *et al*., 2019). Skourti *et al*., (2019) found that the lowest survival figures of *T. castenium* is obtained at both ends of the temperature range. According to the current study, use of synthetic grain protectants and hermetic storage containers in the management of *P. truncatus* will not be adversely affected by the projected warmer temperatures of 32˚C and 38˚C. Predictions indicate that there will be an increase in global mean surface temperature by the end of the 21st century (2081–2100) in the range of 0.3°C to 1.7°C (IPCC, 2014). Global CC will likely compromise the efficacy of available storage pest management technologies, but there is little evidence yet on these effects. A study by Hulme *et al*. (2001) reported that SSA has warmed at an average rate of 0.5°C per century, in the last century. However, there are large variations in warming within SSA, with a maximum warming of 2°C per century recorded in north-west Africa and in southern Africa (Cairns *et al.*, 2013). However, more studies are required to complement these results if these findings will remain efficient under SSA's warming climates.

8.1.4 Assessment of technical and institutional performance of the warehouse receipt systems and community grain banks as adaptive strategies for managing maize postharvest losses in Shire Valley area, southern Malawi

While identifying PHM options and adaptive strategies to climate-related risks in CC prone areas at HH level in Shire Valley, no adaptive strategies at community level were mentioned. Hence a study of the potential roles of warehouse receipt systems (WRSs) and community grain banks (CGBs) as adaptive strategies was initiated. The introduction of WRSs and CGBs in sub Saharan Africa (SSA) by development partners is perceived to help in reducing grain storage losses. Even though CGBs offer a common storage site for multiple smallholder farmers to aggregate, market and distribute their grain from within rural communities, the current study found the CGBs studied, had few registered members regardless of them being able to provide grain storage space. The majority of farmers preferred to store grain within their homes, while the CGB remained empty as farmers were not confident of the security of grain deposited in the CGB. Similarly, in Sierra Leone, farmers were initially reluctant to use community grain banks, although eventually they did (Henson *et al.*, 2008; Markelova *et al.*, 2009). Low maize storage losses during the six months storage period at Balaka WRS (Fig. 7.17), were due to better pest control management despite the challenges the storage system was facing including untimely fumigation (Fig. 7.11). The technical and financial support from the Agricultural Commodity Exchange (ACE) rendered to the three WRSs studied, contributed to the smooth- running of the storage systems. According to Dorward *et al*. (2006), construction of storage grain warehouses in the farmers' communities by the World Food Programme in Malawi improved smallholder farmers' grain management capabilities hence reducing grain storage losses. In Ethiopia, the purchase of local food aid by organizations could not meet the demand because smallholder farmers failed to supply the required quantity grain supply into the storage system (Coulter, 2007). Low crop production due to the small land size per household, negatively affects the grain quantities deposited at the storage systems, although many CGB are also characterized by defaults, corruption and inefficient management resulting in failure to compete with private traders (Coulter, 2007). Similarly, small production areas were also reported in the current study as one of the factors affecting the quantity of grain deposits at the CGBs (Fig. 7.6).

Despite the existing challenges, Gwirima CGB in the current study allows members to borrow money from the CGB account for purchase of farm inputs under farm input subsidy programme (FISP). The performance of some CGB in Africa is characterised by high failure rate of over 90 % such as Benin (Kent, 1998). However, farmers depositing grain at CGB are always fearful of losing their grain to Government in the course of the storage period (Markelova *et al.*, 2009). At Mdeka CGB, some depositors were misled by some Village headmen who informed their subjects that the CGB management would rob them of their grain resulting in the potential grain depositors in the area losing interest. This raises governance capacity issues which need to be addressed if this community storage system is to be promoted for wider adoption. The contributing factor to this low adoption of CGBs was the emptiness and inactiveness of the CGB compared to WRS which had grain in stock at the time of the study. An earlier study conducted on bulk granaries (village level storage) in Africa found the majority of CGBs empty, which was identified as a sign of management problems (Markelova *et al*., 2009). Seed storage in CGBs and local sales to fellow smallholder farmers, proved to be effective as the seed could then be made available to members in the CC prone communities in eastern and southern Africa (Orindi and Ochieng, 2005; Gumbo, 2009). The CGBs act as grain assembly points in times of distribution of relief food items in CC prone areas (Coulter, 2007). Equally, the current study suggests WRS and CGB can be alternative local suppliers of relief food grain, unlike the existing arrangements of withdrawing from the central strategic grain reserves.

8.1.5 Study limitations

In the on-farm participatory storage trials in Shire Valley, data loggers for collection of temperature and relative humidity data were imported from Europe and only became available from week 15 to week 32 during the 2015/2016 storage season. The delay was due to logistical issues during shipment. As soon as the four data loggers arrived they were placed in farmer store rooms to provide a record of the actual temperature and relative humidity conditions in the storage systems. The delayed acquisition of these data loggers, meant data for only part of the storage period in the 2nd year was collected, preventing a full interpretation of the effect and range of temperature and relative humidity conditions in smallholder storage rooms. Further, there were not sufficient data loggers to record the data inside the storage facilities during the on-farm trials. The same problem also affected the measuring of the inside temperature in some of the storage facilities used in the laboratory trials conducted in Entomology Laboratory at Botswana International University of Science and Technology (BIUST), Palapye, Botswana. In view of this, future research should aim to collect temperature and relative humidity data from the external and internal environments of the storage facilities continuously.

The laboratory trials to study the effect of increasing ambient temperature on the efficacy of grain protectants and grain storage facilities in controlling storage pests were initially conducted in a controlled temperature and humidity (CTH) room at Chitedze Agricultural Research Station in Lilongwe, Malawi (Fig. 8.1).

Figure 8.1: Set of grain protectants and grain storage facilities treatments randomly arranged on wooden pallets in a Controlled Temperature and Humidity (CTH) room at Chitedze Agricultural Research Station in Lilongwe, Malawi (Source: Charles Singano, the Department of Agricultural Research Services, Lilongwe, Malawi).

The trials were conducted for 24 weeks at 32 ^{o}C and 38 ^{o}C in 2014/2015 storage season. However, the trials had to be discontinued due to extended and continuing power blackouts in Malawi which made it impossible to maintain the intended increased temperature trial conditions in the CTH rooms. Thus the data were inconclusive and had to be discarded, then new sets of trials were conducted in the Entomology Laboratory in Botswana. Eventually plans were made to use the climate chamber facilities of the Entomology Laboratory of Botswana International University of Science and Technology (BIUST) in Palapye, Botswana, to conduct the trials in 2018. The original set up of the trials had 50 kg of maize per treatment in the CTH room in Malawi, and had to be scaled-down to 100-200 g per treatment in the climate chamber in Botswana. However, this change and failure of the first set of trials in Botswana also caused a short fall in the number of miniature metal silos, as a result the silos (treatment) was excluded in the control/ambient conditions in the lab experiments in Botswana. The trials were successfully conducted but resulted in additional costs (e.g. transport and living costs for the researcher). In addition the miniature silos had to be made to replace the 50kg capacity ones originally made for use in the CTH room complicating logistics and causing significant delays

The first laboratory trials implemented in Botswana used storage insect pests and maize brought from Malawi. However, three months into the study it was observed that both *P. truncatus* and *S. zeamais* were having challenges in adapting to the rearing conditions (temperature and relative humidity) leading to high mortality, which made it difficult to isolate the effect of the treatments. As a result, the trials were terminated after 6 weeks of implementation and another set of trials were then set using Botswana maize grain and only *P. truncatus* obtained from a BIUST laboratory culture which had originated from Zimbabwe, as it was not possible to bring another set of insects and grain from Malawi. This experience highlighted the need for plans to observe whether imported insects are affected by the new environment prior to using them in experiments especially when transferred to very different climatic zones. Insufficient miniature-metal silos were fabricated for the laboratory increased temperature trials, as the need for an ambient set of treatments was overlooked originally.

Regarding the work exploring the potential role of WRS or CGBs in building climate resilience, the study had originally envisaged targeting WRSs and CGBs located within the focal Shire Valley (i.e. within Chikwawa and Thyolo districts) where the survey and on-farm trials were conducted. However, it was realised that none of the storage systems (WRS or CGB) were present within the districts. Therefore, the study was shifted to the nearby districts of Balaka, Blantyre, Machinga, Chiradzulu, Phalombe and Zomba in southern Malawi where

WRSs and CGBs were found. These districts were selected due to their similar climatic conditions and climate risks to those of Chikwawa and Thyolo (Matiya *et al*., 2011). Timing of the studies was very tricky such that it was difficult to get grain stocks at all CGBs under study, hence timing of the study was not optimal for capturing all the activities at these storage systems but this was beyond author's control.

8.2 Conclusions

The occurrence of food insecurity has increased in Shire Valley. Contributory factors include high temperatures, hailstorms, floods, prolonged dry spells and/or erratic rains associated with climate change. The study area now experiences prolonged hot seasons and high temperatures of up to 45 ^oC. The majority of HHs have developed high dependence on relief food from NGOs and the GoM.

The use of synthetic pesticides has increased recently compared to more than 10-20 years ago and the increase in relation to increased insect pest pressure in the study area. At the same, storage of grain has changed from solid outdoor timber or bamboo-based grain storage structures to indoor polypropylene bag storage. The main cause for this change include presence of insect pest attack by *P. truncatus* on both the grain and timber- or bamboo-based structure, and increase in theft cases.

The majority of development agencies in Shire Valley have not incorporated crop PH handling adaptation strategies to CC into their programmes. Some of the PH adaptation strategies recommended based on the current study include increasing extension PH knowledge and skills through training and on-farm demonstrations, safe and effective use of grain protectants, and effective use and distribution of improved cost-effective storage technologies such as hermetic bags

On-farm participatory storage technology trials in Chikwawa and Thyolo districts in Shire Valley showed that the prevailing storage conditions in the area are not recommended for grain storage treated with neem leaf powder or ASD beyond a 24 week storage period. Furthermore, NM, ASD including MS and ZFB bags did not protect grain from insect damage throughout the 32 weeks storage period whereas PICS and SGB effectively kept insect grain damage low in smallholder farmer-managed maize grain stores. Nonetheless, all hermetic storage facilities, including PICS and SGB, were not effective in maintaining grain viability possibly as a result of the constantly high temperatures experienced in the study area. Therefore, PICS and SGB are recommended for use by smallholder farmers for grain storage in Shire Valley and other CC prone areas of SSA. Based on the study findings from the two storage seasons, the study's hypothesis that use of existing local PHM options (ASD, NM and PP) result in high grain losses, making farmers more vulnerable to climate-related risks compared to when newly-introduced PHM options (PICS and SGB) are used, was accepted.

Laboratory studies of the efficacy of different grain protectants and facilities at increased temperatures of 32 °C and 38 °C, showed that these higher temperatures did not negatively affect the performance of SGB, PICS and MS, or AGD, SSD and WSD in preventing grain damage by *P. truncatus* in comparison to ambient conditions (26 °C). These results suggest that smallholder farmers can continue to use these options for stored maize protection as temperatures increase in CC-prone SSA countries. Contrary to the hypothesis that increase in ambient temperature favours the development of insect pests of stored-maize grain under existing and new PHM options leading to increased storage losses, the study results did not find storage losses increased at higher temperatures, therefore, the null hypothesis was rejected.

The WRS maintained grain weight losses to less than 9 % in both maize and pigeon peas throughout the 24-week storage period, and based on responses from CGB members, it is suggested that the WRS and CGB may reduce crop storage losses. The findings suggest that CGB could be a more useful type of storage facility as an adaptive strategy in CC prone communities compared to WRS. These suggestions are based on the responses from the CGBs members who reported that grain deposits were mainly for storage of surplus grain compared to WRSs, which is mainly for marketing purposes. However, with some modification to WRSs, these can reduce grain storage losses, and also become an adaptive strategy to CC-related disasters in CC prone areas. While the WRSs and CGBs could act as grain reserves for use during climate-related events and play a role in the distribution of emergency relief food to the affected HHs, and have the potential to reduce grain storage losses, this is not yet occurring. Therefore, the null hypothesis that collective grain storage options, such as WRSs and CGBs are effective adaptation strategies for helping to buffer smallholder farmers against food insecurity resulting from droughts, floods and increased pest activity, was rejected.

