DETERMINANTS AND BARRIERS OF ADOPTION OF HERMETIC BAGS AS POST-HARVEST MANAGEMENT STORAGE TECHNOLOGY AMONG SMALLHOLDER FARMERS IN CHIKHWAWA DISTRICT.

MSc THESIS IN TRANSFORMATIVE COMMUNITY DEVELOPMENT

KENNEDY CRISTIANO KAPULULA

MZUZU UNIVERSITY

JANUARY, 2026

DETERMINANTS AND BARRIERS OF THE ADOPTION OF HERMETIC BAGS AS POST-HARVEST MANAGEMENT STORAGE TECHNOLOGY AMONG SMALLHOLDER FARMERS IN CHIKHWAWA DISTRICT.

KENNEDY CRISTIANO KAPULULA

MTCD4218

BSc IN AGRICULTURE (AGRICULTURAL EXTENSION)

A THESIS SUBMITTED TO THE FACULTY OF ENVIRONMENTAL SCIENCES, DEPARTMENT OF AGRISCIENCES IN FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN TRANSFORMATIVE COMMUNITY DEVELOPMENT

MZUZU UNIVERSITY

JANUARY, 2026

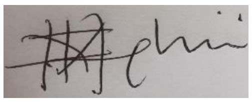
DECLARATION

I, the undersigned, declare that this thesis, titled "Determinants and Barriers of adoption of Hermetic Bags as Post-Harvest Management Storage Technology among Smallholder Farmers in Chikhwawa District", is my original work and has not been presented for an award of a degree in any other university or college. All the sources of information used have been fully indicated and acknowledged by complete references. This thesis is being submitted in fulfillment of the requirements for the award of the degree of Master of Science in Transformative Community Development at Mzuzu University.

Kennedy Cristiano Kapulula	**5th January, 2026**
Student Name	**Date**

CERTIFICATE OF APPROVAL

This thesis, "Determinants and Barriers of adoption of Hermetic Bags as Post-Harvest Management Storage Technology among Smallholder Farmers in Chikhwawa District", is submitted with our approval as university supervisors for the MSc in Transformative Community Development.



Frank Mnthambala (PhD) **Date: <u>5th January, 2026</u>**

Major Supervisor

DEDICATION

To my wife, Memory Chokha, for the support and encouragement throughout my study, to my mum Steria Stefano, my brother Ashan Kapulula and my late father Mr. Eliya Kapulula for inspiring me to excel in education; and also not forgetting my sons who missed my love, care and support during this period.

ACKNOWLEDGEMENTS

First, I would like to express my gratitude to my supervisor, Dr. Frank Mnthambala (PhD), for his motivation, insights, enthusiasm, and very constructive criticism, which have contributed immensely to the evolution of my ideas on this project.

I express my sincere gratitude to Dr Mnthambala's co-supervisor, Mr. Christopher Mbukwa, for never giving up on me. I am so thankful for his invaluable support, time, suggestions, immense knowledge, and all the guidance during the research period and writing of this thesis.

A special word of gratitude to Mr. Daud for his support during my research analysis; his inspiration and opinion motivated me to put in an extra effort.

Let me give special thanks to my late father, Mr. Eliya Kapulula, for his generous financial, emotional, and social support. I do not have the right vocabulary to express my gratitude, but God will remember you for all you have done. Remain blessed, and may your soul continue resting in peace. Finally, I would like to give thanks to my heavenly Father for his endless love and for giving me the opportunity, strength, and grace throughout my study and beyond.

LIST OF ABBREVIATIONS AND ACRONYMS

AEDO	Agriculture Extension Development Officer
AEDC	Agriculture Extension Development Coordinator
PICS	Purdue Improved Crop Storage Bags
HB	Hermetic Bags
BLR	Binary Logistic Regression
EPA	Extension Planning Area
FAO	Food and Agriculture Organization
FGD	Focus Group Discussions
KII	Key Informant Interviews
MOAFS	Ministry of Agriculture and Food Security
MGDS	Malawi Growth and Development Strategy
NGO	Non-Governmental Organisation
TA	Traditional Authority
VDC	Village Development Committee
GoM	Government of Malawi
GAP	Guide to Agriculture Production
HHH	Household Head
NGO	Non-Governmental Organizations
SPSS	Statistical Package for Social Scientist

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This study assessed the determinants and barriers to the adoption of hermetic bag storage technology among smallholder farmers in Chikhwawa District. A mixed-methods approach was employed, combining a quantitative survey of 346 randomly selected households with qualitative methods including six focus group discussions and five key informant interviews that were conducted until saturation point was reached. Quantitative data were analyzed using logistic regression, while qualitative data were analyzed thematically to provide deeper insights into farmers' experiences and perceptions. Results revealed that 74.57% of respondents were aware of hermetic bags, primarily through extension workers (37.28%) and lead farmers (31.50%). The logistic regression model (Pseudo $R^2 = 0.261$, $p < 0.001$) identified age ($\beta = 0.045$, $p = 0.002$), gender ($\beta = -1.305$, $p = 0.006$), education ($\beta = 8.018$, $p = 0.018$), household size ($\beta = -0.741$, $p < 0.001$), and extension worker interaction ($\beta = 0.777$, $p = 0.039$) as significant determinants of adoption. Qualitative findings corroborated these results, with adopters expressing satisfaction with improved grain quality and reduced pest damage, stating that grains remained fresh for months without chemical treatments. However, non-adopters voiced concerns about high initial costs, limited availability in local markets, and insufficient knowledge about proper sealing techniques. Key informants, including agricultural extension officers, emphasized that improper usage compromised the bags' effectiveness, highlighting the need for comprehensive training programmes. Major barriers identified through both methods included high cost, scarcity, and limited knowledge on usage. Adopters reported significant benefits including grain quality preservation, reusability and reduced post-harvest losses. The study recommends strengthening extension services to enhance farmer awareness and knowledge, and developing subsidies or credit schemes to improve affordability and accessibility of hermetic bags among smallholder farmers.

Keywords: *Hermetic bags, Post-harvest management, Food security*

CHAPTER ONE: INTRODUCTION

This chapter introduces the study "Determinants and Barriers of Adoption of Hermetic Bags as Post-Harvest Management Storage Technologies among Smallholder Farmers." It covers a brief background to the study, the problem statement, the objectives of the study, and its significance.

1.1 Background

Postharvest Loss (PHL) of grains and pulses is expressed as the loss in dry weight and quality, which happens during various stages such as at harvesting (4-8%), transportation from farm to the home, drying process, shelling, winnowing, and farm storage (Tesfaye et al., 2021). It was estimated that farmers lose between 20 and 30 per cent of their annual harvest due to weevils. In any form, postharvest loss impacts farmers' income as farmers lose the quantity and quality of the stored food, which cannot fetch a reasonable market price and, in the long run, affect food security. Some of the leading causes of postharvest loss for maize pests like weevils (Sitofilus), Lesser Grain Borer (*Ryzopertha dominica*) and Larger Grain Borer (*Prostephanus truncatus*) have been found to contribute to high food loss (Tesfaye et al., 2021).

The central policy initiative of the Malawian government to address food insecurity is the provision of Affordable Farm Inputs (AIP) to raise production, with little attention to post-harvest losses. Tesfaye et al. (2021) suggests that 14-36% of all maize is lost after harvest due to combination of insect or rodent damage and microbial contamination. Damage levels vary widely with humidity and temperature and grain handling practices that either protect or expose the stock to pests and mold (De Groote, 2016). Crop variety also influences damage levels, as higher-yielding new varieties may have softer grains that are more susceptible to loss (Hengsdijk & de Boer, 2017)

Hermetic storage technologies (HSTs) are air-tight containers that prevent or minimize gas exchange (Marcos Valle et al., 2021 and Baributsa (2020). This technology does not require the use of insecticides. Additionally, hermetic storage can impede the growth of fungi, as these organisms also need oxygen to proliferate (Osei-Asibey et al., 2022). Three types of hermetic bags are produced in Tanzania: The Purdue Improved Crop Storage (PICS) bags, AgroZ Bags, Harsho Ghala, and Hermetic Cocoons. Other common hermetic storage technologies include Metal Silos. The Purdue Improved Crop Storage (PICS) bags are the most popular, and are manufactured by Pee Tanzania Limited (PPTL) in Tanga with financing from the UK Government (through the Food Trade East and Southern Africa Programme).

Globally, postharvest loss (PHL) remains a critical challenge to food security, with an estimated 13.3% of food being lost after harvest at farm, transport, storage, wholesale, and processing levels in 2023. For cereal grains specifically, losses decreased marginally from 8.5% in 2015 to 8.4% in 2023, representing billions of dollars in economic losses and wasted resources. Reducing postharvest losses offers a significant opportunity to enhance food availability without requiring extra production resources (FAO, 2023). The global agricultural community has increasingly recognized that addressing PHL is as crucial as increasing production for achieving food security (Díaz-Valderrama et al., 2020).

Hermetic storage technologies have emerged as a promising solution to combat postharvest losses caused by insect pests, mold, and microbial contamination. The global crop hermetic storage system market was valued at USD 1.2 billion in 2023 and is projected to reach USD 2.6 billion by 2032, growing at a compound annual growth rate of 8.7%, indicating significant global investment in these technologies. These systems create airtight conditions that deplete oxygen through biological respiration processes, creating hypoxic environments unfavorable to pest development and reproduction without the need for chemical insecticides (Dilipan et al., 2022).

Sub-Saharan Africa (SSA) faces disproportionately high postharvest losses compared to other regions. Sub-Saharan Africa continues to report the highest regional food loss at 23.0% in 2023, up from 22.1% in 2015. For cereals, maize is a staple food in diverse regions including Sub-Saharan Africa, with farm-level postharvest losses ranging from 1.4% to 5.9% in Uganda, Tanzania, and Malawi, primarily caused by damage from insects and pests during storage. These losses significantly impact food security in a region where approximately 374 million people experience severe food insecurity (FAO et al., 2023).

Despite the proven efficacy of hermetic storage technologies, adoption rates remain disappointingly low across SSA. Recent evidence shows considerable variation in adoption patterns. In Mozambique, WFP supported the supply chain of hermetic bags, resulting in 3,157,817 bags being sold countrywide in 2023, preventing 1,416 metric tons of crop losses valued at USD 447,747. However, successful distribution does not necessarily translate to sustained adoption. A LUANAR study conducted in early 2024 surveyed 627 participants across four districts and found that only 7% of respondents were continuously using hermetic bags, while 20-23% had never even heard about hermetic bags. Several factors influence adoption in the SSA context, including the severity of storage losses, technology efficacy, cost-effectiveness, ease of use, and local availability (Díaz-Valderrama et al., 2020). The disconnect between technology availability and actual farmer adoption represents a critical gap in achieving food security goals in the region.

Hermetic technologies as an alternative strategy to traditional and chemical control methods have gained significant interest among farmers, the private sector, governments, and development agencies (Yewle et al., 2023). Hermetic technologies owe their effectiveness to the airtight conditions created during storage. Biological processes such as respiration and metabolic activities are driven mostly by the presence of insects and other biological activities that lead to the depletion of oxygen and the release of carbon dioxide inside hermetic containers (Njoroge et al., 2019).

Hence, the hypoxic environments these technologies create become unfavourable to the development and reproduction of insect pests and thus minimize or stop grain damage. Commonly used hermetic technologies include silos (metal and plastic), drums, cocoons, plastic bags, and other containers. These hermetic containers come in different forms and sizes (Dilipan et al., 2022). Among hermetic technologies, hermetic bags are the most widely disseminated among smallholder farmers in sub-Saharan Africa (SSA) and Asia. The use of hermetic bags to store grain has significantly increased in the past 10 years, spearheaded by the development of the Purdue Improved Crop Storage (PICS) bag. The adoption of hermetic bags is driven by several factors, including (i) the severity of storage losses at the farm level, (ii) the efficacy of the technologies, and (iii) other benefits such as being chemical-free, cost-effective, easy-to-use; and locally available technologies. Hermetic bags significantly reduce food safety risks posed by the conventional method of treating stored grains with insecticides. There are several commercially available types of hermetic bags: single-layer (e.g. Super Grainbags bags manufactured by Grainpro Inc.), double-layer (for example, AgroZ bags manufactured by A to Z), and triple-layer bags (for instance PICS bags manufactured by several licensed plastic companies in SSA, Asia and Latin America) (Díaz-Valderrama et al., 2020; Dilipan et al., 2022; Kumar & Kalita, 2017). These hermetic bags come in different forms and sizes, and most of them look similar to transport or storage containers (polypropylene [PP] woven bags and plastic polyethylene [PE] liners) that farmers regularly use. Hermetic bags are appropriate alternatives to traditional storage methods as they maintain the quality of stored products and allow smallholder farmers to be food secure and have the flexibility to sell their grain when prices are high.

Malawi's agricultural sector faces significant postharvest challenges despite maize being the country's primary staple crop. The Malawian government's central policy response to food insecurity has focused predominantly on production-oriented interventions, particularly the

Affordable Farm Inputs programme (AIP), which provides subsidized fertilizer and improved maize seeds to smallholder farmers. Between 2009 and 2012, this subsidy programme was expanded to include maize storage chemicals (Ricker-Gilbert and Jones, 2015). However, this production-first approach has given inadequate attention to postharvest loss reduction, creating a critical policy gap where increased production is undermined by substantial storage losses.

Current economic conditions exacerbate the postharvest challenge. The Malawian economy grew by just 1.5% in 2023, with inflation reaching 35% in January 2024 driven by food inflation, making food security interventions even more urgent. In Malawi, farm-level postharvest loss for maize crops is estimated at 1.4% of national production, though this figure represents self-reported losses which may underestimate actual losses. When considering households that report losses, an average maize postharvest loss of between 21% and 27% of total maize production was reported by smallholder farmers, though notably just 7% of farmers in Malawi reported postharvest loss in LSMS surveys.

Recent research reveals concerning patterns in hermetic storage adoption in Malawi. A comprehensive study conducted in 2022-2023 found that 83% of farmers were aware of hermetic bags for grain storage, but only 11-20% had ever used them, with half of those who used the bags, receiving them through donations, and only 7.2% of farmers used the bags more than once. This low adoption rate persists despite demonstrated technology efficacy and significant promotional efforts by government, NGOs, and development agencies.

Key barriers to adoption identified include unavailability of the hermetic bags, perceived high cost, limited knowledge of the technology, low yields, and misconceptions about the utility of the bags. Economic analysis reveals a mean willingness to pay of 311 Kwacha ($0.42) for one hermetic bag, well below the market price of around 750 Kwacha, indicating significant affordability constraints.

Furthermore, farmers have expressed concerns about theft when using metal silos, which are typically kept outside households in compounds without fencing, contributing to low utilization of these storage technologies.

There is significant policy imbalances in agricultural support systems. While majority of Farmers acknowledged adequate AIP (Affordable Farm Inputs Programme) support for production inputs, some groups of farmers reported complete absence of post-harvest storage support (Matita 2020).

Table 1: Chikwawa crop production trends for the sampled EPAs

Year (crop season)	EPA	Crop variety	Production (metric tons)
2021 – 2022	Mitole	Maize	11268
		Sorghum	1781
		Legumes (groundnuts)	86
	Kalambo	Maize	7238
		Sorghum	2713
		Legumes (groundnuts)	516
2022 – 2023	Mitole	Maize	14,153
		Sorghum	3285
		Legumes (groundnuts)	22
	Kalambo	Maize	12,543
		Sorghum	3733
		Legumes (groundnuts)	83
2023 – 2024	Mitole	Maize	8589
		Sorghum	1353
		Legumes (groundnuts)	78
	Kalambo	Maize	6007
		Sorghum	1723
		Legumes (groundnuts)	333

Source: Chikwawa Agriculture Crop Production Estimate Surveys reports for 2021 to 2024

This asymmetry reflects Malawi's historical policy prioritization of production enhancement over loss prevention (Benson & Weerdt, 2023; Tesfaye et al., 2021). Extension services for storage remain inadequate or absent (32.95. Kamwendo (2018) also observed that Malawi's Agricultural

Sector Investment Plan allocates over 90% of resources to production inputs while neglecting post-harvest infrastructure. The policy gap perpetuates a paradox where increased production through AIP is undermined by storage losses estimated at 21-27% (Baributsa & Njoroge, 2020).

1.2 Problem Statement

Poor post-harvest procedures cause a 14–36% loss of maize grains in Africa, worsening the food situation (Tesfaye et al., 2021). In the case of maize, the post-harvest losses are extremely high at 27% (Baributsa & Njoroge, 2020). MoAFS (2019) claims that during the post-harvest period in Malawi, a sizable percentage of maize is lost, with native maize losing 33% of its produce, composite maize 3%, and hybrid maize 50%. Such losses are primarily attributed to harmful storage pests like the Larger Grain Borer (Prostephanus truncates) and weevils (Sitophillus species). Even with the proper chemicals, six months of storage may still cause 7.5 percent dry weight losses and a 27 percent decline in grain market value (Hell et al., 2016). In Malawi, where there is only one significant harvest per year that must supply food for both urban and rural areas all year round, reducing post-harvest losses of maize is essential for ensuring food security. Households experience consumption shortages because the damaged maize may be wasted or fed to livestock; low incomes from the sale of mouldy or damaged grain that fetches low prices on the market; and undernutrition brought on by consuming rotten/mouldy grains that increases the risk of serious illnesses like cancer and also worsens the effects of HIV and AIDS (FAO, 2016).

Previous studies have extensively documented the effectiveness of hermetic bags in post-harvest management across various regions. Research by Baributsa et al. (2020) demonstrated high adoption rates of PICS bags among smallholder farmers in West Africa, while Njoroge et al. (2019) examined the economic benefits of hermetic storage technologies in Eastern Africa. In Zimbabwe, Manda and Mvumi (2019) explored farmers' perceptions and willingness to pay for hermetic bags, while Kumar and Kalita (2017) evaluated the technical performance of various hermetic storage options in reducing post-harvest losses. However, a notable research gap persists concerning adoption patterns and influencing factors in Malawi's Lower Shire region, where distinct socio-economic and environmental conditions may shape technology uptake. This study addresses this gap by examining the specific drivers and barriers to hermetic bag adoption in this unique context. Agricultural Sector Annual report for 2023 from the Chikwawa District agriculture office indicates that only about 5103 farming families were using hermetic bags out of the total 120,089 farming families, representing 4.2 percent of the adoption rate. This study, therefore, attempts to uncover the determinants and barriers to the adoption of hermetic bags as post-harvest management storage technologies in the Chikwawa district.

1.3 Study Objectives

1.3.1 Main Objective

To analyse the adoption of Hermetic Bags as post-harvest management storage technology among smallholder farmers.

1.3.2 Specific Objectives

1. To determine farmers' level of knowledge on Hermetic Bags as post-harvest management technology among smallholder farmers.
2. To assess farmers' awareness of Hermetic bags as post-harvest management technology among smallholder farmers.
3. To analyze the factors that influence the adoption of Hermetic Bags as post-harvest management technology among smallholder farmers.
4. To assess the perceived benefits and challenges in using Hermetic bags as post-harvest management technology among smallholder farmers.

1.3.3 Research Questions

1. What knowledge do farmers have on the use of Hermetic Bags as a post-harvest technology in Chikwawa?
2. To what extent are farmers aware of the Hermetic bags technologies?
3. What are the factors influencing adoption of Hermetic Bags as postharvest management technology among farmers?
4. What are the perceived benefits and challenges that farmers get in using hermetic bags?

1.4 Justification of the study

Many people are food insecure in the western region and this food insecurity is partly contributed by storage pest which destroy the cereal grain kept in stores. By controlling postharvest losses, there will be increased food available without additional resources/inputs. Reduction in post-harvest losses would increase the amount of food available for human consumption and enhance global food security (Tefera and Abass, 2019; and Kamwendo, 2018). Less environmental degradation and reduction of adverse effects of chemicals pollution will be guaranteed once hermetic bags technology is adopted by smallholder farmers (Maina et al., 2023; Mutambuki et al., 2021). The information generated will help farmers, agro-dealers, farmer associations and individual traders to come up with strategies that could facilitate farmers' adoption of postharvest technology particularly Hermetic Bags in order to increase household food security through reduction of postharvest losses with the help of Hermetic Bags (Baributsa et al., 2017). In this case, cost spent on food aid due to grain loss will be reduced. The information will also be used by other organizations that sell hermetic bags to scale up their sales (Mubayiwa et al., 2018). Mubayiwa et al. (2018) stated that lack of information on unique socioeconomic factors and local barriers affecting technology adoption potentially leads to ineffective implementation strategies. Additionally, opportunities for scaling up hermetic bag usage among smallholder farmers could be missed, perpetuating post-harvest losses and food insecurity in the area. Local agro-dealers and organizations also lack vital market intelligence for expanding their services. Furthermore, environmental pollution would continue to escalate with the use of chemicals to control pests with little attention to hermetic bags usage.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This section provides the outline of the theoretical framework, empirical literature review and the conceptual framework of “Adoption of Hermetic Bags as Post-Harvest Management Storage Technologies”.

2.2 Definition of Terms and Key Concepts

2.2.1 Hermetic Storage Technology

Hermetic storage refers to airtight containment systems that create oxygen-depleted environments, effectively controlling storage pests without chemical interventions. According to Baoua et al. (2018), hermetic technology operates on the principle of creating anaerobic conditions that suffocate insects and inhibit mold growth, thereby preserving grain quality for extended periods. This definition contrasts with traditional storage methods that rely on chemical pesticides or physical barriers. However, while Baoua et al. emphasize the biological mechanisms, they inadequately address the socio-economic dimensions of hermetic storage as an innovation system. The technology encompasses various designs including bags, drums, and silos, each with distinct capacity and cost implications. Critically, the literature often treats hermetic storage as a uniform technology, overlooking how different designs influence adoption patterns. The operational definition must therefore acknowledge both the technical specifications such as oxygen permeability rates below $5cc/m^2/day$ and the user-centered attributes like ease of use, affordability, and compatibility with existing farming practices.

2.2.2 Post-Harvest Loss

Post-harvest loss encompasses quantitative and qualitative deterioration of agricultural produce occurring between harvest and consumption. Kimani et al. (2021) define post-harvest losses as measurable reductions in grain weight, nutritional value, economic worth, and food safety during storage, handling, and processing stages. This multi-dimensional conceptualization is critical, yet existing literature predominantly focuses on weight loss metrics, marginalizing quality deterioration and market value reduction. The emphasis on quantitative losses reflects a productivist bias that overlooks how qualitative degradation—such as aflatoxin contamination disproportionately affects smallholder market access. Furthermore, conventional definitions fail to distinguish between preventable losses amenable to technological intervention and systemic losses rooted in infrastructural deficits. A more nuanced definition must recognize post-harvest loss as a complex phenomenon shaped by biological, environmental, socio-economic, and institutional factors. Critically, loss quantification methodologies vary significantly across studies, limiting comparability and potentially inflating or deflating reported figures depending on measurement approaches employed.

2.2.3 Technology Adoption

Technology adoption represents the decision-making process through which farmers integrate innovations into their production systems (Rogers 1962). Wossen et al. (2019) conceptualize adoption as a continuum ranging from awareness and trial to sustained utilization and adaptation, rather than a binary outcome. This process-oriented definition challenges earlier models that treated adoption as a singular event, recognizing instead the dynamic nature of technology integration. However, this framework inadequately accounts for dis-adoption—the abandonment of previously adopted technologies - which affects up to 30% of agricultural innovations within five years. The literature further distinguishes between adoption intensity (extent of use) and adoption duration (sustained use over time), dimensions often conflated in empirical studies. Critically, most definitions assume rational decision-making frameworks, underestimating the influence of social networks, cultural norms, and institutional constraints. A comprehensive conceptualization must acknowledge adoption as socially embedded, technically contingent, and economically constrained phenomenon. Moreover, the concept should differentiate between individual adoption decisions and collective adoption patterns, as hermetic storage technology adoption often exhibits spatial clustering effects inadequately captured in conventional frameworks.