8.3 Recommendations

Hermetic storage bags and metal silos were recently introduced pesticide-free technologies for the protection of stored grain. However, to ensure their effective use, farmers need to understand how hermetic facilities work to protect their grain from insect damage and deterioration, which requires trained extension staff to extend the messages. During the survey and field trials, it became evident that most of the extension agents and the mass media agents need to be equipped with PH knowledge and skills. The knowledge should be both in English and the local languages through training and on-farm demonstrations. The focus areas include promotion of careful crop drying and good storage hygiene, proper application of grain protectants, and effective use and distribution of improved storage facilities in Shire Valley and elsewhere in SSA. The GoM has been implementing farm input subsidy programme since 2006, focusing particularly on seed and fertilizer inputs, although storage pesticides were included for three years in the course of implementation, they were later withdrawn. It is recommended that the GoM should consider introducing a subsidy on some of the grain storage technologies. The subsidy should target technologies effective in protecting grain under farmer management such as PICS and SGB. Once the subsidies are done, through reduced import taxes would lower the costs of these products and make them easily affordable by more smallholder farmers. Such actions would help farmers reduce their grain storage losses. During the survey, stakeholders suggested that CC awareness and adaptation strategies should be incorporated into educational school curricula from primary level. Based on this observation, it is requested that GoM should consider this proposal for the benefit of all communities. More research into CC and PH adaptation strategies, and their inclusion into policy would be beneficial in the light of global-warming compounded by pest pressures.

Further research areas identified by the field study include the need to monitor temperature and relative humidity variations inside the hermetic storage facilities (MS, PICS and SGB) during grain storage and possible tolerance of different insect species to increased temperatures. Although the ZeroFly bag performed badly due to the use of non-fumigated grain, fumigation of grain by smallholder farmers is illegal in Malawi (and many other SSA countries) due to associated safety risks, and only licensed fumigators are authorized to do fumigation. The recommendation that this storage bag be used on fumigated grain is therefore impractical for smallholder farmer use. The manufacturer of ZeroFly bags has since produced a hermetic ZeroFly storage bag to avoid the need by farmers to fumigate their grain prior to storage in such bags. The authorities such as the Ministry of Agriculture, Irrigation and Water Development (MoAIWD) need to take note of this issue. It is recommended that further close field monitoring of farmers PH systems should be conducted as mean temperatures rise. This is to ensure other changes to elements of the PH system do not lead to variable or reduced efficiency of these grain storage options.

Temperature tolerance varies across insect life-stages and species, therefore, it is recommended that further studies should look at ontogenetic effects of higher temperatures on different species, as well as diurnally varying temperatures and RH on *P. truncatus* survival and damage to stored grain. Further exploration of how higher temperature might differentially affect long-term insect survival, dynamics, and competition among species would be informative. Climate chamber studies simulating temperature fluctuations under ambient conditions need to be conducted, additionally, studies should also target other storage insect pests as different species may respond differently.

Based on the WRS and CGB study findings, it is recommended that further research is needed in building the capacity of the private sector to service smallholders' needs centred on these storage systems. In some CGBs, traditional leaders were taking a leading role in the management teams and this interfered with the proper management and governance of the CGBs. One of the recommendation was that traditional leaders should not be involved at the level of decision-making to promote smooth running of the storage systems. The WRSs and CGBs were recommended to be used as adaptive strategies in CC prone areas to reduce crop storage losses and also become strategic grain reserves in times of climate-related disasters. There is need for these WRS and CGB to be constructed on higher grounds to reduce flood risk given the frequency of flood occurrence in Shire Valley. This task will need support from GoM and hereby requested to consider start up-scaling these storage systems in the targeted areas as suggested.

Overall, the studies showed that hermetic technologies (PICS, SGB and MS) and synthetic pesticides (AGD, SSD and WSD) could be used by smallholder farmers under high temperature scenarios. This is in contrast to the commonly held thinking that high temperatures may render the technologies ineffective. However, there is need to establish the modalities and institutional arrangements for systemic availability of the technologies and creating the demand through awareness creation, training and media publicity. Additionally, more work is also required on the functionality of community or group storage systems as complementary adaptive strategies to HH level storage systems.

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APPENDICES

Appendix A: Checklist for Focus group discussions

(Separate Men and Women Farmer Focus Groups (~15 people in each with representatives from the different wealth groups) NB. Rapporteurs to capture full details of discussion in their notebooks

C1. Identification details

Date:

Focus group description (e.g. men or women, number of people present):

Village/Community: District:

[Prompt: Produce an attendance list detailing name and sex of participants]

C2. Description of their normal climate and how it is changing

- How do you characterize a normal season in this community/ village?
- What climatic aspects are changing/have changed?
- What indicators are there of these climatic changes?
- What are the major impacts you are seeing as a result of these changes,
- How has that affected the way people are now behaving?

[**Suggested tools:** ***brainstorming, discussion – Everyone together]***

[Prompts: timing of rains and hot and cold seasons, how does a bad season differ, how frequently do you experience bad seasons]

C3. Major climate related events affecting this focal community

- What major climate related events have affected this focal community?
- What were the effects of these events and how did people respond to/ cope with them?

[**Suggested tools*: timeline, discussion of relative importance, effects and coping strategies* –** *May want to split the focus group into smaller groups a and b from here onwards, so subgroup a do some of the activities, and sub-group b do some of the activities]*

C4. Livelihoods

- Seasonal timing of the main livelihood activities done in this community?
- What factors influence these activities and choices?
- What agricultural support and social services are available to the community at local level?
- Have livelihoods changed over the years, and if so in what ways and for what reasons?

  [**Suggested tools: *Activity calendar, Brainstorming, Resource mapping* -** *Maybe as Groups a and b]*

  [Prompts: the timeframe of changes should go as far back as possible]

C5. Information systems (as regards climate and any other information related to crop production and postharvest management including markets)

- What information do they currently get and from where?
- What do they use this information for (e.g. how do they choose what and when to grow and how to store etc.)
- How do the quality (usefulness, timeliness and reliability) of these different information sets and sources differ? *[could rank them]*
- What information are they failing to get and why would they want it?
- Any gender differences in accessing/ using these information sets?

  [**Suggested tools: *Brainstorming, Completion of a table on a flip chart, Ranking matrix* -** *Maybe as Groups a and b]*

Source of information	What is it used for?	Quality, (reliability, usefulness, timeliness) of it?	Any gender differences in access or use of it	Improvements required or information gaps?
Information they are failing to get, and why they would want it? *[Checklist: Temps, Soils, EcoFarmer, Market prices, PH management, Implements, Varieties, Pests etc]*				

C6. Hazards

- What are the climate hazards in this area? *(E.g. droughts, floods, temperature trends, hailstones, coastal zone inundation etc.)*
- What are the possible causes of these hazards?
- What factors aggravate these hazards? *(Include social, pest, governance type factors etc.)*
- How are livelihoods and activities changing as a result of these hazards? *(be aware that a wide range of issues might come up e.g. rural to urban migration)*
- Social differentiation – who is more vulnerable to each of these climate hazards and why? (*e.g. age, gender, health, exposure, location, crops, farming systems, ecosystems etc.)*
- What support systems do members of the community use in times of stress?

  [**Suggested tools:** ***role play in small groups, causal diagrams – e.g. to pull out who or which system is most affected, and why*** **-** *Maybe as Groups a and b]*

C7. Adaptation

- What are people already doing in response to each of these hazards? *[relate to timeline]*
- What other adaptation options could people try (including crop production and postharvest options as well as off-farm options)
- What barriers or enhancers are there to their coping and adapting to climate risks? *[tease these out during the role play]*

[**Suggested tools: *Brainstorming, Role play in small groups -*** *Maybe as Groups a and b]* N.B. this section should bring out the pre and postharvest ideas they would like to test in the learning centres. **Questions:** Note of any further questions the focus group have about the discussion and intended activities.

Appendix B: Structured questionnaire for Household interviews

<table>
<tr><th colspan="2">COMPLETE BEFORE THE INTERVIEW</th><th></th></tr>
<tr><td>Respondent name:</td><td>Surname: ______________________
First name:______________________
Gender: 1= Male 2= Female |___|</td><td rowspan="3">Questionnaire numbering:
|___|___|___|
Three digits to represent questionnaire number (#) e.g. questionnaire number 1 would be <u>001,</u> number 10 would be <u>010</u> and number 100 would be <u>100</u></td></tr>
<tr><td>Date :

Interviewer Name:
ID
Supervisor Name
ID</td><td>|__|__| / |__|__| / 2013
Day Month
____
|___|___|___|
____
|___|___|___|</td></tr>
<tr><td>Location ID :</td><td>Country: |________________________|
Region or Province: |______________|
District:
|______________________________|
Village: |________________________|
GPS Coordinates (if available): |_____|</td></tr>
</table>

<u>**Greeting/Explanation**</u>: This questionnaire is in support of an initiative to support smallholder farmers in ………………., to better manage climate-related risks to crop production and post-harvest handling. The project aims to generate innovative methods, technologies and approaches through research so as to enable smallholder farmers to better manage climate-related risks to crop production and post-harvest handling. The results from this research will be shared with the government of ………………………… and its development partners to support planning, implementation and monitoring of farmer climate change risk adaptation activities in the country.

SECTION 1 – DEMOGRAPHICS			
A household (HH) is defined as a group of people who eat daily or at least frequently from the same pot and live in the same compound (or physical location) for at least 3 months. It is possible that they may live in different structures			
1.1	**What** is the sex **of the household head**? Male = 1; 2=Female	|___|	
1.2	What year was the household head born?	|__|__||__|__|	
1.3	What is the marital status of the head of household? 1= Married/single spouse 2= Married/Polygamous 3=Widowed 4=Separated/divorced 5=Cohabiting 6=single/never married 7=Other (specify)	|___|	
1.4	**Can** the household head **read and write**? *(in any language)* Yes = 1 ; No=0	|___|	
1.5	**Is** the head of household functionally **disabled**? Yes = 1; No=0	|___|	
1.6	What is the highest **level of education of the household head**? 0=none 1= Primary 2= Secondary; 3= Tertiary; 4= vocational 5= other	|___|	
1.7	What is the **employment status of the household head**? 1= formally employed; 2=not employed ;3=self-employed 4=fulltime farmer; 5=part-time farmer; 6=Casual/temporal worker; 7=farm labourer 8=student 9=other (specify)	|___|	
1.8	What is the household head's farming status? 1=Full-time farmer; 2=Part-time farmer	|___|	
1.9	How many children and adults are currently living in the HH? 1=male 2=female	Male |___|	Female |___|
	Total	|____|	

1.10	Please give breakdown of the household by the following age ranges		
	0-5 years	|___|	
	6-11 years	|___|	
	12-17 years	|___|	
	18-59 years	|___|	
	Above 60 years	|___|	
1.11	Are there any members who are or were chronically ill in the last 12 months? (Diabetes, BP, TB, HIV etc.) (Give number)	|___|	
1.12	How many members **are fit to work in agriculture** related operations (crop/livestock management)?	Male |___|	Female |___|
1.13	How many **members stay off farm?** (away but rely on this HH e.g. school children in boarding schools)	Male |___|	Female |___|

SECTION 2 – HOUSEHOLD CIRCUMSTANCES		
2.1	Observe and note the general type of construction material of the main dwelling of the HH head? 1= Permanent (bricks, iron/zinc /asbestos/tiles, cement); 2= Semi-permanent (mix of traditional and permanent); 3=Traditional (Mud, grass, dagga and pole); 5=Brick and thatch; 6= other (tent, temporal structure)	|___|
2.2	Observe the geo-physical location of the HH. Where is it located? (refer to page 24) 1=Hill summit; 2=Shoulder;3= Back slope; 4=Toeslope; 5=Flat; 6=Valley	|___|
2.3	What is your main source of energy/fuel for cooking? 1= Fuel wood 2= Animal dung 3= Electricity 4= Gas 5= Coal/charcoal 6= Crop Residues 7=solar; 8=Others (specify)	|___|

SECTION 3 – INCOME, ASSETS AND LIVELIHOOD SOURCES				
3.1	How many members of this HH individually earn/generate income?	Currently |___|	6 months ago |___|	1 year ago and earlier |___|
		3.21 Most important sources	**3.22 Second most important sources**	**3.23 Third most important sources**
3.2	What are the **main sources of livelihood for this household?**	|____|	|___|	|____|
3.3	What are the **main sources of income for this household?**	|____|	|___|	|____|
3.4	How regular/stable is income? 1= temporal/casual; 2= seasonal; 3= stable/permanent 4=erratic	|____|	|___|	|____|