2.2.4 Smallholder Farmers

Smallholder farmers constitute a heterogeneous category of agricultural producers characterized by limited land holdings, resource constraints, and household labour dependence. Lowder et al. (2021) define smallholders as farm operators cultivating less than two hectares, though this threshold varies regionally and inadequately captures the multidimensional nature of smallholder farming systems. This land-based definition obscures critical distinctions in market orientation, resource endowments, and livelihood strategies within the smallholder category. Critically, the literature often homogenizes smallholders, ignoring significant intra-group variation in wealth, education, market access, and risk tolerance factors that substantially influence technology adoption decisions. Furthermore, conventional definitions inadequately address the increasingly blurred boundaries between subsistence and commercial farming, as many smallholders simultaneously engage in production for consumption and sale. A more sophisticated conceptualization must recognize smallholder farming as characterized by limited productive assets, high vulnerability to climate and market shocks, constrained access to information and credit, and reliance on family labour. However, this characterization should avoid deficit-oriented framings that portray smallholders solely through their limitations, acknowledging instead their adaptive capacities and indigenous knowledge systems.

2.2.5 Innovation Characteristics

Innovation characteristics refer to perceived attributes of new technologies that influence adoption decisions. Rogers (1962), as revisited by Genius et al. (2020), identifies five key attributes as follows: relative advantage, compatibility, complexity, trialability, and observability. Relative advantage measures perceived superiority over existing practices, typically assessed through economic returns, though non-monetary benefits remain undervalued in empirical studies. Compatibility addresses alignment with existing values, experiences, and needs a dimension particularly salient for hermetic storage given farmers' familiarity with conventional bagging. Complexity inversely relates to adoption, yet literature inadequately distinguishes between technical complexity and cognitive complexity. Trialability enables experimentation at reduced risk, though hermetic bags' seasonal nature constrains trial opportunities compared to annual crop technologies. Observability facilitates peer learning, yet existing research overlooks how storage technologies' hidden nature (grain quality preservation occurs inside sealed bags) may impede observability compared to field crop innovations. Critically, these five characteristics, though foundational, present a supply-side bias that privileges technological attributes over demand-side considerations like affordability, accessibility, and institutional support systems that shape adoption in resource-constrained contexts.

2.3 Theoretical Framework

2.3.1 Diffusion of Innovations Theory

The Diffusion of Innovations Theory, developed by Everett Rogers, provides a foundational framework for understanding how new technologies spread through social systems over time. According to a report on agricultural innovations in Kenya, Rogers (1962) in Muriithi et al. (2022) posits that adoption follows an S-shaped curve with five adopter categories: innovators, early adopters, early majority, late majority, and laggards. This theory emphasizes communication channels, social systems, and time as critical dimensions shaping diffusion patterns (Dingman & Bauerle Bass, 2021). For hermetic storage technology, the theory suggests adoption rates depend on opinion leaders' influence, peer-to-peer information exchange, and compatibility with existing farming practices. However, critics argue that the theory's linear progression model inadequately captures the discontinuous, context-dependent nature of technology adoption in Sub-Saharan Africa. Specifically, the framework underestimates structural constraints such as market access limitations and credit unavailability that impede diffusion regardless of individual innovativeness (Alyoubi & Yamin, 2021). Moreover, the theory's individualistic orientation obscures collective action dynamics and institutional factors that research shows significantly influence agricultural technology adoption in smallholder contexts, where communal decision-making often supersedes individual agency.

2.3.2 Technology Acceptance Model (TAM)

The Technology Acceptance Model, originally developed for information systems, has been adapted to agricultural technology adoption contexts. As applied by Muema et al. (2018) regarding post-harvest technologies in Kenya, TAM posits that perceived usefulness and perceived ease of use determine technology acceptance and subsequent adoption behaviour. Perceived usefulness refers to farmers' beliefs that hermetic storage will enhance grain preservation and economic returns, while perceived ease of use addresses operational simplicity and compatibility with existing skills (Gupta et al., 2022). The model incorporates external variables including farmer characteristics, institutional support, and technology attributes that indirectly influence adoption through their effects on perceived usefulness and ease of use. TAM's strength lies in its parsimony and empirical validation across diverse contexts. However, the model exhibits significant limitations when applied to agricultural innovations in developing countries (Sukwadi et al., 2022). Specifically, TAM inadequately accounts for resource constraints, risk perceptions, and social influences that qualitative research reveals as critical adoption determinants (Sukwadi et al., 2022). Furthermore, the model's cognitive focus overlooks how experiential learning and peer observation shape adoption decisions in contexts where formal information systems are weak, potentially explaining why hermetic storage adoption patterns diverge from TAM predictions.

2.3.3 Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework provides a holistic lens for analyzing how farmers' asset endowments and vulnerability contexts shape technology adoption decisions. As operationalized by Khatri-Chhetri et al. (2019) for climate-smart agriculture technologies, the framework examines five capital assets: human (skills, education), social (networks, trust), natural (land, water), physical (infrastructure, equipment), and financial (savings, credit access). This framework posits that technology adoption depends on how innovations enable farmers to build resilience, reduce vulnerability, and achieve livelihood outcomes within specific institutional and policy contexts (Delgado Jiménez et al., 2022). For hermetic storage technology, the framework suggests adoption patterns reflect farmers' existing asset portfolios and how the technology leverages or complements these assets. The framework's strength lies in recognizing adoption as embedded in broader livelihood strategies rather than isolated decisions. However, critics note the framework's complexity and descriptive rather than predictive nature limit its analytical utility. Moreover, the framework inadequately specifies causal mechanisms linking asset endowments to adoption outcomes, often resulting in post-hoc rationalizations (Natarajan et al., 2022). Empirical applications frequently struggle to operationalize capital assets, particularly social and human capital, leading to measurement challenges that compromise the framework's explanatory power.

2.4 Empirical Literature Review

2.4.1 Farmers' awareness and knowledge of hermetic storage technologies

Farmer awareness constitutes a prerequisite for technology adoption, yet substantial knowledge gaps persist regarding hermetic storage solutions. Ndegwa et al. (2020) conducted a cross-sectional study across three Kenyan counties, and found that only 38% of smallholder maize farmers demonstrated awareness of hermetic storage bags despite their commercial availability since 2013. This limited awareness contradicts industry claims of widespread technology diffusion, suggesting significant information asymmetries. The study identified agricultural extension services as the primary information source (47%), followed by farmer cooperatives (28%) and agro-dealers (18%) (Odjo et al., 2020a). However, the research inadequately explored information quality, focusing solely on exposure rather than comprehension depth. Critically, Ndegwa et al. overlooked how awareness varies by gender, with female farmers often excluded from extension contacts despite their predominant roles in post-harvest management. Furthermore, the study's cross-sectional design cannot establish whether low awareness causes non-adoption or whether non-adopters simply forget promotional messages, a methodological limitation that undermines causal inference regarding the awareness-adoption relationship in hermetic storage contexts.

Beyond mere awareness, effective technology utilization requires comprehensive technical knowledge. Stathers et al. (2018) examined knowledge depth among Tanzanian farmers exposed to hermetic storage training, revealing that 62% could correctly explain the technology's pest control mechanism (oxygen depletion), yet only 31% understood proper moisture content requirements before storage. This finding reveals a critical knowledge gap: farmers grasp the conceptual principle but lack procedural knowledge for effective implementation (Odjo et al., 2020b). The study employed knowledge tests and practical demonstrations, methodologically superior to self-reported understanding measures common in adoption studies. However, Stathers et al. failed to investigate whether knowledge gaps result from inadequate training content or farmers' educational constraints, limiting practical implications. More critically, the research assumes linear knowledge-adoption relationships, ignoring evidence that farmers often adopt technologies through experiential learning rather than formal instruction. The emphasis on technical knowledge also marginalizes indigenous storage knowledge systems, potentially overlooking opportunities for integrating hermetic principles with traditional practices, an integration approach that research suggests enhances adoption sustainability.

Extension service quality significantly influences both awareness and knowledge depth, yet service delivery remains inadequate in many contexts. Kihoro et al. (2023) analyzed extension-farmer interactions in Western Kenya, documenting that only 18% of farmers received hermetic storage training despite 54% reporting extension contact within the previous year. This gap indicates that extension services prioritize production technologies over post-harvest innovations, reflecting institutional biases that perpetuate post-harvest loss. The study further revealed that group-based training sessions (average 35 participants) predominated over personalized demonstrations, potentially compromising learning effectiveness. Kihoro et al. critically note that extension messages often emphasize technology benefits while inadequately addressing implementation challenges, creating unrealistic expectations that may lead to subsequent dis-adoption. However, the research inadequately examines extension agents' own knowledge and confidence regarding hermetic storage, a factor that influences message quality and conviction (Baributsa & Njoroge, 2020). Moreover, the study's focus on public extension services overlooks the growing role of private sector actors and farmer-to-farmer extension, potentially mischaracterizing the actual information landscape. The failure to assess extension message retention over time further limits understanding of how knowledge influences adoption decisions.

Modern information channels increasingly complement traditional extension, yet their effectiveness for hermetic storage promotion remains underexplored. Fabregas et al. (2019) evaluated mobile phone-based agricultural advisory services in Kenya, finding that SMS messages increased awareness of post-harvest technologies by 23 percentage points compared to control groups. The study's randomized controlled trial design provides robust causal evidence, methodologically superior to correlational adoption studies. However, the research revealed that information provision alone produced minimal adoption effects (4 percentage points), suggesting awareness constitutes a necessary but insufficient adoption condition (Odjo et al., 2022). Critically, Fabregas et al. (2019) overlooked how literacy levels constrain SMS effectiveness, a significant limitation in contexts where functional illiteracy exceeds 40%. Furthermore, the study's focus on text messages ignores video and audio formats that may better communicate storage technologies' practical aspects. The research also inadequately addresses information timing, despite evidence that farmers receptivity to storage information peaks immediately post-harvest. Most problematically, the study treated information as a one-way transmission, ignoring interactive communication possibilities that might enable farmers to ask clarifying questions, potentially explaining the awareness-adoption gap observed.

2.4.2 The factors influencing farmers' adoption decisions for hermetic storage bags

Economic considerations fundamentally shape adoption decisions, yet affordability assessments vary substantially across contexts. Nduku et al. (2021) analyzed cost-benefit perceptions among Kenyan smallholders, finding that hermetic bags' upfront cost (approximately KSh 250) represented 8-12% of stored grain value for farmers storing 100kg, a proportion perceived as prohibitive by 67% of respondents. These finding challenges technology proponents' characterization of hermetic bags as "affordable," revealing how absolute cost differs from relative affordability in resource-constrained contexts. The study employed willingness-to-pay experiments, methodologically stronger than hypothetical scenario approaches, revealing farmers would pay on average KSh 180 28% below market prices. However, Nduku et al. inadequately explored how affordability perceptions vary by harvest timing, with farmers potentially more willing to invest immediately post-harvest when cash availability peaks. More critically, the research focused exclusively on purchase costs, ignoring total cost of ownership including replacement needs every 2-3 years. The failure to analyze credit access as an adoption enabler represents another limitation, particularly given evidence that input credit significantly influences agricultural technology adoption in similar contexts.

Farmers' beliefs about technology performance critically influence adoption decisions, yet effectiveness perceptions often deviate from objective performance data. Mutambuki et al. (2022) investigated perceived effectiveness among adopters and non-adopters in Eastern Kenya, finding that adopters reported 89% effectiveness in preventing storage losses while non-adopters estimated only 45% effectiveness. This perception gap suggests information asymmetries and possibly confirmation bias among adopters. The study employed recall-based loss assessments rather than objective measurements, introducing potential reporting bias. Critically, Mutambuki et al. revealed that 32% of adopters reported continued insect presence in hermetic bags, indicating either improper use or unrealistic expectations of complete pest elimination. However, the research inadequately investigated whether effectiveness perceptions derive from direct experience, peer reports, or promotional messages, limiting understanding of how perceptions form. Furthermore, the study overlooked how effectiveness assessments vary by storage duration, with farmers potentially evaluating performance over 3-4 month periods while promotional messages emphasize year-long storage. The failure to distinguish between pest prevention and grain quality preservation represents another analytical weakness, as these outcomes may matter differentially to farmers.

Social networks substantially influence adoption decisions, yet their mechanisms remain inadequately theorized in hermetic storage literature. Tjernström et al. (2021) examined peer effects in agricultural technology adoption across Kenyan villages, employing social network analysis to identify how adoption spreads through interpersonal connections. Their findings revealed that farmers were 34% more likely to adopt when a direct network contact had adopted, with effects strongest for farmers sharing kinship ties. This provides robust evidence of peer influence using advanced statistical methods controlling for homophily and contextual effects. However, Tjernström et al. (2021) studied improved seeds rather than storage technologies, potentially limiting generalizability given storage technologies' private nature compared to visible field innovations. The research inadequately explored negative peer influence—how non-adoption by respected community members might deter adoption representing a theoretical blind spot. Furthermore, the study's network boundary specification excluded inter-village connections, potentially underestimating diffusion processes in contexts where market interactions connect farmers across village boundaries. The failure to examine how network structure (dense versus sparse) moderates peer effects represents another limitation, given theoretical reasons to expect differential influence patterns.

Risk perceptions substantially influence adoption decisions for agricultural innovations, yet remain underexplored for hermetic storage technologies. Kassie et al. (2018) analyzed risk attitudes and technology adoption in Malawi, finding that risk-averse farmers were 23% less likely to adopt novel agricultural technologies, including improved storage methods. The study employed incentivized risk elicitation experiments, providing objective risk attitude measures superior to self-reported risk preferences. However, Kassie et al. (2021) inadequately distinguished between downside risk (potential losses) and upside risk (uncertain gains), dimensions that behavioral economics suggests influence decisions differentially. For hermetic storage, relevant risks include:

bag failure leading to total crop loss, unfamiliarity with proper usage techniques, and uncertainty about resale value for used bags. The research overlooked how risk perceptions vary by wealth status, though theory suggests resource-poor farmers exhibit greater loss aversion. Furthermore, the study's focus on risk attitudes neglects risk perceptions farmers' subjective assessments of technology-specific risks which evidence suggests more directly influence adoption than general risk preferences. The failure to examine how trial opportunities and money-back guarantees might mitigate perceived risks represents a practical oversight.

2.4.3 The relationship between farmer characteristics and hermetic storage adoption

Farmer age exhibits complex relationships with technology adoption, yet findings remain inconsistent across contexts. Mzyece et al. (2021) examined age effects on improved storage technology adoption in Zambia, finding an inverted U-shaped relationship where adoption peaked among 35-50year-olds (43% adoption rate) compared to younger (28%) and older farmers (19%). This non-linear pattern challenges simplistic assumptions that younger farmers universally embrace innovations. The study employed regression analysis with age-squared terms, appropriately capturing non-linearity. However, Mzyece et al. inadequately explained the mechanisms driving these patterns. Younger farmers' lower adoption despite presumed openness to innovation suggests capital constraints or limited farming experience override innovation orientation. Older farmers' lower adoption might reflect shorter planning horizons, physical limitations handling bags, or accumulated skepticism from failed past innovations. Critically, the research failed to distinguish chronological age from lifecycle stage and farming experience, conceptually distinct constructs often confounded in adoption studies. The study also overlooked cohort effects how historical exposure to different agricultural paradigms shapes technology receptivity potentially misattributing cohort differences to age effects. Furthermore, the analysis inadequately considered how age interacts with other characteristics like education and wealth in shaping adoption decisions.

Educational attainment consistently associates with technology adoption, yet the specific mechanisms and thresholds remain debated. Wossen et al. (2019) meta-analyzed 30 studies examining education-adoption relationships across Sub-Saharan Africa, documenting positive associations in 87% of studies with an average marginal effect of 3.2 percentage points per additional schooling year. This systematic evidence synthesis provides robust generalizability. However, the meta-analysis revealed substantial heterogeneity ($I^2 = 68\%$), suggesting context-specific factors moderate education effects. Wossen et al. identified three potential mechanisms: education enhances information processing capacity, improves access to information networks, and increases awareness of technology benefits. Yet the research inadequately tested these mechanisms empirically, relying on theoretical speculation. For hermetic storage specifically, the relevant educational dimension may be technical literacy rather than formal schooling the ability to understand usage instructions and troubleshoot problems. The study also overlooked education quality variations, treating years of schooling as equivalent regardless of instructional quality. Furthermore, the analysis failed to examine threshold effects whether minimum education levels are necessary or if returns accrue linearly a distinction with significant policy implications. The reliance on household head education also neglects other members' education, particularly relevant when women manage post-harvest activities.

Gender significantly influences agricultural technology adoption, yet hermetic storage research largely overlooks these dynamics. Fischer et al. (2018) investigated gender and storage technology adoption in Uganda, finding that female-headed households exhibited 18% lower adoption rates than male-headed households for improved storage technologies. However, this analysis inadequately captures intra-household gender dynamics in dual-headed households where post-harvest responsibilities predominantly fall to women despite men's control over investment decisions. The study employed household-level analysis, methodologically inadequate for understanding gendered adoption processes. Fischer et al. identified several explanatory factors: women's limited asset ownership constrains purchasing capacity, their restricted extension access reduces awareness, and their time poverty from multiple responsibilities limits market engagement. Yet the research inadequately examined how these factors interact and their relative importance. Critically, the study overlooked how hermetic storage might appeal differentially to men and women based on distinct priority outcomes women potentially value food safety while men emphasize marketable quantity. The failure to analyze how women's bargaining power influences adoption in dual-headed households represents another limitation. Furthermore, the research inadequately considered how gender norms regarding technology legitimacy affect adoption, with "modern" technologies potentially perceived as masculine domains in some cultural contexts.

Farm size and resource endowments substantially influence adoption capacity, yet their effects exhibit context-dependency. Bezu et al. (2020) analyzed farm size-adoption relationships across four East African countries, finding positive associations in three countries but insignificant effects in Tanzania. This geographic heterogeneity challenges universal assumptions about resource constraints determining adoption. The study employed multi-country comparable data, enhancing generalizability. However, Bezu et al. inadequately explored why farm size effects vary geographically, limiting theoretical advancement. For hermetic storage, farm size likely influences adoption through multiple pathways: larger farms generate greater surplus for market sale (increasing storage value), provide economies of scale (reducing per-unit storage costs), and enable learning investments (making information acquisition worthwhile). Yet the research failed to test these mechanisms empirically. Critically, the study measured farm size continuously, potentially obscuring threshold effects where minimum production scales make storage investment viable. The analysis also conflated farm size with other resource endowments like wealth and equipment ownership, making causal attribution problematic. Furthermore, the research overlooked how land fragmentation farming multiple small plots might differentially affect adoption compared to consolidated holdings of equivalent total area.

2.4.4 Crop production and postharvest losses in world

Crop production contributes large parts of average incomes in some regions areas of the world, for example, 70 per cent and 70 per cent in sub-Saharan Africa, and reducing food loss can directly increase the real incomes of the farmers. (Bank, 2022). In measuring the overall ratio of PHL to total production, FAO (2014) takes into account the losses that occurred during each of the five stages from farm to fork; losses during harvesting, such as from mechanical damage and spillage; during postharvest handling, such as drying, winnowing, and storage insect pests, rodents, and rotting; during processing; during distribution and marketing, during consumption. This signifies that a substantial amount of quality food that could be consumed is being wasted. Market success relies on a consistent supply of higher-quality products, and using innovative technologies that also lower Post-Harvest Losses can assist in achieving this. These technologies come in various forms (World Bank 2010, for example), and innovation systems can introduce new forms of technology and methodology (Roberts & Khattri, 2015). A comprehensive understanding of the direct and indirect advantages by producers is necessary for adoption, nevertheless. For a sustainable approach to reduce PHL, planning an intervention within the context of the relevant value chain is required, and it may be essential to employ various solutions. The extensive analyses of postharvest losses for grains by Abrehet, (2018) and Debebe, (2022) have both been published. High losses, subpar product quality, and insufficient crop use are issues with Ethiopia's current post-harvest system. This is related to the severe lack of accessibility to the necessary instruments and equipment, their major unavailability, and their lack of market knowledge. Ethiopia's introduction of post-harvest technology will rely on the kind of technology used, how easily farmers can access it, and how committed the government and partner organizations are to promoting rice throughout the nation (Irfan et al., 2023). A crop is first harvested, then handled, stored, processed, packaged, transported, and then sold in any postharvest agricultural supply chain.

2.5 Understanding types of Hermetic Bags Storage Technologies

Hermetic bags are fairly affordable, costing KSh 250 (US$ 3) for a bag with a 100 kg capacity. There are two brands being marketed in Africa by different companies. Purdue Improved Crop Storage (PICS bags) and Super Grain Bag. PICS bag is a simple, low-cost triple bagging technology originally developed for postharvest storage of cowpea but had been evaluated for applicability to maize storage mainly in West (Muriuki et al., 2023). The three layers include an outer polypropylene bag and two inner linings of high-density polyethylene (HDPE). Purdue University introduced its PICS bag to the Kenyan market in partnership with local distributor Bell Industry Ltd. In Kenya, Purdue sold more than 46,699 PICS bags, giving thousands of smallholder farmers' access to technology that might cut their postharvest losses by as much as 40%. (Feed the future, 2014). PICS bags may result in less pesticide use, better grain quality and storage capacity, and access to more expensive markets.

The PICS bags should be updated more regularly than other local containers since their lifespan is typically between two and three years. Thus, supply chain management becomes crucial to expanding the range of affordable solutions for small companies. Vales et al. (2013) compared storage in PICS and gunny sacks for hermetic pigeon pea seed. Compared to 17% infestation in gunny sacks, there is a reported 1% bruchid infestation with PICS. Additionally, they indicate improved seedling vigor in PICS, as seen by the lengthened seedling radicle and Plumule, and

88% germination in PICS as opposed to 69% in gunny sacks. Trials have demonstrated that PICS bags may be used to store maize even in regions with significant populations of bigger grain borer, however maize storage should start as soon as the crop is harvested and dried (Baoua et al, 2013).

The second brand, Super Grain Bag TM, is made in the Philippines by Grain Pro Inc. Although the market is not yet completely grown since the technology is still new and the levels of awareness are still low, their bags are commercially accessible in Kenya. Since the inner lining is the component that maintains air tightness while in storage, farmers have the option of purchasing just the inner lining from Grainpro and utilizing it with their standard bags. The Super Grain Bags passed the test while being tested on station (De Groote et al., 2013).

High value crops like seeds, cocoa, and coffee are becoming acknowledged as the norm for safe, multi-month preservation using hermetic storage (Baributsa et al., 2020). Six formerly challenging storage issues may now be solved with hermetic storage, which is contemporary, environmentally friendly, chemical-free, transportable, user-friendly, and reasonably priced. Providing safe, long-term storage, obviating the need for pesticides, fumigants, or refrigeration in storage; safeguarding seed germination; and preserving crops from insect infestation, including reducing aflatoxin development and preventing rancidity in goods for a maximum of one year.

2.5.1 Metallic Silos

Since 2009, CIMMYT has promoted the metal silo technology in an effort to significantly minimize post-harvest losses of maize during storage. Very little evidence shows that these technologies were examined economically before being launched (Akumu et al., 2020). Butenko et al. (2022), demonstrated that it is possible to efficiently manage maize weevils and the larger grain borer without the use of pesticides like Actellic Super and Phostoxin.

2.5.2 The contribution of Technology Transfer

Transfers of technology don't just happen. There are some pieces of knowledge that can only be shared through direct communication. Because of this, strong communication between suppliers and consumers is necessary for understanding technology and adaptability. Effective interpersonal interactions would therefore be necessary for the spread of tacit information and its assimilation. The interaction that occurs in person is the most significant (Westerman et al., 2014). These supply and demand dynamics will probably be improved by three factors. First of all, information and communication technologies improve access to knowledge and foster stronger interpersonal relationships, which promotes understanding of cutting-edge technology. The market's vertical and horizontal integration, on the other hand, favors information and technological flows.