Codes for the sources of income

1= Sale of cereal and pulses (maize, rice, sorghum, millet)
2 = Sale of root crops (cassava, sweet potato, potato)
3= Sale of own grown vegetables or fruits
4= Sale of cash crops (cotton, tobacco, etc.)
5= Sale of animals
6= Sale of animal products (eggs, milk, meat, wool/mohair)
7= Agricultural wage labour (employed for farm work)
8= Non-agricultural labour (employed as store guard, domestic worker, etc.)
9= Self-employment (carpenter, electrician, brick making, etc.)
10= Government employee (teacher, health agent, administration)
11= Private company or NGO employee
12= Irregular daily labour, casual worker
13= Sale of handicrafts
14= Petty trade 15= Brewing
16= Family business (larger scale)
17= Pension
18= Benefit from social cash transfer 19= Remittances
20= Sale of non-timber forest products (wild fruits, insects, mushroom)
21= Mining minerals (gold, chrome…)

3.5	Has your livelihood sources changed in the last 10 to 20 years? 1=Yes	|___|

	2=No						
3.5.1	If yes to 3.5, please indicate how your income livelihood sources have changed and the reasons for the changes						
		Three most important sources of livelihood income (Use codes in 3.4 above)					
		3.5.2 1st Source of income |____|		3.5.3 2nd Source of income |____|		3.5.4 3rd source of income |____|	
		3.5.5 2 yrs ago	3.5.6 10 yrs ago	3.5.7 2 yrs ago	3.5.8 10 yrs ago	3.5.9 2 yrs ago	3.5.11 10 yrs ago
1	Observed change 1= No change 2= Increase 3=Decrease	|____|	|____|	|____|	|____|	|____|	|____|
2	3.5.12 If there is change, please explain the reasons for the observed change						

3.6	Do you have any family members who **have migrated to town/another country?** 0=No; 1=Yes. If no please go to 3.10	|___|

If there is no migrant indicate with 99	**3.7 When** did they leave?	**3.8 Why** did they leave? (main reason)
	1= Less than 1 month ago 2= Less than 6 months ago 3= 6-12 months ago 4= More than 1 year ago	1= Work; 2= Studies; 3= Health treatment; 4= Family reunion; 5=Insecurity/threats; 6= Food insecurity; 7=New opportunities; 8=Family problems; 9=Resettlement; 10= Others (specify)
Migrant No.1	|___|	|___|
Migrant No.2	|___|	|___|
Migrant No.3	|___|	|___|
Migrant No.4	|___|	|___|
Migrant No.5	|___|	|___|
Migrant No.6	|___|	|___|

3.9	Do any of the migrants **send money back?** 0= No; 1= Yes	|___|
3.10	Do you use **credit to finance agricultural activities?** **0= No; 1= Yes**	|___|
3.11	If you use credit what are the **sources?** 1=bank; 2=cash crusaders; 3=co-operative;4=micro finance;5= Government loan scheme;6=Relatives and friends; 7=contract farming 8=other (specify) 99=N/A	|___||___|

3.12 Indicate whether you currently own the following assets 0= No 1= Yes

3.13.1	Fridge	|___|	**3.13.9**	Cultivator,	|___|	**3.13.17**	Water pump	|___|
3.13.2	Sewing machine	|___|	**3.13.10**	Oxcart	|___|	**3.13.18**	Motorbike	|___|
3.13.3	Stove (electric, gas)	|___|	**3.13.11**	Plough	|___|	**3.13.19**	Car, truck,	|___|
3.13.4	Television	|___|	**3.13.12**	Hoe	|___|	**3.13.20**	Tractor	|___|
3.13.5	Satellite dish	|___|	**3.13.13**	Knap sack sprayer,	|___|	**3.13.21**	Investment/ savings	|___|

3.13.6	Radio	|___|	**3.13.14**	Planter	|___|	**3.13.22**	Bank account	|___|
3.13.7	Cell phone	|___|	**3.13.15**	Bicycle	|___|	**3.13.23**	Table, chairs	|___|
3.13.8	Solar panel/Power	|___|	**3.13.16**	Generator	|___|	**3.13.23**	Wheelbarrow	|___|

SECTION 4 – HOUSEHOLD COPING STRATEGIES

4.1 Were there any days in the past 12 months that your household faced difficulties in accessing enough food to eat? 1=yes; 0=No (If no skip to Section 5) |___|

4.2 If Yes, how frequently did your **household** resort to using one or more of the following strategies in order to deal with the food access difficulties during that period?

Coping Strategies		**Frequency** **Never =1** **Seldom=2** **Sometimes** (1-3 days per month)**=3** **Often** (1-2 days per week)=**4** **Daily** (3-6 days a week)**=5**
4.2.1	Skip entire days without eating?	|___|
4.2.2	Limit portion size at mealtimes?	|___|
4.2.3	Reduce number of meals eaten per day?	|___|
4.2.4	Borrow food or rely on help from friends or relatives?	|___|
4.2.5	Rely on less expensive or less preferred foods?	|___|
4.2.6	Purchase/borrow food on credit?	|___|
4.2.7	Gather unusual types or amounts of wild food / hunt?	|___|
4.2.8	Harvest immature crops?	|___|
4.2.9	Produce food through off-season cropping	|___|
4.2.10	Divert seed to food consumption	|___|

4.2.11	Rely on community ‘food-for-work’ programmes?	|___|
4.2.12	Rely on rations from local leadership/NGOs?	|___|
4.2.13	Reduce adult consumption so children can eat?	|___|
4.2.14	Rely on casual labour for food?	|___|
4.2.15	Has your household sold/bartered any household assets to buy food in the past 3 months? 1 = Yes; 2 = No |___| *NB. As a way of coping with difficulties in accessing adequate food*	

Section 5 – Land Holding and land use	

A. LAND HOLDINGS

5.0 For the listed land use systems please indicate access, ownership, land sizes, utilization, and whether they are fenced or not.

	Agricultural Land-use system	**5.1 Do you have any of the listed land-use systems** *0=N* *1=Yes*	**5.2** Main soil type 1=clay 2=loam 3sandy	**5.3 Type of land ownership:** 1= leasehold 2=Freehold 3=Private 4=Communal 5=Traditional allocation by chief 6=Other (specify)	**5.4 Total Area (Ha)**	**5.5 Area currently being used:** 1=0%, 2=25%, 3=50%, 4=75%, 5=100%	**5.6 If underutilized, main reason for underutilization of land.** 1= Lack of money 2= Inadequate labour 3= No markets for produce 4=No reason for producing more 5= Traditional beliefs 6= Lack of animal draught power 7= No inputs; 8= No equipment 9= Other	**5.7 Is your field/ garden protected** 1=Fenced (wire or live fencing) 2=Not fenced 3=Partly fenced
1	Homestead garden	|____|	|____|	|____|	|______|	|____|	|____|	|____|
2	Dryland farming	|____|	|____|	|____|	|______|	|____|	|____|	|____|
3	Irrigation	|____|	|____|	|____|	|______|	|____|	|____|	|____|
4	Wetlands	|____|	|____|	|____|	|_____|	|____|	|____|	|____|
5	Grazing	|____|	|____|	|____|	|_____|	|____|	|____|	|____|
6	Fruit tree plantation	|____|	|____|	|____|	|_____|	|____|	|____|	|____|
7	Private woodlot	|____|	|____|	|____|	|_____|	|____|	|____|	|____|
	Other *(specify)*	|____|	|____|	|____|	|_____|	|____|	|____|	|____|

CHANGES IN WATER AVAILABILITY

	Please indicate any noted changes in the following hydrological features in the last 20 years and the reasons for the changes.					
	Your main sources of water	**5.8** Indicate the time period the water source would last in the given time period Use month, 1=Jan….12=Dec 0=never dry up Note: **start** refers to the earliest month when water is seen to have dried up in the given time period **In Recent 3 years**		**In the last 10-20 years**		**5. 9** If there is change, what is the reason?
		5.8.1 Start (month)	5.8.2 To (month)	**5.8.3**Start (month)	**5.8.4**To (month)	
1	Homestead well	|_____|	|_____|	|_____|	|_____|	
2	Wetland	|_____|	|_____|	|_____|	|_____|	
3	Dam	|_____|	|_____|	|_____|	|_____|	
4	Nearest stream/river	|_____|	|_____|	|_____|	|_____|	
5	Borehole	|_____|	|_____|	|_____|	|_____|	
6	Pool	|_____|	|_____|	|_____|	|_____|	
7	Other	|_____|	|_____|	|_____|	|_____|	

<table>
<tr><th colspan="2"></th><th colspan="6">SECTION 6 ACCESS TO INFORMATION AND USE OF INDIGENOUS KNOWLEDGE SYSTEM</th></tr>
<tr><td>6.0</td><td colspan="7">Please indicate your access to the following information, the sources and adequacy of the information for decision making</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Type of information</td><td rowspan="2">6.1 Do you access information
1=yes 0=no</td><td rowspan="2">6.2 Three main source of information

1=Govt extension
2=radio/television
3=newspapers
4=other farmers
5=relatives/children
6=other Govt dept.
7=NGOs;8= Education Institution 9= Indigenous10=other</td><td rowspan="2">6.3 Rate timeliness of the information
1=good
2=fair
3=poor</td><td rowspan="2">6.4 Rate reliability/adequacy of information for decision making
1= good 2=fair
3=poor</td><td colspan="2">6.5 Do you use Indigenous knowledge for the indicated types of information?</td></tr>
<tr><td>6.5.1 Usage
0=no,
1=traditional leaders
2= Community leaders
3= elders
4= on observation & experience
5=Others</td><td>6.5.2 Reliability

1= good
2=fair
3=poor</td></tr>
<tr><td>1</td><td>Agronomic and post-harvest information</td><td>|___|</td><td>|___||___||___|</td><td>|___|</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>2</td><td>Animal production and health related information</td><td>|___|</td><td>|___||___||___|</td><td>|___|</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>3</td><td>Agricultural commodity markets and prices</td><td>|___|</td><td>|___||___||___|</td><td>|___|</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>4</td><td>Climatic/weather in general</td><td>|___|</td><td>|___||___||___|</td><td>|___|</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>5</td><td>Seasonal forecasts</td><td>|___|</td><td>|___||___||___|</td><td>|___|</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
<tr><td>6</td><td>Daily/3 day</td><td>|___|</td><td>|___||___||___|</td><td>|___|</td><td>|___|</td><td>|___|</td><td>|___|</td></tr>
</table>

	forecasts						
7	Post-harvest handling	|___|	|___||___||___|	|___|	|___|	|___|	|___|

SECTION 7 –CROP PRODUCTION		
7.1	Which is the main factor that **constrains crop production for you?** 1=rainfall; 2=temperature; 3=pests & diseases; 4=soil fertility; 5=labour; 6=access to inputs; 7=lack of knowledge; 8=markets; 9=no idea; 10= lack money 11=other (specify)	|___|

	Variables →	**7.2 What is the main season crop was grown** 1=Summer 2= Autumn 3=Winter 4=Spring 5=All year	**7.3 Area of production (ha)** **Or count for fruit trees****	**7.4 How much did you harvest?** *(write quantity eg 20x50kg bags)*	**7.5 How much of these crops were sold?** *(write quantity eg 20x50kg bags) put zero if did not sell*	**7.6 How much income did you realize from the sales USD equivalent** *put zero if did not sell*	**7.7 How much of these crops do you usually BUY for home use during the year? (Kg)**	**7.8 How much do you currently have in stock? (Production, purchase, gift, food aid, etc.) (kg)**	**7.9 How long will the stocks last for family consumption? (months)** Write 0 if less

														than 1 month
	Crop ↓ Year →	**2011/12**	**2012/13**	**2011/12**	**2012/13**	**2011/12**	**2012/13**	**2011/12**	**2012/13**	**2011/12**	**2012/13**			
1	Maize													
2	Sorghum													
3	Millet													
4	Rice													
5	Wheat													
6	Sunflower													
7	Tobacco													
8	Sugar cane													
9	**Fruit trees													
10	Tea/Coffee													
11	Irish potatoes													
12	Sweet potatoes													
13	cassava													
14	Pigeon Peas													
15	Cowpeas													
16	Bambara													

	Variables →	**7.2 What is the main season crop was grown** 1=Summer	**7.3 Area of production (ha)**	**7.4 How much did you harvest?** *(write quantity eg 20x50kg*	**7.5 How much of these crops were sold?** *(write quantity eg 20x50kg*	**7.6 How much income did you realize from the sales USD**	**7.7 How much of these crops do you**	**7.8 How much do you currently have in**	**7.9 How long will the**