2.5.3 Characteristics of innovation that influence its adoption

Potential adopters evaluate an innovation based on their assessment of its five features, according to (Adeola, 2020). The trialibility is the first attribute. This is the extent to which an idea may be tested out on a small scale. Easy-to-test innovations are more frequently adopted. The second factor is observability. This is the extent to which an innovation's outcomes are apparent to outsiders. Innovations with more obvious outcomes are more likely to be accepted. Another quality of innovation is relative advantage. The degree to which an invention is thought to be superior to the concept it replaces is known as relative advantage (Ngwenyama et al., 2022). This can be quantified in financial terms, but social, cultural, and religious considerations, prestige aspects, convenience, and satisfaction are frequently significant determinants as well and complexity comes in at number four.

The perception of an innovation's complexity affects how quickly it is adopted. Compatibility comes in at number five. The adoption of an invention will not occur as quickly as it would if it were more in line with the social system's norms and values. Re-innovation is the last and sixth option (Negede et al., 2024). This is the extent to which a user alters or modifies an innovation throughout acceptance and implementation. The pace of adoption increases with how much of the innovation can be altered.

2.5.4 Factors leading to the promotion of Hermetic Bags

Although the use of hermetically sealed storage bags is new in Kenya, farmers have long preserved their harvests in polypropylene bags. As a result, the initial effort was to enlighten the target market about the differences and benefits of Hermetic bags in comparison to traditional procedures (Kuyu et al., 2022). Making enough units to satisfy the increased demand was the next challenge encountered by PICS team. The farmers believed that the approaches being used to combat insect infestations were unsuccessful. The effects of post-harvest insect infestations on farmers' livelihoods and access to food were well known to them. They were mixing chemical pesticides in an effort to make up for these losses (USAID, 2016).

To handle storage pest infestations on cowpeas (Vigna inguiculata, L. Walp.) in West and Central Africa, Purdue University created the PICS technology (Baributsa & Njoroge, 2020). Insect pests (Callosobruchus maculatus, Fabricius) cause cowpea farmers in West Africa to lose a significant amount of their harvest (from 10% to as high as 100% after only a few months) during storage (Moussa et al., 2010, 2011). PICS bags were created to provide farmers an affordable and chemical-free means of storage. Granaries, ash, sand, botanicals, metal drums, jerrycans, and pesticides were examples of existing storage techniques that had drawbacks. Some of these techniques were risky to one's health, expensive, and unscalable (Baributsa, 2019). Grain storage options that are both secure and affordable would increase food security and provide farmers access to higher grain prices during the lean season.

2.5.5 Factors affecting adoption of the Hermetic Bag technology

While hermetically sealed storage bags may be new to Kenya, storage bags per se are not; farmers have been using polypropylene bags to store their harvests for generations. So the initial effort undertaken by Purdue's PICS team and Partnering for Innovation, and then by USAID-KAVES, Bell Industries, and a number of non-governmental partners, was to educate the potential market about the differences and benefits of Hermetic bags compared with traditional practices (Coeurderoy et al., 2014). The next challenge was to produce a sufficient number of units to satisfy the resulting demand.

The farmers interviewed perceived the effectiveness of existing practices in curbing insect infestations as inadequate. Farmers were already aware of the impact on their livelihoods and food security of post-harvest insect infestations (Ngoma et al., 2024). They were doing their best to counteract such losses by using chemical pesticides with their traditional bagging practices. However, according to interviewees and local officials, the effectiveness of the chemicals was between 80 and 90 percent, and this was only for the first month. The effectiveness of the pesticides declined sharply thereafter, and farmers had to empty the bags and re-treat the grain with pesticides every two or three months before re-bagging.

According to Ngoma et al. (2024), farmers interviewed reported that they found the explanation of the use of the Hermetic bags easy to understand. Faced with high costs of chemicals for treating grain in non-hermetic conditions, and believing that the chemicals are harming their children's health, farmers are easily persuaded to adopt the new technology. In addition, the technology is promoted by public or NGO extension workers and non-governmental contacts with whom farmers are already familiar and with whom they have already established relationships of trust.

The disastrous impact of severe insect infestation in recent memory has also played a role in farmers' seeking effective methods of control. Initial demonstrations by USAID-KAVES, CSOs, and NGOs, as well as the supplier, Bell Industries, had an immediate effect. Whereas Bell had supplied a mere 3,105 units in 2013, almost all of which went to promoters, the following year 88 percent of over 66,000 units went to the commercial sector, and by 2015 almost all the production was sold through the commercial distribution network (Charry et al., 2023). At the beginning of 2016, demand had risen so sharply that Bell was unable to keep up with it, and the network of suppliers was reporting empty shelves throughout the country. Farmers uptake of technologies depends on several factors which are grouped into broad categories; technology specific for example soil type, management regime, household specific like farmer perceptions, resource endowment, and household size, policy and institutions context within which the technology is disseminated for example input and output prices, land tenure and property rights ((Benimana et al., 2021).

Mwinuka and Hyera (2022), found that age, education, and source of land holding have significant relationship with adoption of innovation while sex, choice of production and cropping systems have no significant relationships with farmers' adoption of innovation. The survey that he conducted in Kenya found that the adopters of modern technology like improved varieties were young in age than non-adopters (Rono et al., 2018). This means that the introduction of Hermetic Bags would meet a lot more resistance by older people than younger ones. Similarly, he found that the majority of the literate farmers were adopters while the majority of the illiterates were non-adopters. In a similar study, Rono et al. (2018), reported that one of the important factors that influence the adoption of any new technology among smallholder farmers is the literacy level of household head from the study conducted in Mangochi district.

In the Sub Saharan Africa, the use of modern inputs by farmers is low and substantially below levels of use in other parts of the world. For example, the area planted to modern seed varieties is far lower in Africa than in Asia (Upendram et al., 2023). In a similar study, Moyo et al. (2022), pointed out the general reasons why more farmers are not using improved inputs and techniques vary with farmers, region and countries, but the major ones are that many farmers have meager cash resources, improved techniques often do not solve the farmers' real problem, new techniques are not viewed by the farmers as proven, having acceptable risks associated with them, profitable and socially accepted, and the required inputs are unavailable at the time they are required.

According to Rono et al. (2018), the development of technology alone, may not increase crop yields and production in the country. The technology must be tested and adopted on farms and determine any constraints at farm level. However, while these are general factors, the assessment of specific factors affecting farmers' adoption of Postharvest technologies, Hermetic Bags in particular, is of great importance as many of these factors are location specific and require further in situ studies.

2.6 Conceptual Framework

The conceptual framework illustrates relationships between independent variables (determinants and barriers) and the dependent variable (adoption of hermetic bag technology among smallholder farmers in Chikwawa District). This framework addresses the significant adoption gap in Malawi, where 83% of farmers are aware of hermetic bags yet only 7.2% use them more than once, indicating limited sustained adoption (Ngoma et al., 2024). The framework is anchored in Rogers' (1962) Diffusion of Innovation Theory, which explains how innovations spread through social systems based on individual characteristics, communication channels, time, social systems, and change agents. Understanding these multifaceted relationships is essential for designing effective interventions that promote not just initial trial but sustained integration of hermetic storage technologies into farming practices (Dilipan et al., 2022).

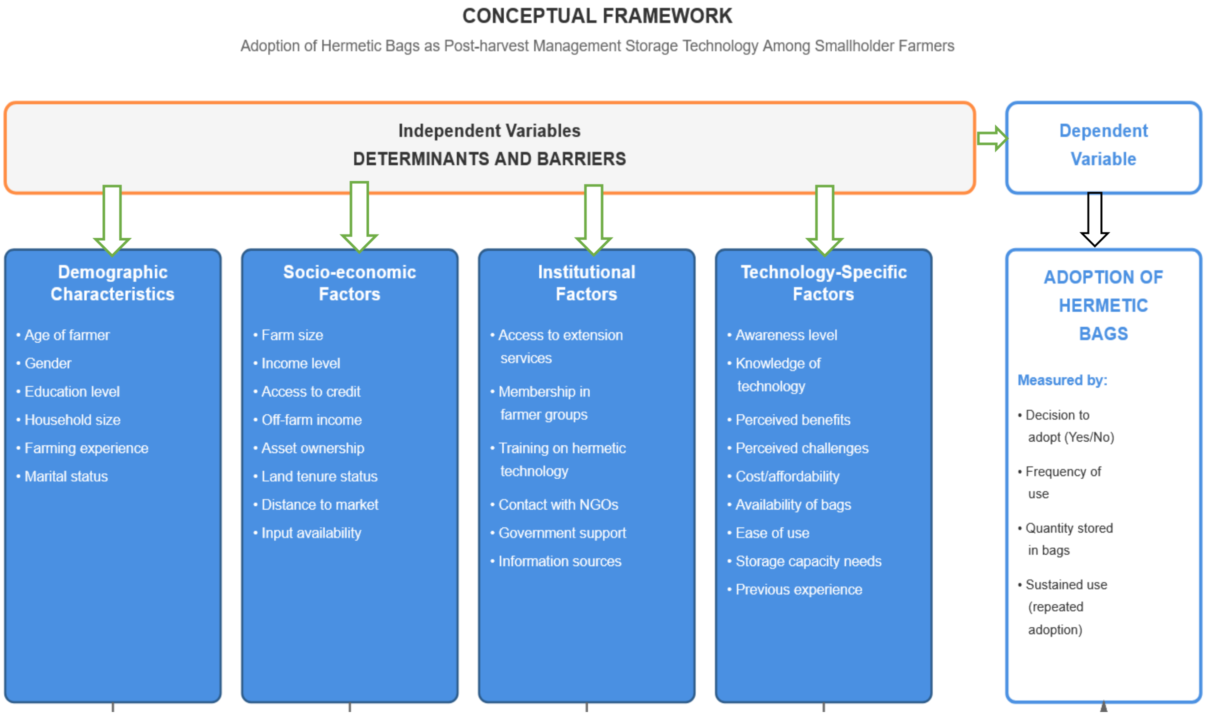


Figure 1: Conceptual Framework

All four independent variable categories influence adoption through different mechanisms with varying strengths. Demographic characteristics provide foundational context shaping cognitive capacity, risk orientation, and social positioning; younger, educated farmers with larger households hypothesized to show higher adoption due to openness to innovation and better technical understanding (Khanna, 2024). Socio-economic factors operate through enabling or constraining resource availability; farmers with higher incomes, larger farms, credit access, and market proximity expected to show higher adoption rates due to greater financial capacity and stronger economic incentives (Kipkogei et al., 2025). Institutional factors work through information diffusion, skill development, and social influence; farmers with extension access, group membership, and government support more likely to adopt through enhanced knowledge and reduced transaction costs (Ma & Rahut, 2024). Technology-specific factors directly shape attitudes and experiences; farmers with higher awareness, greater knowledge, and positive benefit perceptions, despite facing some challenges, are expected to achieve sustained adoption (Masters, & Alvarez, 2018).

The dependent variable is adoption of hermetic bag technology, operationalized through four indicators: decision to adopt (binary yes/no), frequency of use, quantity of grain stored (kilograms), and sustained use beyond the initial trial. This multidimensional conceptualization recognizes that true adoption involves meaningful integration into farming systems, not mere trial. Evidence from Malawi reveals that only 7.2% of farmers used hermetic bags more than once, highlighting significant drop-off between initial trial and continued use (Ngoma et al., 2024). Research in Rwanda examining hermetic storage found that adopters had relatively higher incomes than non-adopters, with negative correlations suggesting self-selection in technology adoption (Tesfaye et al., 2021). The distinction between awareness, knowledge, initial adoption, and sustained use is particularly important given that 83% of Malawian farmers are aware of hermetic bags but the adoption of the technology remains low (Masters & Alvarez, 2018).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents an overview of the methodologies used in the research study. These include research design, study area, data collection, and data analysis.

3.2 Study Area

The study was conducted in Kalambo and Mitole Extension Planning Areas (EPAs), under the Chikhwawa District Agricultural Office in the Shire Valley Agricultural Development Division (SHVADD). Chikhwawa district has 6 Extension Planning Areas (EPAs), including Kalambo, Mbewe, Mitole, Livunzu, Mikalango and Dolo EPAs (Chikhwawa Agricultural Production Estimate Survey report 202/2023 season). The area was chosen because it is where Feed the Future Malawi has been working and conducting Hermetic bag demonstrations for farmers.

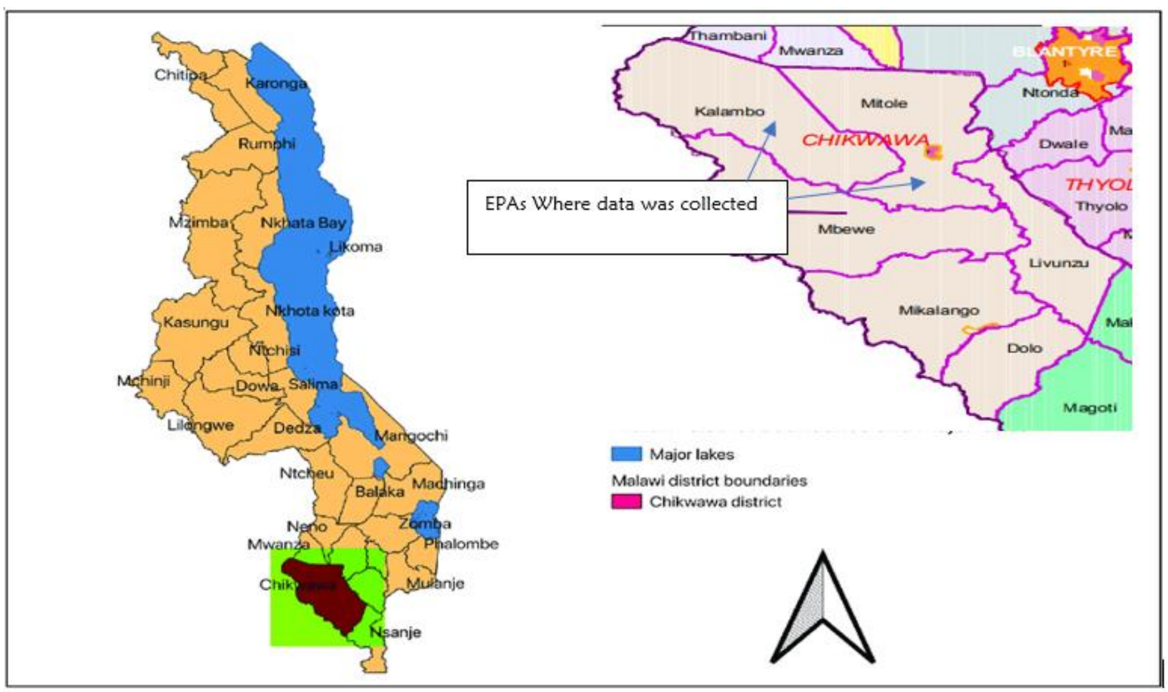


Figure 2: Map of Malawi showing the location of Chikhwawa District where the project was implemented and Showing Kalambo and Mitole EPAs under TA Chapananga and Kasisi

3.3 Research Approach and Design

The study design was a cross-sectional survey with both quantitative and qualitative approaches. Given the large number of respondents and the fact that data was gathered from them all at once, the cross-sectional research design was chosen because it saved the researcher time and money (Cohen et al., 2007).

Qualitative design involved the researcher interacting and recording views of the selected respondents and it emphasizes the depth of understanding associated with perceptions (Östlund et al., 2011). Qualitative data was collected through five focus groups discussions and five Key Informant Interviews (KII). The qualitative design helped the researcher to get a deeper insight on farmers' knowledge of hermetic bags, their awareness of hermetic bags as well as the benefits and challenges that they face when using hermetic bags.

The quantitative method, on the other hand, aims at collecting and analyzing some data in a numeric form for easy measurements, generalization and replication of a situation which helps the researcher to have a breadth understanding of the phenomenon (Creswell & Plano-Clark, 2011). The respondents' views were recorded in numerical and narrative format during the interactions. The interactions and the recording of the respondents' views had a qualitative research element, while the capturing of numerical data had a quantitative element. Using the two methods provided room for triangulation, where the researcher could use several ways to examine the same phenomenon. The quantitative data helped analyse factors influencing the adoption of hermetic bags as post-harvest management technologies.

3.3 Study Population

Chikhwawa district has 120,089 farm families, of which 54520 are male-headed households, and 65569 are female-headed households. Mitole EPA has 12054 farm families (4804 male-headed households and 7250 female-headed households), and Kalambo has 9968 total farm families, of which 4868 are male-headed and 5100 are female-headed households (Chikhwawa Agricultural Production Estimate Survey report 202/2023 season). The principal food crops grown include maize, sorghum, millet, rice, cow peas and sweet potatoes.

3.4 Sample Size and Sampling technique

Two sampling methods were used to select respondents. These include purposive sampling and simple random sampling.

3.4.1 Purposive Sampling

Purposive sampling was used to sample Mitole and Kalambo Extension Planning Areas. This survey-type research was carried out in two out of six EPAs in the Chikhwawa District. These EPAs were purposively sampled because these were the areas where Feed the Future Malawi had been conducting Hermetic bag demonstrations. Purposive sampling, also known as selective sampling, is a sampling technique in which a researcher relies on his or her own judgment when choosing members of the population to participate in the study (Blessed et al., 2022). Purposive sampling is one of the most cost-effective and time-effective sampling methods available. In addition, purposive sampling may be the only appropriate method available if there are only limited number of primary data sources that can contribute to the study.

Purposive sampling was also used to select participants in key informant interviews (KII). This involved identifying and selecting five participants who are involved in Hermetic Bags selling and distribution and dissemination of information and knowledge. Purposive sampling is the one whose characteristics are defined for a purpose relevant to the study (Bryman and Burgess, 1999). Therefore, the sample size for KII was 5, which included agro-dealers, AEDOs, and AEDC.

3.4.2 Simple random sampling

Simple random sampling was used to sample respondents for the study. Through simple random technique every item in the population had an even chance and likelihood of being selected in the sample. Here, the selection of items entirely depended on luck or probability, and therefore, this sampling technique is also sometimes known as a method of chance (Blac, 2010). Simple random sampling was used to sample 346 respondents.

3.5 Sample Size

The ideal sample size for the study was determined using a simplified formula by Israel (2013) at 95% confidence level, 0.05 degree of variability, and 10% level of precision

Where **n** is the sample size, **N** is the population size, and **e** is the level of precision

$$n = \frac{N}{1 + N(e)^2} \quad \text{---------- (1)}$$

In this research, .05 was the level of Precision

n=44,022

$$n = \frac{44022}{1 + 44022(0.05)^2} = 346$$

These households were expected to be practising postharvest technologies, particularly the use of hermetic Bags. The head of household or their spouse or a senior boy or girl above 17 was the respondent.

3.6 Data Collection Methods

Both qualitative and quantitative data was collected through respondent interviews and focus group discussions. The questionnaire (Appendix 1) and checklists (Appendix 2) were designed to collect data on factors determining the adoption of hermetic bags as post-harvest management technologies. The questions focused on capturing data on socio-economic, demographic, and awareness of hermetic bags as well as the benefits and challenges of hermetic bags as factors that determine the adoption of hermetic bags as post-harvest management storage technologies. Farmers uptake of technologies depended on several factors which, among other things, included soil type, management regime, farmer perceptions, resource endowment, and household size, policy and institutions context within which the technology was disseminated for example input and output prices, land tenure and property rights (Kwisiga *et al* 1999). The data weas collected from two Extension Planning Areas (EPAs) that were systematically sampled. Focus Group Discussions (FGDs) and individual interviews were conducted to collect qualitative data in the sampled EPAs. Key informant interviews were conducted to cross check on some of the data given by the respondents during FGD and individual interviews.

3.6.1 Focus Group Discussion (FGD)

Focus group discussions were conducted to allow interaction with the respondents and to triangulate the data. The data collected from the focus group discussions weas used to cross-check with the data collected from the household survey. Focus group discussions were conducted in five groups: Female Hermetic Bags Farmers, Male Hermetic Bags Farmers, female farmers who do not use hermetic bags; male farmers who do not use the technology and lead farmers. The method, which used an open-ended guide checklist as a tool, was utilised to gather information from the groups. FGDs with community members took a maximum of one hour each and were held in separate groups of males and females.

Holding separate FGDs for males and females created a conducive environment for women to share their views on the adoption levels and determinants of the adoption of Hermetic bags. Holding two separate FGDs was in line with the cultural setting of Chikhwawa, where women are not as open to expressing their views in a group of men as they are in a group of fellow women.

The embedded structures of power in Malawi keep women at a distance from what is meant to be a public discussion. The gender-sensitive FGDs in Malawi have been utilized in many studies (Chiweza, 2017) to prevent the distortion of data because of the limited voices on the part of women, owing to gender-power group dynamics. Each group discussion comprised 10 members.

3.6.2 Household Survey

A household survey was conducted to all 346 sampled households to collect data on knowledge, awareness, factors that determine adoption and benefits and challenges farmers face in adopting the innovation. A semi-structured questionnaire was used as a tool during the survey (Chiweza, 2017). Interviews were conducted using coded questionnaires (Appendix 1) which were administered to both Hermetic Bags Farmers and non-hermetic bags farmers in the study area. This approach enabled the researcher to rephrase or amplify any of the questions in case the respondent did not understand. In order to get a full record of the interviews without missing any point, and to be free from lengthy notetaking during the interviews, responses from the respondents were recorded using recorders and assurance about confidentiality was given to them before starting the interviews. The categories were assigned values that were used in data entry and analysis.

3.6.3 Key Informant Interviews

Key informant interviews were used to collect data that could not be gathered in individual interviews and Focus Group Discussions. In addition, it helped in cross-checking data collected in FGD and individual interviews. In this study, key informant interviews were conducted with AEDOs, AEDC and Hermetics Agro-dealers. Purposive sampling was also used to select participants in key informant interviews (KII). This involved identifying and selecting five participants who were involved in the selling and distribution of Hermetic bags and the dissemination of information and knowledge. Through purposive sampling, participants whose characteristics were defined for a purpose relevant to the study were selected (Bryman and Burgess, 1999). Therefore, the sample size for KII was 5, which included agro-dealers, AEDOs, and AEDC.

3.7 Data Analysis

3.7.1 Demographics and Socioeconomic Characteristics

The study used descriptive statistics such as means, frequencies, and percentages to characterize the study participants based on demographics and socioeconomics. This helped to understand the variables used in the regression models used in the study. Then, inferential statistics were employed to compare the differences between the adopters and non-adopters of Hermetic bags storage based on demographics and socio-economic characteristics.

3.7.2 Knowledge level of farmers on the adoption of Hermetic bags

Descriptive data analysis determined farmers' knowledge of hermetic bags as post-harvest management storage technologies. The knowledge was examined based on three items: usage, source/availability and cost of Hermetic bags. Descriptive statistics describe the basic features or characteristics of the data. It assigns numerical values to describe the trend of samples collected (Ohri, 2020). Quantitative data was coded into SPSS version 20. SPSS was used to generate descriptive data, which was in large volumes, and presented in a more straightforward and more meaningful format, such as frequencies and percentages, for easier understanding and interpretation.

3.7.3 Farmers' awareness of Hermetic bags

Descriptive data determine farmers' awareness of hermetic bags as post-harvest management storage technologies. The awareness was examined based on items including frequency of meeting extension workers and sources of information on hermetic bags as post-harvest management storage technologies.

3.7.4 Influencing factors to the adoption of Hermetic bags

A binary Logistic Regression Model was used to assess factors influencing adoption of hermetic bags as post-harvest management storage technology. The study used the Binomial Logistic Model (BNL) to estimate the influence of several categorical and continuous independent variables on the dependent variable. The Binomial Logistic Model is an appropriate binary choice model because it is used to predict the membership of two categories (Kleinbaun & Klein, 2002; Field 2009). Furthermore, BNL is often considered an attractive analysis because it does not assume normality, linearity, or homoscedasticity.