		2= Autumn 3=Winter 4=Spring 5=All year				*bags)*		*bags)* *put zero if did not sell*		**equivalent** *put zero if did not sell*		**usually BUY for home use during the year? (Kg)**	**stock? (Production, purchase, gift, food aid, etc.) (kg)**	**stocks last for family consumption? (months)** Write 0 if less than 1 month
17	Beans													
18	Groundnuts (shelled)													
19	Soya Beans													
20	Vegetables (tomatoes, onions)													
21	Other													

7.10 How long did own harvested staple (cereal or tuber) last you in the last season? |_____| (months)

7.11 In the last 10-20 years? |____| (months)

7.12	For the main staple/ cereal crop you grow did you use the following seed types in 2011/12? **7.12.0** Name of main cereal/staple |___| 1=maize 2=sorghum 3=millets 4=wheat 5=cassava 6= other specify	**7.12.1 Use** Yes=1; No=0	**7.12.2 Source** 1=Self-produced ;2=Government subsidy;3=local shop/dealer ;4= City/Town shop/dealer; 5=cooperative/farmer association; 6=NGO / donation; 7=Gift; 8)Others (specify)
1	local landraces	|____|	|____|
2	improved Open Pollinated Varieties	|____|	|____|
3	commercial hybrids	|____|	|____|
4	retained (hybrid/OPV) seed	|____|	|____|

7.13	In 2011/12 season did your HH use these crop-inputs?	**7.13.1Use** 1= Yes 0=No	**7.13.2 Reason for not using** 1= do not have money ;2= no local agro-dealers;3= access points too far; 4= inputs destroy the soil 5=no information; 6=lack labour 7=other
	animal manure/compost	|____|	|____|
	Inorganic fertilizers	|____|	|____|
	crop chemicals (herbicides/pesticides);	|____|	|____|
	leaf litter	|____|	|____|

7.14	**7.14.1** What are your major reasons/goals for crop farming? in their rank of importance 1= Marketing 2= Consumption 3=Cultural purposes First|___| Second|___| Third |___| *(select applicable, could be more than 1 and you can rank)*	**7.14.3** Do you aspire to increase your scale of production? 1= Yes 0=No |___| If yes proceed to **7.14.4**	If you market, what is your preferred market/buyer for the main marketed crop? **7.14.5 Crop name** **________________** **7.14.6 preferred Market** |____| 1=Hawkers 2= Neighbours 3=Local shops 4=Fresh produce market

			5=Agro- processors 6= Marketing boards 7=Other(s)
	7.14.2 Do you meet your goals for crop farming? 1=yes 0=no |___|	**7.14.4** Explain reason: 1= improved availability of inputs ; 2= firming prices 3=better/more market opportunity 4=increased household needs 5=other |___|	**7.14.7** Explain why? 1=higher prices; 2=prompt payment 3=ready market; 4=proximity 5=other |____|

7.15	Does your HH use the following implements for your farming operations? 1=yes 0=no		Tractor |___|Animal drawn|___|; Hand|___|	
		7.16 Indicate area covered by implement in the 2012/13 season		
	Operational Cost Aspects	**Tractor [_______ha]**	**Animal [________ha]**	**Hand [_________ha]**
7.17.1	Do you own the means of power? 1= Yes 0= No	|___|	|___|	|___|
7.17.2	How much do you pay per hectare- ploughing?	|________|	|_________|	|________|
7.17.3	How much did you pay (cash equivalent) for planting	|________|	|_________|	|________|
7.17.4	How much did you spend on crop weeding	|________|	|_________|	|________|
7.17.5	Crop chemical application Cost	|________|	|_________|	|________|
7.17.6	Harvesting cost	|________|	|_________|	|________|
7.17.7	Fertilizers application	|________|	|________|	|_______|

7.18.0	Do you practice off-rainy season crop production? 1=yes, 0=No |___| **If yes**							
	7.18.1 Which crops do you grow off-season?	**Crops** Yes=1 No=0	**7.18.2** Does the following provide a source of water for your crops?		**Source of water** Yes=1 No=0	**7.18.3** Do you use the following method for conveying water to your crop?		**7.18.4 Water conveyance** Yes=1 No=0
1	Maize	|___|	1	household connection	|___|	1	Bucket	
2	Vegetables (local and exotic)	|___|	2	borehole / hand pump	|___|	2	Treadle pump	|___|
3	Cucurbits (pumpkin, cucumber, butternut, squash)	|___|	3	Hand dug well	|___|	3	Motorized pump	|___|
4	Beans and other legumes	|___|	4	Wetland	|___|	4	Furrow irrigation	|___|
5	Sweet potato	|___|	5	Spring	|___|	5	Residual moisture utilization	|___|
6	Others (specify)	|___|	6	Residual moisture	|___|	6	Drip Irrigation	|___|
		|___|	7	rain harvested water	|___|	7	Others (specify)	|___|
			8	Rivers, lake, stream, dam or ponds	|___|			

7.19	Have there been any changes in your land use systems? 1=Yes 2=No (please refer to 5) if yes proceed to 7.20				|___|
7.20	Please indicate how your use of the following land systems has changed in the last 20 years and the reasons for the changes.				
	Land use system	**Average hectarage (ha) **count for fruit trees**		**7.20.3 Change**	**7.20.4 Reason for change***
		7.20.1 Recent 2 years	**7.20.2** 10-20 years ago	1= increase 2=decrease 3=no change	
1	Wetlands	|_____|	|_____|	|___|	|___|

2	Abandoned/fallowed fields	|_____|	|_____|	|___|	|___|
3	Dryland	|_____|	|_____|	|___|	|___|
4	Fruit tree plantation**	|_____|	|_____|	|___|	|___|
5	Private woodlot	|_____|	|_____|	|___|	|___|
6	Irrigation	|_____|	|_____|	|___|	|___|
7	Homestead garden	|_____|	|_____|	|___|	|___|
8	Grazing	|_____|	|_____|	|___|	|___|
*reasons 1=change in availability 2=Droughts 3=infertility 4=change in market demand 5=economic needs 6= lack of inputs/labour 7=closeness 8= floods 9=other__________					

SECTION 8 –LIVESTOCK	

8 Does the household keep any livestock? **1=** Yes **0=**No |___|

	Livestock Type	**8.1Total Number Owned** **If not put zero**	**8.3 What is the main source of water for each type of livestock?** 1=Dam 2=River 3=Tap water 4=Borehole 5=Vleis/springs 6=well 7=other	**8.4 Do you have adequate water for all livestock categories that you keep in all seasons?** 1=Yes 0=No	**8.5 What is the main environmental challenge greatly affecting livestock production in your area?** 1=Rainfall 2=Temperature 3=Grazing/ feeding 4=Pests & diseases 5 =lack of water 6=Don’t know	**8.6 Explain the main socioeconomic challenge you face for each livestock enterprise.** 1= lack of feed 2= lack of shelter 3=poor extension service 4= lack of markets 5=theft 6=no labour for husbandry 7=Lack of knowledge

						8=other
1	Cattle	|___|	|___|	|___|	|___|	|___|
2	Sheep	|___|	|___|	|___|	|___|	|___|
3	Goats	|___|	|___|	|___|	|___|	|___|
4	Chickens	|___|	|___|	|___|	|___|	|___|
5	Turkeys	|___|	|___|	|___|	|___|	|___|
6	Donkeys	|___|	|___|	|___|	|___|	|___|
7	Pig	|___|	|___|	|___|	|___|	|___|
8	Guinea fowl	|___|	|___|	|___|	|___|	|___|
9	Ducks	|___|	|___|	|___|	|___|	|___|
10	Geese	|___|	|___|	|___|	|___|	|___|
11	pigeons	|___|	|___|	|___|	|___|	|___|
12	Rabbits	|___|	|___|	|___|	|___|	|___|
13	Fisheries	|___|	|___|	|___|	|___|	|___|
14	Other (specify)_	|___|	|___|	|___|	|___|	|___|

8.7	**Indicate sources of grazing/feed for your livestock?** 1=yes 0=No		**8.8 What is your overall assessment of the condition of the rangelands?** 1=good; 2= average; 3= Bad |___|	
1	Communal grazing	|___|	**8.9 Grazing pastures/veld** 1=Very good condition; grass is plenty plus is nutritious 2=Good; plenty grass 3=Fair; fair amount of grass 4=Poor; some grass; bush encroachment 5=Very poor; little grass	**8.10 Browse** 1=Very good condition 2=Good; plenty of shrubs 3=Fair; fair amount of shrubs 4=Poor; some big trees; bush encroachment 5=Very poor; little grass and no
2	Private pastures/leys/fallows	|___|		
3	Crop residues	|___|		
4	Bought-in-feeds	|___|		
5	Agro-processing by-products	|___|		
6	Govt support	|___|		

7	NGO support	|___|	6=I cannot say/do not know	shrubs. 6=I cannot say/do not know.
8	Own crop harvest	|___|		
9	Other specify	|___|	|___|	|___|

8.11	**Please indicate how your herd sizes have changed in the last 20 years and the reasons for the changes.**						
	Livestock	**Average herd sizes**		**8.11.3 Reason for change recent 2 yrs****		**8.11.4 Reason for change 10-20 yrs****	
		8.11.1 Recent 2yrs	**8.11.2** 10-20 yrs ago	Change	Reason	Change	Reason
1	Cattle	|___|	|___|			|___|	|___|
2	Sheep	|___|	|___|			|___|	|___|
3	Goats	|___|	|___|			|___|	|___|
4	Pigs	|___|	|___|			|___|	|___|
5	Donkeys	|___|	|___|			|___|	|___|
6	Fowls(all birds)	|___|	|___|			|___|	|___|
7	Other(specify)	|___|	|___|			|___|	|___|

** reasons for decrease
1=Disease related death 2=Drought related death
3=Sold/slaughtered 4=Theft 5=Paid lobola 6=predation
7= weather related (heat wave, excessive rains)
8=Others

Change
1=increase
2=Decrease
0=no Change

**reasons for increase
1=Purchased (buying in) 2=Natural increase (calving) 3=Donations/gifts 4=Received from lobola 5=good management 6=less livestock diseases 7=others

SECTION 9 – POST HARVEST PRACTICES								
9	**Describe your postharvest handling as guided by the questions below.**							
	Practice → **CROP** ↓	**9.1 Who does most of the harvesting** 1=females 2= males 3= adults only 4 =children only 5=any members of HH 6=hired labour 7. All members	**9.2 At what stage is crop harvested?** 1=before maturity 2=at maturity 3=dry	**9.3 Are there preferences for time of day for harvesting?** 1=anytime 2=morning 3=afternoon 4=evening	**9.4 What main postharvest treatments do you apply to your produce?** 1=traditional curing 2=chemical treatment 3=other 4=none	**9.5 What main type of packaging do you use for storing produce?** 1=woven baskets (plastered) 2=woven baskets (unplastered) 3=woven baskets (partially plastered) 4= bags (e.g. jute, polypropylene) 5=Hermetic bags 6=drums 7=metal silos 8=other 9=no packaging	**9.6 What main type of storage facility do you use for storing your produce?** 1 = Ordinary room, 2 = granary pole only 3= granary pole and mud, 4=woven basket- unplastered 5=woven basket- plastered 6=woven basket – partially plastered 7=metal silos 8=plastic tanks 9 = Brick granary with foundation, 10= Improved granary (Brick, raised off ground and concrete ceiling), 11=below ground structure 12=Others (specify	**9.7 How do you check for moisture content after drying and before storing your cereals and pulses?** 1 = Visual 2 = Texture 3 = Reduction in weight 4 =

								Period in the sun 5 = Instinctive 6 = Biting 7 = Sound 8= Other (specify) 9=Do not check
1	Maize	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|
2	Small grains (sorghum & millets)	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|
3	Pulses (g/nut, cowpeas, beans, bambara etc)	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|
4	Sunflower	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|
5	Roots &tubers crops	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|
6	Horticultural produce	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|

7	Other cash crop (specify)	|___||___|	|___||___||___|	|___||___|	|___|	|___||___||___|	|___||___||___|	|___||___|

9.8	Do you experience **challenges** with your **produce after harvest**? 1= yes, 0=No				|__|
9.9	**What are the major causes if any of post-maturity losses of produce? Indicate the top 3 for each crop below** 1=Field pests (e.g. Termites) 2=storage pests attack 3=Variety of seed 4=Harvesting Methods 5=Methods used for shelling/threshing 6=storage environment 7=Rotting 8=pre-harvest pests 9=Others Specify				
9.9.1	Maize	|__| |__| |__|	**9.9.3**	Pulses (groundnuts, cowpeas, beans, Bambara etc.)	|__| |__| |__|
9.9.2	Small grains (sorghum and millets)	|__| |__| |__|	**9.9.4**	Horticultural Produce	|__| |__| |__|
9.9.5	Root and tuber crops	|__| |__| |__|			