The model is specified according to Hausman and McFadden (1984). Since the dependent variable adoption had more than one response, it was necessary to use the Binomial Logistic Regression Model. The independent variables included knowledge, awareness, perceived benefits, perceived challenges and external factors (socio-economic and demographic characteristics). In the case of this study, the model is relevant because it has five outcome categorical variables in which adoption has been designated as the reference category. The binary logistic regression was run for objective 3. This aimed at determining significant relationships between dependent and independent variables. The model involves a binary output variable Y, with the goal of modeling the conditional probability Pr (Y = 1|X = x) based on x. The unknown parameters in this probability function was estimated through maximum likelihood.

Formally, the model logistic regression model was that:

$$log\frac{p(x)}{1-p(x)} = \beta_0 + x.\beta \quad \text{---------} \ (2)$$

Solving for p

$$p(x;b,w)=\frac{e^{\beta_0+x.\beta}}{1+e^{\beta_0+x.\beta}}=\frac{1}{1+e^{-(\beta_0+x.\beta)}} \text{ ------ (3)}$$

As logistic regression was designed to predict probabilities rather than mere classes, it was fitted through the utilization of likelihood. For every data point in the training set, comprising a feature vector xi and an observed class yi, the probability of the class was represented as p if yi equaled 1, or 1 − p if yi equaled 0. The likelihood was subsequently calculated based on these probabilities.

$$L(\beta_{0,}\beta)=\prod_{i=1}^{n}p(x_1)^{y_1}(1-p(x_i))^{1-y_i} \text{ -------- (4)}$$

$$\ell(\beta_{0,}\beta)=\sum_{i=1}^{n}y_i\, logp(x_i)+(1-y_i)log1-p(x_i)$$

$$\ell(\beta_{0,}\beta)=\sum_{i=1}^{n}log1-p(x_i)+\sum_{i=1}^{n}y_i log\frac{p(x_1)}{1-p(x_i)}$$

$$\ell(\beta_{0,}\beta)=\sum_{i=1}^{n}log1-p(x_i)+\sum_{i=1}^{n}y_i(\beta_0+x_i.\beta)$$

$$\ell(\beta_{0,}\beta)=\sum_{i=1}^{n}-log1+e^{\beta_{0+x_i}.\beta}+\sum_{i=1}^{n}y_i\,(\beta_0+x_i.\beta)$$

The process of determining the maximum likelihood estimates, the common approach involved taking the derivative of the log-likelihood concerning the parameters. This was followed by setting these derivatives to zero and solving for the parameters.

$$\frac{d\ell}{d\beta_j}=-\sum_{i=1}^{n}\frac{1}{e^{\beta_{0+x_i}.\beta}e^{\beta_0+x_i.\beta}}\;x_{ij+}\;\sum_{i=1}^{n}y_ix_{ij} \text{ ------- (5)}$$

$$\frac{d\ell}{d\beta_j}=-\sum_{i=1}^{n}(y_i-p(x_i\,;\;\;\beta_0,\beta))x_{ij}$$

$yi=\alpha+\beta_{i1}xi_1+\beta_{i2}xi_2+\cdots+\beta_{ik}x_{ik}+\varepsilon_i$ Where y represented the dependent variable under observation on the pretext of the changes of variables represented by $\beta_1x_1+\beta_2x_2+\cdots+\beta_kx_k$ also known as independent variables or predictors. α and β are coefficients to be estimated. Specifically, α is the intercept or constant of the equation and β was the slope of the equation line. The intercept gave us the variation in y that was not being explained by the variable(s) under consideration. εi represented the error term to indicate the uncertainty in the model. The model explicit form was presented as follows; $Adoption\ of\ HB = \alpha + \beta_1 gender + \beta_2 age + \beta_3 householdhead + \beta_4 marital\ status + \beta_5 income\ level + \beta_6 education + \beta_7 total\ harvest + \beta_8 farming\ and\ capentry + \beta_9 farming\ and\ tailoring + \beta_{10} farming\ and\ other\ businesses + \beta_{11} extension + \beta_{12} friends + error\ term$

3.7.5 Definition and measurement of variables

Table 2: shows the names of the variables identified and used in the model, including their definitions and expected relationships from the literature reviewed in Chapter Two. These variable specifications guided the empirical analysis presented in Chapter Four, enabling a systematic examination of variables.

Table 2: Variables definition and expected relationship

SN	Sub variables	Description	Expected sign
1	Adoption of hermetic bags	1=Yes, 0= No	
2	Gender	1 = male, 0 = female	-
3	Age	In years (continuous)	+
3	Education	In years (continuous)	+
4	Marital status	1=married, 0=others	+
5	Family male member	In number (continuous)	+
7	Crop income	In kwacha (continuous)	+
8	Livestock income	In kwacha (continuous)	+
9	Knowledge	1 = Yes, 0 = No	+
11	Total expenditure	In kwacha (continuous)	+
12	Farming experience	In years (continuous)	+
13	Access to extension services	1=Yes, 0=No	+
14	Active male members	In numbers (continuous)	+
15	Active female members	1=Yes, 0=No	-
16	Access to formal training	1=Yes, 0=No	+
17	Access to non-formal training		+
18	Farm size operated	1=Yes, 0=No	-
19	Size of acres	In acres (continuous)	-

Source: Author's conceptualization

The variables that were used include Gender of respondents, marital status, age of respondents, literacy level, awareness method, occupation, relationship to household head, harvest storage type, harvest size, and income level. Furthermore, the t-test was used to determine the factors that determine adoption. The study used a dependent t-test (called the paired-samples in SPSS statistics) to compare the means in the yield between adopters and non-adopters, and the non-adopter was to determine whether there was a significant difference, which would be attributed to the adoption of hermetic bags. Data was then analysed using transcribed verbatim; the researcher manually identified the themes, views, opinions, and feelings expressed by the respondents during the interviews to allow themes to emerge by the respondents during the interviews, where a voice recorder was used. Then, the researcher manually identified the themes, which were categorised according to the research objective and reported in narrative form along with the quantitative form.

3.7.6 Dependent Variable

Hermetic Bag Adoption constitutes the dependent variable, measured as a binary outcome where 1 represents farmers who have adopted hermetic bags for post-harvest storage and 0 represents non-adopters. Following Rogers' (1962) Diffusion of Innovation Theory, adoption is operationalized as the actual use of hermetic bags during at least one post-harvest storage cycle, regardless of whether bags were purchased or donated, (Baributsa et al., 2017; Díaz-Valderrama et al., 2020).

3.7.6.1 Demographic Variables

a) Age

Age was measured as a continuous variable representing the respondent's age in completed years at the time of survey. Literature suggested a non-linear relationship with adoption: older farmers possessed greater farming experience and risk awareness favoring adoption, while simultaneously exhibiting greater resistance to innovation (Feder et al., 1985; Manda & Mvumi, 2019). The expected sign remained ambiguous, requiring empirical determination within the Chikhwawa context.

b) **Gender**

Gender was operationalized as a binary variable coded 1 for male respondents and 0 for female respondents. Consistent with gender and development literature, males typically demonstrated higher technology adoption rates due to superior access to productive resources, agricultural extension services, credit facilities, and decision-making authority within household structures (Doss & Morris, 2001; Njuki et al., 2011). A positive coefficient was anticipated.

c) **Marital Status**

Marital Status was measured categorically with three levels: married (baseline category), divorced, and widowed. Married farmers theoretically benefitted from enhanced household labour availability, pooled resources, and shared decision-making that facilitated technology adoption investments (Kpadonou et al., 2017). The variable captured household stability and resource availability affecting adoption capacity, with married status expected to positively influence hermetic bag adoption.

d) **Education Level**

Education Level represented years of formal schooling completed by the respondent, measured as a continuous variable ranging from zero (no formal education) to the highest educational attainment. Educational attainment enhanced comprehension of technology benefits, ability to process technical information, risk assessment capabilities, and proper usage implementation (Knight et al., 2003; Baributsa et al., 2017; Kumar & Kalita, 2017). A positive relationship was anticipated. Education facilitated access to written extension materials, product instructions, and agricultural information disseminated through printed media, complementing formal education's effect on technology adoption (Aker, 2011).

3.7.6.2 Socio-Economic Variables

a) Household Size

Household size measured the total number of individuals permanently residing in the household, captured as a continuous variable. Theoretical expectations remained ambiguous: larger households provided expanded labour availability for agricultural activities supporting adoption, while simultaneously facing intensified resource constraints and competing expenditure demands that constrain technology investment (Kassie et al., 2013; Shifera et al., 2014). Empirical evidence will determine the net effect.

b) Income Level

Income level represents total annual household income measured in Malawi Kwacha, functioning as a proxy for purchasing power and liquidity constraints. It was anticipated that higher income households could more readily afford hermetic bags' upfront costs, absorb potential technology failure risks, and make future-oriented investments without threatening immediate consumption needs (Foster & Rosenzweig, 2010; Suri, 2011). A positive coefficient aligning with economic theory was expected.

c) Occupation

Occupation was categorized to distinguish households engaged exclusively in farming from those combining farming with supplementary income-generating activities including carpentry, tailoring, or small-scale business. Income diversification potentially provided capital for agricultural investments while reducing vulnerability to agricultural shocks, though it may diminish farming focus (Kassie et al., 2011; Teklewold et al., 2013). The expected relationship remained theoretically ambiguous.

d) Farm Size

Farm size measurements included total cultivated land area in acres as a continuous variable. Larger farms generated greater agricultural output requiring proper storage infrastructure, experience economies of scale in technology adoption, and faced potentially larger absolute post-harvest losses motivating protective investments (Langyintuo & Mungoma, 2008; Shiferaw et al., 2014). A positive relationship between farm size and hermetic bag adoption was theoretically expected.

e) Harvest Size

Harvest size captured total maize quantity harvested, measured in standard 50-kilogram bags, serving as a continuous variable reflecting production scale. Larger harvests created intensified storage requirements, magnified potential economic losses from inadequate storage, and justified investments in improved storage technologies that protect substantial harvest values (Affognon et al., 2015; De Groote et al., 2013). Positive association with adoption was anticipated.

f) Total Harvest Stored

Total harvest stored represented the proportion of total harvest retained for storage rather than immediately consumed or sold, measured as a continuous variable ranging from 0 to 1. Farmers storing larger proportions face extended exposure to storage pests and losses, creating stronger motivation for effective storage solutions like hermetic bags (Tefera et al., 2011; Njoroge et al., 2019). A positive coefficient was expected.

g) Total Amount Spent on Chemicals

Total Amount Spent on Chemicals measures annual expenditure on storage pesticides including aluminum phosphide (phosphine) in Malawi Kwacha. The expected relationship is ambiguous: high chemical expenditures may motivate seeking cost-effective alternatives like hermetic bags, or alternatively indicate path dependency and complementarity where farmers supplement hermetic storage with chemical treatments (Baributsa & Njoroge, 2020). Empirical analysis will clarify the direction.

3.7.6.3 Information Access Variables

a) Awareness of HBST

Awareness of HBST was operationalized as a binary variable where 1 indicated that the respondent had heard about hermetic bags for post-harvest storage and 0 indicated no awareness at all.

Following Rogers' (2003) innovation-decision process, awareness constituted the foundational prerequisite stage preceding adoption consideration, with “awareness” farmers substantially more likely to adopt the technology (Díaz-Valderrama et al., 2020). A positive coefficient was theoretically expected.

b) Knowledge of HBST

Knowledge of HBST use measured whether respondents possessed practical understanding of proper hermetic bag usage techniques, and whether it was coded as a binary variable. Technical knowledge encompassing proper drying requirements, correct sealing procedures, handling practices, and troubleshooting differentiated mere awareness from adoption-enabling competence (Baributsa et al., 2020; Affognon et al., 2015). Farmers with operational knowledge demonstrated higher adoption likelihood.

3.7.6.4 Extension Worker and Other sources of information

Extension Worker Contact was measured as a binary variable indicating whether the respondent received information about hermetic bags through agricultural extension services. Extension workers provided credible technical information, demonstrations, and ongoing support that reduce perceived risks and build adoption confidence (Anderson & Feder, 2007; Genius et al., 2014). A positive relationship with adoption was anticipated based on extension effectiveness literature.