9.10 In the past consumption years did you ever notice a change in appearance, taste and or smell of your produce after some period in storage?
1=yes 0=No |___|

9.10.1 Crop		**9.10.2 change (multiple response)** 1= Colour change, 2 = Taste change, 3 = Smell changes, 4= insect damage holes 5 = No changes Chng1 chng2 chng3	**9.10.3 After what storage duration was change observed?** (number of months)	**9.10.4 Action taken** 1= Food destroyed; 2= given to animals; 3 = Still consumed, 4 = N/A
1	Maize	|___| |___| |___|	|___|	|___|
2	Small grains (millets, sorghum)	|___| |___| |___|	|___|	|___|
3	Groundnuts	|___| |___| |___|	|___|	|___|
4	Bambara nuts	|___| |___| |___|	|___|	|___|
5	Cowpeas	|___| |___| |___|	|___|	|___|
6	Beans	|___| |___| |___|	|___|	|___|
7	Sweet potato	|___| |___| |___|	|___|	|___|

8	Cassava	|___|	|___|	|___|		|___|	|___|
9	Taro	|___|	|___|	|___|		|___|	|___|

9.11	**Please indicate your usage of storage protectants in the last 10-20 years** *(If Protectant material is used ask for sample or container where applicable)*				
9.12					
	Crop	**Protectant used** 0= none 1=Ash 2=commercial stored grain pesticide; 3=plant extracts 4=Animal dung; 5=others		**9.12.3 Have quantities of protectants used changed** 1=increase 2=decrease 0 no change	**9.12.4 Reasons for change** 1= increase in pests 2=pest resistance 3=new species of pests 4=less pests 5= shorter storage period 6=knowledge 7=availability
		9.12.1 currently	**9.12.2 10-20 yrs ago**		
1	Maize	|____|	|____|	|___|	|___|
2	Small grains (millets, sorghum, Rice)	|____|	|____|	|___|	|___|
3	Groundnuts	|____|	|____|	|___|	|___|
4	Bambara nuts	|____|	|____|	|___|	|___|
5	Cowpeas	|____|	|____|	|___|	|___|
6	Beans	|____|	|____|	|___|	|___|
7	Sweet potato/Taro	|____|	|____|	|___|	|___|
8	Cassava	|____|	|____|	|___|	|___|

SECTION 10 – FARMER PERCEPTIONS ON LONG TERM CLIMATIC AND ENVIRONMENTAL CHANGES				
10	**Have you noticed any long-term changes in the following environmental factors over the last 10-20 (1993-2003) years? Please explain.**			
	Factor	**10.1 Noticed change** 1=yes 0=No 2=do'nt know	**If yes, kind of change**	**10.2** Change
1	mean temperature	|___|	*1= Increased 2=Decreased 3=range altered 4= Other*	|___|
2	mean rainfall	|___|	*1= Increased 2=Decreased 3=range altered 4=Other*	|___|
3	frost/snow occurrences	|___|	*1 = Increased 2=Decreased 3= No change 4=Other*	|___|
4	uncontrolled veld fire occurrences	|___|	*1 = Increased 2=Decreased 3=Other*	|___|
5	vegetation cover	|___|	*1= Increased bush encroachment 2=Decreased bush encroachment 3=Reduced herbaceous cover 4=Increased herbaceous cover 5= Other*	|___|
6	wetlands area	|___|	*1= Emergence of wetlands 2= Disappearance of wetlands 3=Other*	|___|
7	pest abundance and seasonality	|___|	*1= Increased pest abundance 2=Decreased pest abundance 3=Other*	|___|
8	pest seasonality	|___|	*1=Changed seasonality of pests 2= New pest species 3=Other*	|___|
9	crop disease prevalence and severity	|___|	*1= Increased prevalence 2=Decreased prevalence 3= increased severity 4= decreased severity 5=Other*	|___|
10	crop disease seasonality	|___|	*1=Changed seasonality of pests 2= New pest species 3= Other*	|___|
11	weed abundance/density	|___|	*1= Increased weed abundance 2=Decreased weed abundance 3= Other*	|___|
12	weed seasonality	|___|	*1= Changed weed seasonality 2=New weed species 3=Other*	|___|

10.3	Please indicate the specific crop pests and weeds that have increased in abundance and prevalence & severity for diseases. (can use local names)		
		10.3.1 That have **increased** in prevalence	**10.3.2** That have **decreased** in prevalence
1	Crop diseases	1|________________| 2 |____________| 3|________________| 4|____________|	1|________________| 2 |________________| 3|________________| 4|________________|
2	Weed species	1|________________| 2 |____________| 3|________________| 4|____________|	1|________________| 2 |________________| 3|________________| 4|________________|
3	Crop pests	1|________________| 2 |____________| 3|________________| 4|____________|	1|________________| 2 |________________| 3|________________| 4|________________|

10.4	**10.4.1** Have you noticed any climatic/weather patterns associated with the following? 1=Yes 0=No	**10.4.2** Explain
1	The periods of peak abundance of weeds |___|	
2	Prevalence &Severity of crop diseases |___|	
3	Crop pests |___|	

10.4.3	What adjustments in your crop farming have you made to these long-term changes?	**10.4.4** Explain
1	Temperature	
2	Rainfall	
3	frost/snow occurrences	
4	uncontrolled veld fire	
5	pest abundance and seasonality	
6	crop disease prevalence, severity and seasonality	
7	weed abundance/density and seasonality	
10.4.5	Have you noticed any other changes in your crop farming over the last 10-20 years? 1= yes; 0=No	**|___|**
10.5.6	Explain what has changed and why you think it has changed?	

SECTION 11 – PERCEIVED FARM-LEVEL ADAPTATION STRATEGIES AMONG SMALLHOLDER FARMERS			
	11.1 REF responses to 10.4.3: Why did you not use any of the following adaptations?	**Did you use adaptation strategy?** *1= yes 0=no*	**11.1Main reasons for not using adaptation.** *1= lack of money, 2= lack of information/knowledge 3= shortage of labour 4= not relevant/necessary 5=Others*
1	Different planting dates	|___|	|___|
2	Adjusted crop varieties	|___|	|___|
3	Moving field to different site	|___|	|___|
	Increased/adopted agroforestry options (fruit trees, soil fertility etc.)	|___|	|___|
4	Changing cultivated acreage	|___|	|___|
5	Changed from crops to livestock	|___|	|___|
6	Changed from livestock to crops	|___|	|___|
7	Leave dryland Farming for home garden only	|___|	|___|
8	Adjust livestock management practices	|___|	|___|
9	use/ increased irrigation	|___|	|___|
10	Changing use of chemicals, fertilizers, manure and pesticides	|___|	|___|
11	Increasing water conservation	|___|	|___|
12	Increased soil conservation	|___|	|___|
13	Use insurance	|___|	|___|
14	Do off-farm income generation activities	|___|	|___|
15	Prayer/Cultural adaptations	|___|	|___|
16	Other adaptations	|___|	|___|

SECTION 12 FARMER PERCEPTIONS ON LONG TERM CLIMATIC AND ENVIRONMENTAL CHANGES ON ANIMALS				
12.0	Have you noticed any change in the following animal parasite and disease related factors in the last 10-20 years? Please explain			
	Factor	**12.1** Noticed change 1=yes 0=No 2=Don't know	**12.2** Kind of change *1=Increased* *2= Decreased 3=Changed seasonality* *4=New species 5=Other*	**12.3** Have you noticed any climate related patterns associated with the change?
1	Animal **parasite**/vector abundance	|____|	|____|	
2	Animal **parasite**/vector seasonality	|____|	|____|	
3	Animal **disease** prevalence, severity	|____|	|____|	
4	Animal **disease** **s**easonality	|____|	|____|	

12.4	Did you make any adjustment to these changes?	**12.4.1** 1=yes 0=No	**12.4.2** Explain adjustment
1	Animal parasite/vector abundance and seasonality	|____|	
2	Animal disease prevalence, severity and seasonality	|____|	

SECTION 13 USE OF AGRICULTURAL TECHNOLOGIES				
	Technology/ Management Practice	**13.1** Do you know this technology? 1=Yes 0=No	**13.2**Have you ever used this technology 1=Yes 0=No	**13.3** Did you use this technology during the 2012/13 season?1=Yes0=No
1	Mulching	|___|	|___|	|___|
2	Water harvesting	|___|	|___|	|___|
3	Irrigation (bucket, treadle pump, drip)	|___|	|___|	|___|
4	Conservation farming	|___|	|___|	|___|
5	Organic nutrient resources (manure, compost)	|___|	|___|	|___|
7	Crop rotation	|___|	|___|	|___|
8	Intercropping	|___|	|___|	|___|
9	Rhizobia inoculation	|___|	|___|	|___|
10	Chemical fertilizer	|___|	|___|	|___|
11	Organic pesticides	|___|	|___|	|___|
12	Inorganic pesticides	|___|	|___|	|___|
13	Herbicides	|___|	|___|	|___|

SECTION 14 Market Risk			
14	How well do you trust local markets in accessing the following in times of need?		
	Market function	**14.1** Rate Availability (1-5) 1=very good 5= very poor	**14.2** Rate Favourable prices (1-5) 1=very good 5=very poor
1	Buying staple cereal	|___|	|___|
2	Buying agricultural inputs	|___|	|___|
3	Selling cereal grain	|___|	|___|
4	Buying livestock	|___|	|___|
6	Selling livestock	|___|	|___|

SECTION 15 HOUSEHOLD EXPENDITURE		
15	How much did your household spend on the following items in 2013 Jan-Dec Malawi Kwacha (MK)	
1	Food items (main staple meal),	|____________|
2	Equipment and tools (including for agriculture bolts, nuts …)	|____________|
3	Agricultural inputs (seed, fertilizer, chemicals, hired labour, draft power etc)	|____________|
4	Construction, house repair	|____________|

Appendix C: Semi-structured questionnaire for Key secondary stakeholders

Code: |__|__| / |__|__| / |__|__| / |__|__|__|

(Government Departments; Private Sector; NGOs; Research/ Education/ Agricultural/ Environmental/ Academic Institutions; Climate change adaptation projects etc.)

Location		
A1.1 **Country:**		
A1.2 **Province/Region:**		
A1.3 **District:**		
A1.4 **Sub-district:**		
A1.5 **Community:**		
Organisational Background		
A2.0 Date of interview:	(dd/mm/yy) |__|__||__|__|__|__|	
A2.1 Name of Respondent	a) Surname: b) First name:	
A2.2 Organisation name: A2.3 Tel: A2.4 Cell: A2.5 Email: A2.6 Location of respondent's office:		
A2.7 What are the primary objectives of your organisation?		
A2.8 Where in the country does your organisation work?		
A2.9 What criteria does your organisation use to decide which geographical areas to work in?		
A2.10 How long has your organisation operated in the focal area?		|1__|6__|years
A2.11 What are the main activities of your organisation in the focal area?		
A2.12 Is addressing the impact of climate change and variability part of your programme goals? Yes, No. If yes how?		
Climate risk awareness/ perceptions		
A3.1 What projected climatic changes have you heard of for this focal area? *[Prompts: Rainfall, Temperature, Wind, Cyclones etc.]*		
A3.2 What are the indicators of these climatic changes?		
A3.3 What are the impacts of these climate changes on livelihoods and natural resources?		
A3.4 What is your source of information about these climatic changes?		

A3.5 In your opinion, have the focal areas experienced significant climate variability in the past 10-20 years? Yes, No

If yes, please describe the climate variability they have experienced.

[Prompts: Precipitation, Temperature, Wind, Cyclones etc.]

A3.6 Do you have any records on climate variables in the focal areas? If so, what data parameters are being recorded, where and over what timeframe?

A3.7 What are the most prevalent climate related hazards and risks in the focal area?

A3.8 Of the above hazards you have mentioned which are the 3 most important, which social groups in the community are most vulnerable and why are they vulnerable, which locations are most vulnerable?

Hazard	Most vulnerable social group/s	Reason for their greater vulnerability	Most vulnerable location in the community

A3.9 Has the occurrence of these hazards changed in the wake of climate change and vulnerability in the last 10-20 years? Yes, No. If yes describe:

Disaster Risk Reduction

A4.1 Please describe the early warning systems supporting the focal communities against disasters?

Traditional leaders, early warning disaster personnel in the villages

[Prompts: Traditional, Central government, Local government, Community, Religious, others]

Administrative level	Describe and name the structures responsible for implementation and monitoring of the early warning system
National	
Provincial/ Regional	
District	
Sub-District	
Community/	

Village	

A4.2 When was the existing early warning system established?……2010……………(year)
A4.3 Does this early warning system function effectively for the focal community? Yes/No/ Not sure, not sure
A4.4 What aspects of the early warning system could be improved and why?
A4.5 Are there Contingency plans for responding to disasters covering the focal community? Yes, No yes
A4.6 If yes, what types of plans are in existence in the contingency plan?
A4.7 Have the contingency plans changed over the last 5-10 years? Yes, No
A4.8 If yes describe **how** the contingency plans have changed
A4.9 Describe **why** the contingency plans have changed
A4.10 Do the contingency plans contain an agriculture and food security component? Yes, No. If yes, Please describe it briefly.
A4.11 Have there been major risk assessments, related to your area of programme, carried out in the focal area in the last 5 years? Yes. No. If yes describe:
A4.12 Has community risk and vulnerability assessment/mapping been conducted in the past 5 years? Yes, No yes
A4.13 If yes to the above, who conducted the assessment/mapping and when?
Adaptation
A5.1 Do you foresee changes in the crop production and post-harvest systems by communities in the focal areas? Yes, No. If yes, what changes are you expecting to see, and please describe why? *[Prompts: reduction in growing of certain crops, abandoning certain crops, increase in production of certain crops, us of adaptable techniques etc.]*
A5.2 Which of the changes you expect to see in A5.1 are in response to climate change & variability?
A5.3 Which crops or agricultural farming systems are most at risk from climate change and variability in the focal areas?
A5.4 Are communities in the focal areas undertaking adaptive measures in response to climate change & variability? Yes. No. A5.4.1 If yes, please describe the adaptations being taken by communities: *[Prompts: Appropriate varieties, Conservation and climate smart agriculture, Cover crops,*

Mulching, production in alternative seasons, water harvesting, adaptive cropping practices, adjustment to planting time, improved processing and storage, improved marketing systems, livelihood diversification, migration]
A5.5 What adaptations to climate risks and changes would you like to see the community making?
A5.6 What challenges do communities in the focal area face in adapting their crop production and postharvest systems to climate change & variability? *[Prompts: Lack of knowledge and skills; traditional beliefs; lack of money; labour of labour; the systems are not effective]*
Capacity Building in Climate Change Adaptation
A6.1 What actions or measures do you think should be undertaken to support communities in the focal area at high risk from climate change & variability to adapt their crop production and post-harvest handling to this phenomenon?
A6.2 Which institutions or organizations, involved in agriculture and climate risk adaptation activities does your organization regularly collaborate with?
A6.3 Are you aware of your country's NAPA (National Adaptation Programme of Action)? Y/N If yes, how does it influence your activities?
A6.4 What are your organisation's capacity building needs regarding climate change adaptation work? A6.4.1 What documented concrete plans do you have for meeting these needs? Are these plans being implemented yet, and if not why not?
A6.5 What climate related capacity building activities (of the focal community members and other stakeholders) is your organisation currently implementing?
N.B. Ask for copies and details of supporting documents relevant to climate risk management.

Appendix D: Semi-structured questionnaire for Community key informants

(Councillors, Elders, Extension,, Religious leaders, Teachers)

Location
B0. Date of interview: (dd/mm/yy) |__|__|/|__|__|/|__|__|
B1.1 Name of community/village
B1.2 GPS Coordinates
B1.3 Sub-District *B1.4 District* *B1.5 Province/Region* *B1.6 Country*
B1.7. Name of interviewer:
B1.8 Name of Respondent: Surname: First name: B1.9 Role in the community: B1.10 Sex: B1.11 Cell/mobile no:
Community/Village background information
B2.1 Please tell us briefly about the history of this community/ village? *[Prompts: when was it established, how many households/ people, what is the meaning and origin of the village name]*
Vhat leadership structures exist in this community/ village? *[Prompts: Traditional inherited ; Elective at community level; appointed]*
B2.3 What are the migration/ immigration trends and patterns in this community (capture: temporal (e.g. temporary or permanent), scale, and the reasons why)?
B2.4 In your opinion, how has migration/emigration changed the risk profile of the community? Describe

Livelihoods

B3.1 What are the general livelihoods in the focal area? Which of these are the 3 most important livelihoods in the focal area?
B3.2 How have livelihoods in the focal area changed, and is it related to climate risks?
B3.3 What social services do people in the focal area have ready access to? What are the constraints (in terms of goods and services)? *[Prompts: clinic, schools, inputs storage shed, crop marketing depot, Disaster Shelter, dipping tank, bus routes, mobile networks, banks, savings schemes, agricultural input suppliers]*
B3.4 What natural products/resources and services do people in the focal area have ready access to? What are the constraints (in terms of goods and services)? *[Prompts: river, lake, dam, borehole, forest, communal rangeland]*
B3.5 What are the important modes of communication in the community/village (order of importance? *[Prompts: mobile networks, TV; radio, internet, newspapers, word of mouth, others (indicate)]*
Climate change and variability awareness
B4.1. Have there been any changes in temperature in the focal area? *[in the last 10-20 years]*. Please provide details, including about what impacts this has had on natural resources and social constructs.
B4.2 Have there been any changes in rainfall in the focal area? *[in the last 10-20 years]*. Please provide details, including about what impacts this has had on natural resources and social constructs.
B4.3 Have there been any notable changes in other climatic factors in the focal area? *[in the last 10-20 years]* Please provide details and records if any.
B4.4 What are the most prevalent climate related hazards and risks in the focal area?
B4.5 Have these hazards increased in the last 20 years. Yes/ No

B4.5.1 If yes, describe how they have changed?
B4.6 What adjustments in farming have the community made to respond to the long-term shifts in temperature? Please list below:
B4.7 What adjustments in farming have the community made to respond to the long-term shifts in rainfall pattern or amounts? Please list below:
B4.8 How does the community receive climate information, and from where?
B4.9 What evidence is there for greater awareness of environmental changes due to climate change?
Institutional Capacity/ Mapping
B5.1 Which institutions and organisations are currently supporting communities in the focal area to adapt agriculture to climate change & variability? And in what ways?
B5.2 Which socio-economic groups are these institutions/organisations in B4.1 above targeting? *[Prompts: Everyone, Vulnerable, Youths, Women, Elderly, Disabled, Orphans, others]*
B5.3. What programmes/activities are the institutions and organisations in B4.1 currently implementing in the focal area to help communities adapt to climate change & variability?
B5.4 In your opinion are the institutions you mentioned in B4.1 adequately addressing the needs of the focal communities to adapt to climate change and variability? Yes, No
B5.5 If No, please explain where the challenges are and what should be done for improvement:
B5.6 Which local and non-local institution/organizations do you think should be involved in supporting communities in the focal area to adapt to climate variability? Why?
B5.7 What rules and regulations have impacted on agriculture *(including production and postharvest)* and natural resources in this community? Please explain: *[Note: rules and regulations refers to any policies, laws or strategies]*

B5.8 What are the community leaders doing to help make agriculture and natural resources more resilient to climate risks in this community?

Appendix E: Multivariate analysis for grain protectants

Multivariate analysis of variance (MANOVA) of the main effects of storage condition, storage facilities and storage duration on the combined dependent variables

Summary: Grain protectants

	Df	Pillai	approx F	num Df	den Df	Pr(>F)	
tempfac	2	0.45388	13.9929	6	286	5.831e-14	***
treatfac	5	0.99522	14.2969	15	432	< 2.2e-16	***
timefac	3	1.08450	27.1763	9	432	< 2.2e-16	***
tempfac:treatfac	10	0.34716	1.8845	30	432	0.003718	**
tempfac:timefac	6	0.94579	11.0499	18	432	< 2.2e-16	***
treatfac:timefac	15	1.20446	6.4397	45	432	< 2.2e-16	***
tempfac:treatfac:timefac	30	1.07696	2.6882	90	432	1.138e-11	***
Residuals	144						

Response Damaged grain by number

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	47.4	23.69	13.1581	5.645e-06	***
treatfac	5	2291.4	458.28	254.5173	< 2.2e-16	***
timefac	3	3553.5	1184.51	657.8410	< 2.2e-16	***
tempfac:treatfac	10	35.3	3.53	1.9632	0.0414666	*
tempfac:timefac	6	49.3	8.21	4.5597	0.0002892	***
treatfac:timefac	15	1319.9	87.99	48.8673	< 2.2e-16	***
tempfac:treatfac:timefac	30	83.8	2.79	1.5504	0.0470213	*
Residuals	144	259.3	1.80			

Response: Grain weight loss

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	2.728	1.3638	1.6245	0.2006	
treatfac	5	80.880	16.1759	19.2688	1.184e-14	***
timefac	3	66.761	22.2537	26.5087	1.034e-13	

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
***						
tempfac:treatfac	10	7.961	0.7961	0.9483	0.4913	
tempfac:timefac	6	7.351	1.2252	1.4595	0.1962	
treatfac:timefac	15	47.889	3.1926	3.8030	1.141e-05	***
tempfac:treatfac:timefac	30	19.747	0.6582	0.7841	0.7791	
Residuals	144	120.886	0.8395			

Response Live *Prostephanus truncatus*

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	67.34	33.67	13.1519	5.675e-06	***
treatfac	5	787.93	157.59	61.5523	< 2.2e-16	***
timefac	3	1195.81	398.60	155.6938	< 2.2e-16	***
tempfac:treatfac	10	120.60	12.06	4.7107	7.966e-06	***
tempfac:timefac	6	210.32	35.05	13.6920	2.871e-12	***
treatfac:timefac	15	1575.52	105.03	41.0262	< 2.2e-16	***
tempfac:treatfac:timefac	30	338.84	11.29	4.4117	7.885e-10	***
Residuals	144	368.67	2.56			

Response Dead *Prostephanus truncatus*

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	5.78	2.89	1.7577	0.176112	
treatfac	5	660.83	132.17	80.4169	< 2.2e-16	***
timefac	3	1780.11	593.37	361.0366	< 2.2e-16	***
tempfac:treatfac	10	26.56	2.66	1.6158	0.107549	
tempfac:timefac	6	34.67	5.78	3.5155	0.002823	**
treatfac:timefac	15	516.39	34.43	20.9465	< 2.2e-16	***
tempfac:treatfac:timefac	30	93.00	3.10	1.8862	0.007321	**
Residuals	144	236.67	1.64			

Response Total *Prostephanus truncatus*

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	70.9	35.45	8.9660	0.0002139	***
treatfac	5	147.1	29.43	7.4436	3.077e-06	***

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
timefac	3	4708.1	1569.37	396.9368	< 2.2e-16	***
tempfac:treatfac	10	159.7	15.97	4.0382	6.748e-05	***
tempfac:timefac	6	199.1	33.19	8.3946	8.198e-08	***
treatfac:timefac	15	2674.4	178.30	45.0960	< 2.2e-16	***
tempfac:treatfac:timefac	30	399.0	13.30	3.3637	6.217e-07	***
Residuals	144	569.3	3.95			

Response: Moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	192.174	96.087	2500.0250	< 2e-16	***
treatfac	5	0.391	0.078	2.0351	0.07714	.
timefac	3	9.218	3.073	79.9450	< 2e-16	***
tempfac:treatfac	10	0.377	0.038	0.9804	0.46317	
tempfac:timefac	6	72.870	12.145	315.9943	< 2e-16	***
treatfac:timefac	15	0.659	0.044	1.1428	0.32407	
tempfac:treatfac:timefac	30	0.964	0.032	0.8362	0.71009	
Residuals	144	5.535	0.038			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix F: Multivariate analysis of variance for storage facilities

Multivariate analysis of variance (MANOVA) of the main effects of storage condition, storage facilities and storage duration on the combined dependent variables

Summary: Storage facilities

	Df	Pillai	approx F	num Df	den Df	Pr(>
tempfac	2	0.45388	13.9929	6	286	5.831e-
treatfac	5	0.99522	14.2969	15	432	< 2.2e-
timefac	3	1.08450	27.1763	9	432	< 2.2e-
tempfac:treatfac	10	0.34716	1.8845	30	432	0.0037
tempfac:timefac	6	0.94579	11.0499	18	432	< 2.2e-
treatfac:timefac	15	1.20446	6.4397	45	432	< 2.2e-
tempfac:treatfac:timefac	30	1.07696	2.6882	90	432	1.138e-

Residuals	144					

Response Damaged grain by number

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	115.48	57.74	46.7820	1.445e-14	***
treatfac	3	2352.91	784.30	635.4610	< 2.2e-16	***
timefac	3	1274.40	424.80	344.1835	< 2.2e-16	***
tempfac:treatfac	5	102.81	20.56	16.6597	1.504e-11	***
tempfac:timefac	6	47.48	7.91	6.4110	1.246e-05	***
treatfac:timefac	9	1336.93	148.55	120.3566	< 2.2e-16	***
tempfac:treatfac:timefac	15	64.90	4.33	3.5056	0.0001058	***
Residuals	88	108.61	1.23			

Response: Grain weight loss

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	10.790	5.395	11.6140	3.340e-05	***
treatfac	3	146.888	48.963	105.4050	< 2.2e-16	***
timefac	3	82.872	27.624	59.4678	< 2.2e-16	***
tempfac:treatfac	5	19.307	3.861	8.3125	1.809e-06	***
tempfac:timefac	6	12.387	2.065	4.4445	0.0005667	***
treatfac:timefac	9	68.700	7.633	16.4326	1.699e-15	***
tempfac:treatfac:timefac	15	27.620	1.841	3.9640	2.043e-05	***
Residuals	88	40.878	0.465			

Response: Live *Prostephanus truncatus*

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	9.36	4.682	1.0388	0.3582	
treatfac	3	428.37	142.789	31.6775	5.571e-14	***
timefac	3	433.58	144.525	32.0627	4.235e-14	***
tempfac:treatfac	5	29.15	5.830	1.2933	0.2741	
tempfac:timefac	6	18.72	3.119	0.6920	0.6566	
treatfac:timefac	9	765.59	85.065	18.8716	< 2.2e-16	***
tempfac:treatfac:timefac	15	86.45	5.764	1.2786	0.2328	
Residuals	88	396.67	4.508			

Response: Dead *Prostephanus truncatus*

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	1.82	0.91	0.7474	0.47657	
treatfac	3	492.07	164.02	134.4799	< 2e-16	***
timefac	3	1388.63	462.88	379.5010	< 2e-16	***
tempfac:treatfac	5	7.81	1.56	1.2814	0.27912	
tempfac:timefac	6	11.73	1.96	1.6032	0.15570	
treatfac:timefac	9	330.56	36.73	30.1127	< 2e-16	***
tempfac:treatfac:timefac	15	31.33	2.09	1.7126	0.06269	.
Residuals	88	107.33	1.22			

Response: Total Prostephanus truncatus

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
tempfac	2	5.83	2.92	0.4668	0.6286
treatfac	3	7.01	2.34	0.3741	0.7719

timefac	3	2820.08	940.03	150.4044	<2e-16	***
tempfac:treatfac	5	16.83	3.37	0.5387	0.7465	
tempfac:timefac	6	36.62	6.10	0.9767	0.4459	
treatfac:timefac	9	1421.61	157.96	25.2730	<2e-16	***
tempfac:treatfac:timefac	15	52.27	3.48	0.5575	0.8991	
Residuals	88	550.00	6.25			

Response: Grain moisture content

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
tempfac	2	31.759	15.8795	160.6201	< 2.2e-16	***
treatfac	3	1.974	0.6580	6.6560	0.0004203	***
timefac	3	11.269	3.7563	37.9944	7.597e-16	***
tempfac:treatfac	5	19.245	3.8491	38.9332	< 2.2e-16	***
tempfac:timefac	6	13.672	2.2787	23.0488	3.558e-16	***
treatfac:timefac	9	2.362	0.2625	2.6549	0.0090249	**
tempfac:treatfac:timefac	15	7.790	0.5193	5.2532	2.382e-07	***
Residuals	88	8.700	0.0989			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix G: Warehouse receipt system and community grain bank management questionnaire

SURVEY TO ASSESS THE TECHNICAL AND INSTITUTIONAL ASPECTS OF THE WAREHOUSE RECEIPT SYSTEMS AND COMMUNITY GRAIN BANKS AS ADAPTIVE STRATEGIES FOR MANAGING GRAIN POSTHARVEST LOSSES: MANAGEMENT COMMITTEE			
A. IDENTIFICATION INFORMATION			
		Date of the interview: / /2015	
I	GPS Coordinates:	X	Y
II	Name of interviewer:	Surname:	First name:
III	Actual name of the storage system		
IV	Name of district where the storage system is located:	[1] Zomba [2] Balaka [3] Dedza [4] Lilongwe [5] Mchinji [6] Other (specify)	
V	Estimate distance from the storage system to the interviewee location (in km)		
VI	Interviewee ID number		

B. GREETING/BRIEFING		
This discussion is part of an initiative to support (Non material) smallholder farmers in Shire Valley to better manage climate-related risks to postharvest handling. The project aims to bring technologies and approaches through collective learning processes. The results from this research will be shared with the Government of Malawi to support its planning, implementation and monitoring of farmer climate change risk adaptation activities in Malawi. Are you happy to discuss storage system (WRS or CGB) with us? All your responses will be anonymized		
C. INTERVIEWEE CHARACTERISTICS		
No.	**Question**	**Responses**
1	Name of interviewee	Surname: First name:
2	Position of interviewee	[1] Member [2] Chairman [3] Secretary [4] Treasurer [5] committee member [6] Other (specify)
3	Sex	[1] Male [2] Female
4	Age (in years)	[1] 15-35 [2] 36-56 [3] 57- 77 [4] Over 78
5	What is the level of education of the interviewee?	[1] Never attended [2] Primary [3] Secondary [4] Tertiary

6	Household size (number of people living in the household for at least 3 months, including children and servants)	___________________people
7	On average what is the total amount of monthly income of your household?	[1] Less than MK5,000 [2] MK5,000 – MK10,000 [3] MK11,001 – MK20,000 [4] MK21,000 – MK40,000 [5] More than MK41,000
D. GENERAL FARMING INFORMATION AND STORAGE SYSTEM		
No.	**Question**	**Responses**
8	Name of Agricultural Development Division (ADD) where the storage system is located	[1] Machinga [2] Blantyre [3] Shire Valley [4] Lilongwe [5] Kasungu
9	Type of storage system:	[1] Warehouse receipt systems (WRS) [2] Community grain banks (CGB)
10	Among the crops grown, which crops are deposited in the storage system	[1] Maize [2] Rice [3] Pigeon pea [4] Sorghum [5] Cowpea [6] Common beans [7] Finger Millet [8] Pearl Millet [9] Other (specify)

11	What quantity of maize grain was produced in the 2014/15 growing season (in metric tons)?	[1] < 1 [2] 1-3 [3] 4-6 [4] 7-10 [5] > 11
12	What quantity of maize grain was deposited in the storage system in 2014/15 growing season (in metric tons)?	[1] < 1 [2] 1-2 [3] 3-5 [4] 6-10 [5] > 11
13	How is the grain deposited at the storage system?	[1] Individually [2] Farmer group [3] Cooperative [4] Association [5] Other (specify)
14	What quantities of grain are allowed for individual depositing (in metric tons)?	Minimum____________________Maximum_________
15	What quantities of grain are allowed for group depositing (in metric tons)?	Minimum____________________Maximum________
16	Who owns the storage system?	[1] Community members [2] Individual operator [3] Cooperative [4] Farmer group [5] NGO (provide name) [6] Other (specify)
17	Which year did the storage system start operating in the area?	

18	What was the main purpose of establishing the storage system?	[1] To assist farmers with storage space for excess produce [2] Provide better market access for their grain [3] Provide a reliable grain supply during hunger period [4] To enable farmers to access capital at harvest time and safely store their produce for sale later in the season when prices are higher [5] Don't know [6] Other (specify)
19	What is main reason for depositing the grain to the storage system?	[1] Cash [2] Consumption [3] Both cash and consumption [4] Food security [5] To avoid losses [6] Other (Specify)
20	What criteria were used for selection of site for the storage system?	[1] Proximity to farmers [2] Number of farmers [3] Grain production levels [4] Proximity to urban centre for sales [5] Other (specify)
21	What membership criteria exist for famers wanting to become members of this storage system?	[1] Quantity of grain [2] Member of the community/village [3] Individual interest [4] Payment of membership fee [5] Other

22	How many farmers or members belong to the storage system?	Males: _______________ Females_________
23	What is the composition of the management committee?	Males: _______________ Females_________
24	Are banks or MFIs involved in the implementation of the storage system	[1] Yes [2] No
25	If yes to question # 24 above, which bank or banks are involved	[1] Malawi Savings Bank [2] National Bank [3] NBS Bank [4] Standard Bank [5] Opportunity International Bank of Malawi [6] First Merchant Bank [7] INDE Bank [8] FDH Bank [9] ECO Bank [10] Other (specify)
26	What was the minimum and maximum value of grain upon depositing (MK per 50kg bag)?	Minimum (MK)_______________ Maximum (MK) _____________
27	What was the minimum and maximum value of grain upon selling or withdrawal (MK per 50kg bag)?	Minimum (MK)_______________Maximum (MK) _____________
28	If banks are involved in the storage system, what is the interest rate paid to the banks [%]?	
29	What is the maturity period?	
30	What is the repayment frequency [per year]?	
31	Which month of the year can one take the loan?	Month___________________Anytime_______________

32	What type of collateral is required?	[1] Grain [2] Land [3] House [4] Other (specify)
33	How often can one withdraw the grain?	[1] Weekly [2] Monthly [3] 3 months [4] 4 months [5] 6 months [6] anytime [7] Other (specify)
34	Under what circumstances is a member allowed to withdraw grain?	
35	Can the family withdraw on behalf of a member?	[1] Yes [2] No
36	Can non-members buy the grain?	[1] Yes [2] No
37	Does the storage system cater for social welfare cases?	[1] Yes [2] No
38	What is the longest period grain can be kept in a storage system? (months)	
E. POSTHARVEST LOSSES AND MANAGEMENT		
No.	**Question**	**Responses**
39	Do you experience any postharvest losses on the stored crops in the storage system?	[1] Yes [2] No
40	If yes to question # 39, what are the causes of post-harvest losses (Tick appropriate boxes –may have multiple answers)	[1] Rodents [2] LGB [3] Moulds [4] Maize weevil [5] Termites [6] Rain damage during storage [7] Theft [8] Other (specify)
41	How are the postharvest losses controlled?	

42	Equipment used for pest control	[1] Tarpaulin [2] Sprayers [3] Assorted fumigation equipment [4] Pallets [5] Pesticides [6] Weighing equipment [7] General warehouse equipment [8] Other (specify)
43	Where do you procure the equipment mentioned in Question 44	[1] ATC [2] Farmers Organisation [3] Chemicals & Marketing [4] Others (specify)
44	What is the capacity of the storage system? (MT)	[1] 1-20 [2] 21-50 [3] 51-100 [4] > 101
45	What data are recorded at the time of depositing grain?	[1] Quality [2] Quantity [3] Name of crop [4] date deposited [5] Name of farmer [6] Other (specify)
46	Who does the recording?	[1] Members of the storage system [2] Hired [3] Other (specify)
47	Sex of recorder	[1] Male [2] Female [3] Both
48	If quality is recorded, what are some of the factors considered under quality?	
49	If quality factors are recorded, how are they measured?	
50	Are there any management activities associated with the	[1] Yes [2] No

	deposited grain (commodities)?	
51	If yes to question # 50, what are the activities?	[1] Grading [2] Drying [3] Pest control [4] Repacking [5] Other (specify)
52	Who does the pest control activities?	[1] Members of the storage system [2] Hired [3] Other (specify)
53	If the answer to question # 52 above is hired, please provide the name of the company	
54	If the answer to question # 52 is done by members of the storage system, what is the sex of pest controller?	[1] Male [2] Female [3] Both
55	What is the frequency of pest control per storage season?	[1] Monthly [2] Bi-monthly [3] Quarterly [4] Semi-annually [5] Annually
56	What is the basis for the treatment?	[1] Fixed calendar treatment [2] Regular inspections [3] Both
57	Are there any formal inspection conducted?	[1] Yes [2] No
58	If yes to question # 57, how often per season?	
59	If treatment is repeated, is it done using the same pesticide?	[1] Yes [2] No

60	Which chemicals are used in controlling pests?	[1] Fungicides [2] Insecticides [3] Fumigants [4] Rodenticides
61	Mention the trade names of such chemicals used? [*ask for the containers to confirm identity of the pesticides*]	
62	Is the frequency of application the same for all the pesticides?	[1] Yes [2] No
63	What kind of personnel provide labour to the storage system activities such as bagging, stacking, offloading during depositing, loading during withdraw or sales?	[1] Members of the system [2] Hired labour
64	Do you deposit any maize variety at the storage system?	[1] Yes [2] No
65	If yes to question # 64, which maize varieties are deposited?	[1] Local [2] Hybrid [3] Composite [4] re-cycled
66	When do you start receiving grains from farmers?	[1] March [2] April [3] May [4] June [5] July [6] Aug [7] Other (specify).................................
67	What moisture content of maize is accepted at the WRS or CGB?	[1] <13% [2] >13% [3] Other (specify)
68	Which method do you use for checking moisture content of the grain?	[1] Using oven method [2] Using moisture meter [3] Other (specify)
69	Is the grain re-handled after depositing?	[1] Yes [2] No

70	If the answer is yes to question # 69 above, how is the grain rehandled? (there could be multiple responses)	[1] Graded [2] winnowing [3] Re-drying [4] Re-bagging [5] Other (specify)
71	Is the grain from different farmers mixed together or kept separate?	[1] Mixed [2] Kept separately [3] Other (specify)
72	At what point do you start selling the grain?	[1] When the prices are good [2] When there is demand [3] Other (specify)
73	Which months do you typically start selling the grain?	[1] June [2] July [3] Aug [4] Sept [5] Oct [6] Nov [7] Dec [8] Jan [9] Other (specify)...................
74	Who are the main buyers or beneficiaries of the grain (*May have multiple responses*)?	[1] Producers [2] Farmers [3] Traders [4] Processors [5] Exporters [6] Govt agencies [7] NGOs [8] Vulnerable households
75	How frequently do buyers or beneficiaries come to buy or get grain from the storage system	[1] Monthly [2] Bi-monthly [3] Quarterly [4] Semi-annually [5] Annually [6] Other (specify)
76	What are the causes of postharvest losses (Tick appropriate boxes –may have multiple answers)	[1] Rodents [2] LGB [3] Moulds [4] Maize weevil [5] Termites

77	Do extension workers from the government or non-governmental organisations supply you with information on the risks of postharvest losses and how you can manage them? (*tick one)*	[1] Yes [2] No
78	Are you satisfied with the extension workers assistance rendered to help in the management of postharvest losses? (tick one)	[1] Very satisfied [2] Satisfied [3] Neither satisfied nor unsatisfied [4] Unsatisfied [5] Very unsatisfied
79	What dangers do postharvest losses pose to your maize? (Tick appropriate box – may have multiple response)	[1] Lower price [2] Lowers quality [3] Lower quantity [4] Other (specify)
80	Have you ever experienced LGB attack in this storage system?	[1] Yes [2] No
81	If yes to question # 80, when (*specify month and year*)?	
82	How did you respond?	
83	Was the response effective?	[1] Yes [2] No
84	If no to question # 83, what do you think needs to be done to control this pest effectively in your system?	

85	If you were to sum up postharvest losses of maize caused by all factors (*including larger grain borer*), how many units of your local unit of measurement have you lost?	
86	Who shoulders the cost for the lost grain?	[1] Depositor [2] WRS/CGB operators [3] Other (specify)
87	What are the advantages of depositing grain at the WRS or CGB?	[1] Access to market links [2] Better prices [3] Reduce PHL [4] Increases grain availability [5] Other (specify)
88	What are the costs incurred by the depositor?	[1] Storage [2] Re-handling costs [3] Pest control [4] Other (specify)
89	What safety mechanism have you put in place to ensure grain safety in storage system?	[1] Padlock [2] Security guard [3] Fire extinguisher [4] Other (specify)
90	What challenges do you face?	
91	How do you address them?	
92	Any suggestions for improved service delivery?	
F.TRAINING		

93	Have you ever been trained with regards CGB or WRS?	[1] Yes [2] No
94	Which topics were you trained on?	[1] Storage pest management [2] Grain management [3] Storage pesticide management [4] Marketing [5] Storage system management [6] Other (specify)
95	Duration of training? (In days)	
96	Quality of training (Level of satisfaction)	[1] Satisfied [2] Not satisfied
97	Who provided the training?	[1] Extension staff [2] Research staff [3] NGO staff [4] Other (specify)
98	How often? (*state number of times per year*)	
99	When was the last training held? (*state month and year*)	
100	Are there any areas where further training is required?	[1] Yes [2] No
101	If yes to question # 100, state the areas/topics where further training is required	
G. CLIMATE RISKS AND ROLE OF WRS AND CGB IN BUILDING COMMUNITY RESILIENCE TO THESE RISKS		

102	What are the main climate-related risks faced by the local community?	
103	Have the frequency or severity of these climate-related risks changed over the last 20 to 30 years? If yes, provide details	
104	Does this storage system impact on these climate-related risks in any way? If yes, please provide full details	
105	What changes do this storage system (structure, management, role etc) could be made to better help communities become more resilient to climate-related hazards?	
106	Why do you think these changes are not already being implemented?	
107	Do all members of the community benefit from the storage system? Explain who does and why, and who doesn't and why they don't?	
108	Does the storage system have any other benefits for the community that you have not already mentioned? If yes, what.	

109	Are there any negative effects related to the storage systems which you have not already mentioned? If yes, what	

Any other relevant comments?

THANK YOU FOR YOUR PRECIOUS TIME

Appendix H: Warehouse receipt system and community grain bank beneficiaries questionnaire

SURVEY TO ASSESS THE TECHNICAL AND INSTITUTIONAL ASPECTS OF THE WAREHOUSE RECEIPT SYSTEMS AND COMMUNITY GRAIN BANKS AS ADAPTIVE STRATEGIES FOR MANAGING GRAIN POSTHARVEST LOSSES: BENEFICIARY FARMERS		
A. IDENTIFICATION INFORMATION		
		Date of the interview: / /2015
I	Which storage system are you affiliated to?	[1] CGB [2] WRS

II	What is the actual name of the storage system?	
III	Name of district where the storage system is located:	[1] Zomba [2] Balaka [3] Dedza [4] Lilongwe [5] Mchinji [6] Other specify

B. GREETING/BRIEFING

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C. INTERVIEWEE CHARACTERISTICS

No	Question	Responses
1	Name of interviewee	Surname: First name:
2	Position of interviewee	[1] Member [2] Chairman [3] Secretary [4] Treasurer [5] committee member [6] Other

		(specify)
D. GENERAL FARMING INFORMATION AND STORAGE SYSTEM		
3	Name of Agricultural Development Division (ADD) where the storage system is located	
4	Type of storage system:	
5	Size of your farm (in hectares[ha])	
6	Name of crops grown	
7	Among the crops grown, which crops are deposited to the storage system?	
8	Quantity of maize grain produced in 2013/14 growing season (in metric tonnes)?	
9	Quantity of maize grain deposited to the storage system using one receipt (in metric tonnes)	
10	How do you deposit the grain at the storage system? Checklist: Individually, Farmer group, Cooperative, Association, Other (specify)	
11	What is the minimum quantity allowed for depositing (in metric tonnes)?	

12	Who owns the storage system? Checklist: Community members, Individual operator, Cooperative, Farmer group, NGO (provide name), Other (specify)
13	Which year did the storage system started operating in the area?
14	What was the main purpose of establishing the storage system? Checklist: To assist farmers with storage space for excess produce, provide better market access for their grain, provide a reliable grain supply during hunger period, to enable farmers to access capital at harvest time and safely store their produce for sale later in the season when prices are higher, don't know
15	What is main reason for depositing the grain to the storage system?
16	What membership criteria exist for famers wanting to become members of this storage system? Checklist: Quantity of grain, member of the community/village, individual interest, payment of membership fee
17	How many farmers are members of the storage system?
18	Are banks or MFIs involved in the implementation of the storage system? If yes what is their role?

19	If yes to question # 18, which bank or banks are involved? Checklist: Malawi Savings Bank, National Bank, NBS Bank, Standard Bank, Opportunity International Bank of Malawi, First Merchant Bank, INDE Bank, FDH Bank, ECO Bank
20	What the minimum and maximum value of grain upon depositing (MK per 50kg bag)?
21	What the minimum and maximum value of grain upon selling or withdrawal (MK per 50kg bag)?
22	If banks are involved in the storage system, what is the interest rate paid to the banks?
23	What is the maturity period?
24	What is the repayment frequency?
25	Which month of the year can one take the loan (mention the month)?
26	What type of collateral is required?
27	How often can one withdraw the grain?
28	Under what circumstances is a member allowed to withdraw grain?
29	Can the family withdraw on behalf of a member?
30	Can non-members buy the grain?

31	Does the storage system cater for social welfare cases?
32	What is the longest period grain can be kept in a storage system? (months)
E. POSTHARVEST LOSSES AND MANAGEMENT	
33	Do you experience any postharvest losses on the stored crops in the storage system?
34	If yes to question # 33, what are the causes of post-harvest losses (Tick appropriate boxes –may have multiple answers) Checklist: Rodents, LGB, Moulds, Maize weevil, Termites, rain damage during storage, theft
35	How are the losses controlled?
36	What equipment is used for pest control?
37	What other equipment is available to the storage system?
38	Where do you procure the equipment mentioned in question # 44
39	What is the capacity of the storage system? (Metric tonnes)
40	What data are recorded at the time of depositing grain?
41	If quality is recorded, what are some of the factors considered under quality?
42	If quality factors are recorded, how are they measured?

43	Are there any management activities associated with the deposited grain (commodities)? If Yes, what are the activities?
44	Who does the pest control activities?
45	If the answer to question # 44 above is hired, please provide the name of the company
46	If done by members of the storage system, what is sex of pest controller
47	What is the frequency of pest control? (per storage season)
48	If treatment is repeated, is it done using the same pesticide?
49	Which chemicals are used in controlling pests?
50	Mention the trade names of such chemicals used?
51	Is the frequency of application the same for all the pesticides?
52	Personnel providing labour to the storage system activities such as bagging, stacking, offloading during depositing, loading during withdraw or sales
53	Do you deposit any maize variety at the storage system?
54	If Yes, to question 61, which maize varieties are deposited?

55	When do you start receiving grains from farmers?
56	Maize of what moisture content is accepted at the WRS or CGB?
57	Which method do you use for checking moisture content of the grain?
58	Is the grain rehandled after depositing?
59	If the answer is yes to question # 58 above, how is the grain rehandled? (there could be multiple responses)
60	Is the grain from different farmers get mixed together or is it kept separate?
61	At what point do you start selling the grain?
62	Which months do you typically start selling the grain?
63	Who are the main buyers or beneficiaries of the grain (*May have multiple responses*)
64	How frequently do buyers or beneficiaries come to buy or get grain from the storage system
65	What are the causes of postharvest losses (Tick appropriate boxes –may have multiple answers)

66	Do extension workers from the government or non-governmental organisations supply you with information on the risks of postharvest losses and how you can manage them? (*tick one)*
67	Are you satisfied with the extension workers assistance rendered to help in the management of postharvest losses? (tick one)
68	What dangers do postharvest losses pose to your maize? (Tick appropriate box – may have multiple response)
69	If you were to sum up postharvest losses of maize caused by all factors including larger grain borer, how many units of your local unit of measurement have you lost?
70	Who shoulders the cost for the lost grain?
71	What are the advantages of depositing grain at the WRS or CGB?
72	What are the costs incurred by the depositor?
73	What safety mechanism have you put in place to ensure grain safety in storage system?
74	What challenges do you face?
75	How do you address them?
76	Any suggestions for improved service delivery?

F.TRAINING	
77	Have you ever been trained with regards CGB or WRS?
78	Which topics were you trained on? (Checklist: Storage pest management, grain management, storage pesticide management, marketing, storage system management)
79	Duration of training? (In days)
80	Quality of training (Level of satisfaction)
81	Who provided the training?
82	How often? (number of times per year)
83	When was the last training held? (mention the name of month)
84	Areas where further training is required?
G. CLIMATE RISKS AND ROLE OF WRS AND CGB IN BUILDING COMMUNITY RESILIENCE TO THESE RISKS	
85	What are the main climate-related risks faced by the local community?

86	Have the frequency or severity of these climate-related risks changed over time? If yes, provide details
87	Does this storage system impact on these climate-related risks in any way? If yes, please provide full details
88	What changes do this storage system (structure, management, role etc) could be made to better help communities become more resilient to climate-related hazards?
89	Why do you think these changes are not already being implemented?
90	Do all members of the community benefit from the storage system? Explain who does and why, and who doesn't and why they don't?
91	Does the storage system have any other benefits for the community that you have not already mentioned? If yes, what are they?
92	Are there any negatives related to the storage systems which you have not already mentioned? If yes, what are they?
93	Any other relevant comments?

THANK YOU FOR YOUR PRECIOUS TIME