Information from friends captured whether respondents learned about hermetic bags through informal social networks including friends, neighbours, or relatives, which was coded as binary. Peer information and observational learning from trusted community members reduced uncertainty, provided locally-credible evidence, and facilitated technology diffusion through social networks (Bandiera & Rasul, 2006; Conley & Udry, 2010). Positive influence on adoption was expected.

Information from Lead Farmers indicated whether respondents received hermetic bag information from designated lead farmers or agricultural champions within their communities. Lead farmers served as locally-embedded innovation promoters who combined peer credibility with enhanced technical knowledge, bridging formal extension systems and farming communities (David, 2004; Franzel et al., 2014). A positive coefficient was anticipated.

Information from media measured exposure to hermetic bag information through mass media channels including radio broadcasts, television programs, or printed materials, which was operationalized as binary. Mass media expanded information reach beyond immediate social networks, created general awareness, and reinforced messages from interpersonal sources, though its effectiveness varied by media type and message design (Munshi, 2004; Aker, 2011). Positive influence was theoretically expected.

3.7.6.5 Storage-Related Variables

Storage type categorized farmers' primary post-harvest storage methods distinguishing traditional approaches (baskets, pots, jars, plastic containers, conventional polypropylene sacks) from modern hermetic technologies (PICS bags, Zero Fly bags). Current storage practices reflected existing technology awareness, openness to improved methods, and baseline storage infrastructure, with modern storage users more receptive to hermetic bag adoption (Tefera et al., 2011; De Groote et al., 2013).

Total expenditure on hermetic bags measured cumulative spending on hermetic bag purchases in Malawi Kwacha as a continuous variable. This variable captured both adoption intensity (number of bags purchased) and sustained commitment to the technology. Higher expenditures indicated strong adoption with multiple bags or repeated purchases across seasons, reflecting positive experiences and economic capacity for continued investment (Mutambuki et al., 2021; Opit et al., 2018).

3.8 Ethical Consideration

Ethics served as a standard for moral judgement and action. In essence, they served as the ethical principles that guide action. According to Mugenda & Mugenda (2003), ethics is the branch of philosophy that addresses behaviour and serves as a moral code. The study had been carefully planned, vetted, and executed to assure honesty, quality, and transparency. The confidentiality of any information provided by respondents, as well as their respondents' anonymity, was upheld. There would be no use of compulsion to compel study volunteers to participate in the study, and every effort was done to protect them from damage. Ethical approval was obtained from Mzuzu University Ethics Commitees. Participation in the study was voluntary.

CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter presents the study conducted in the district of Chikhwawa, encompassing two Extension Planning Areas (EPAs) known as Mitole and Kalambo. The initial section provides a concise overview of the findings from the descriptive analysis conducted on determinants and barriers to adopting Hermetic bag storage technology (HBST). The socio-economic analysis examined the elements that influence the decision to adopt or not adopt hermetic bags as a post-harvest management storage technology. It aimed at creating a deeper understanding and awareness of the hermetic bags among the respondents. The econometric analysis presents factors influencing adoption of hermetic bags as post-harvest management storage technology.

4.2 Demographic and Socio-economic Characteristics of Respondents

To understand the variables used in the regression models, inferential statistics, that is, chi-square and t-tests, were computed, and the results are indicated in Table 3 and Table 4. It can be observed from Table 3 that there were significant differences between adopters and non-adopters of hermetic bags on four out of seven variables at a 5% significant level. The variables that show considerable differences are as follows: gender, relationship to household head, occupation, and education level of respondents.

4.2.1 Household head of the respondents

The Chi-squared test indicates no significant difference in adoption rates based on household head (Chi2 = 0.0865, p = 0.958). Among male-headed households, 52.02% were non-adopters, and 34.39% were adopters. For female headed households, the corresponding percentages were 7.08% and 5.20%, and for child headed households, both percentages are 0.29%. The findings suggested that there were more male headed households than female headed households in the study area.

Table 3: Demographic and Socio-economic Characteristics of Respondents

Variable	Category	Non- Adopters %	Adopters %	Chi-square
Gender	Female	33.82	13.58	16.3***
	Male	26.3	26.3	
Marital status	Married	54.62	35.55	2.2 **
	Divorced	3.18	3.47	
	Widowed	2.13	0.87	
Household Head	Male HH	52.02	34.39	0.08 **
	Female HH	7.08	5.2	
	Child HH	0.29	0.29	
Relationship to HH	Head	16.76	21.21	23.6 ***
	Spouse	43.06	18.39	
	Other	0.29	0.29	
Occupation	Farming only	56.94	35.26	11.8 **
	Faming & Carpentry	0.29	0.58	
	Farming & Tailoring	0	1.73	
	Farming & Business	2.89	2.29	
	Other	0	0.29	
Farmers Literacy	Read Only	7.8	5.49	8 0**
	Read & write	43.35	23.7	
	None	8.96	10.69	
Storage Type	Basket/Pot Jar/Plastic	60.12	17.63	0.78*
	PICS Bags/ Zero Fly	0	22.25	

*** Significant at 1% ** significant at 5% * significant at 10%

4.2.2 Gender of respondents

Table 3 presents a comprehensive breakdown of the adoption of hermetic bag storage technology, examining it through the lenses of household gender. Notably, males constitute 52.02% of non-adopters and 34.39% of adopters, totalling 299 individuals, while females represent 7.08% of non-adopters and 5.20% of adopters, totalling 47 individuals. Despite these variations, a Chi-squared test indicates no statistically significant association between gender and technology adoption (p = 0.958). This implies that many households in the study area are male-headed.

4.2.3 Marital status

Regarding marital status, the majority of the respondents were married, totaling 312, representing 90.17%, followed by divorced 23, representing 6.65%, and widowed 11, representing 3.18% of the total 346 respondents. Among married individuals, 39.10% adopted Hermetic bags, compared to 60.90% who did not. Similarly, 60.87% of divorced individuals adopted, whereas only 18.18% of widowed individuals did. These findings suggest that many households in the study area are married.

4.2.4 Relationship to Household Head

An investigation into the relationship among the households head reveals significant disparities. Those identified as the household head account for 16.76% of non-adopters and 21.21% of adopters, amounting to 132 individuals, while spouses, comprising 43.06% of non-adopters and 18.39% of adopters, total 212 individuals. This discrepancy is statistically significant ($p < 0.001$), suggesting that more respondents were spouses in the study area.

4.2.5 Occupation of Respondents

The table presents data on the respondents' occupations and the adoption of hermetic bags as post-harvest storage. Among adopters, farming-only individuals comprise the largest group (27.62%), followed by farming and carpentry (15%) and farming and business (22%). Interestingly, those solely in farming show the lowest adoption rate. Non-adopters are predominantly on farming only (72.38%). The Pearson Chi2 value (94.71) indicates a significant association between occupation and adoption ($p < 0.001$). This implies that most people in the study area depend on farming only.

4.2.6 Farmers literacy

The analysis explores the relationship between farmers' literacy levels and the adoption of HBST, revealing significant associations (Chi2 = 8.0181, p = 0.018**). Farmers who can only read exhibit a non-adoption rate of 7.80%, whereas those who can read and write show a higher adoption rate of 23.70%. Interestingly, farmers with no literacy knowledge also demonstrate a notable adoption rate of 10.69%. This suggests that literacy, to some extent, influences the adoption of HBST, with literacy farmers, especially those who can read and write, demonstrating a higher propensity to adopt.

4.2.7 Storage Types

Table 3 examines the relationship between storage types and the adoption of HBST on the significance levels. The Chi-squared test yields a p-value of 0.0764, which falls above the conventional 5% significance level. Therefore, the association is not statistically significant at the 5% level, but it exhibits a trend that is considered marginally substantial ($p < 0.1$). Among those using Basket/Pot Jar/Plastic storage, 60.12% are non-adopters, and 17.63% are adopters. In contrast, PICS Bags/Zero Fly storage users display a higher adoption rate of 22.25%. The results, therefore suggest that most of the farmers in the study area use conventional methods sacs, Jerry can, pots) than modern methods (Hermetic bags).

4.2.8 Age of respondents

The t-test examining respondents' ages, stratified by their Hermetic Bag Storage Technology (HBST) adoption status, reveals a statistically significant difference. The "Adopted" group, with a mean age of 37.46, displays a lower average age than the "Not adopted" group, with a mean age of 41.14 (mean difference = -3.69, p = 0.009). This finding implies that individuals who were adopters of the HBST were younger on average than those who were non-adopters in the study area.

Table 4: Demographic Characteristics of Continuous Descriptive Statistics

Variable	Adopters (n1=138)	Non-Adopters (n2=208)	T-test	P value
Age	37.45588	41.14286	-2.379	0.991
Education Level	6.97	7.05	46.0709	1.000***
Household Size	4.47	4.57	41.0699	0.0001*
Level of Income	73586.95	83846.15	0.8886	0.1874*
Farm Size	5.264706	1.890476	8.713	0.000***
Harvest Size	22.63235	12.45714	5.4825	1.0000*
Total Harvest stored	0.2173913	0.0528846	3.3727	0.9996***
Total Amount-chemicals	260.8841	480.7981	1.3315	0.1839**
Total Expenditure on HB	40942.03	2932.692	-12.6736	1.0000*

*** Significant at 1% ** Significant at 5% * Significant at 10%

4.2.9 Education Level

The analysis of education levels reveals a diverse distribution among respondents. A significant proportion, 38.44%, have completed secondary education, indicating a substantial base of basic academic knowledge. Primary education follows closely, with 26.30%, suggesting a foundational understanding among a considerable portion of the population. However, 20.81% lack formal education, indicating a need for essential educational interventions. Tertiary education stands at 14.45%, indicating a smaller but notable portion with advanced academic qualifications. However, statistical tests (Pearson chi-squared and t-test) reveal no significant difference in adoption rates based on education level (p = 0.260 and p = 0.0691, respectively).

4.2.10 Household Size

This t-test assessed the household size between the adopters and non-adopters of hermetic bag storage technology. The mean household size is 4.53, while the mean adoption status is 0.40. The paired difference (mean household size - mean adoption status) is 4.13, indicating a substantial positive difference. The t-statistic of 41.0699 with a p-value close to zero ($p < 0.0001$) suggests a highly significant difference.

4.2.11 Income Level

Table 4 provides a comparison of the level of income between two groups: Adopters (n1=138) and non-Adopters (n2=208). The mean income for adopters is K73,586.95, whereas non-adopters have a higher mean income of K83,846.15. The T-test statistic (2.6187) indicates a statistically significant difference between the two groups. The associated p-value (0.0092) is less than 0.01, indicating significance at the 1% level. In statistical terms, this suggests that there is a very low probability (less than 1%) that the observed difference in income between Adopters and Non-Adopters occurred by random chance alone. This finding supports the conclusion that the level of income is significantly different between the two groups in the study area.

4.2.12 Harvest Size and Farm Size

In this study, we conducted t-tests to explore the impact of adopting hermetic bags on harvest. The t-test outcomes for "Harvest Size" and "Farm Size," categorized by the adoption status of Hermetic Bag Storage Technology (HBST), reveal noteworthy patterns. In terms of "Haverst_Size," the "Adopted" group demonstrates a significantly higher mean harvest size (22.63) compared to the "Not adopted" group (12.46), indicating a substantial mean difference of 10.18 ($p < 0.001$). This finding suggests a positive association between HBST adoption and increased harvest quantities, potentially reflecting enhanced post-harvest management. Similarly, regarding "Farm Size," the

"Adopted" group exhibits a substantially larger mean farm size (5.26) than the "Not adopted" group (1.89), with a mean difference of 3.37 ($p < 0.001$). These results underscore the correlation between HBST adoption also larger harvest sizes and expanded farm areas, as farmers who had smaller farm sizes and harvest sizes were mostly mainly non-adopters. In contrast, farmers of large farm sizes and harvest sizes were adopters in the study area.

4.2.13 Total Amount Spent on Chemicals

The two-sample t-test assessed the relationship between hermetic bag adoption and the total amount spent on chemicals. In the "Not adopted" group (n=208), the mean expenditure was K480.80, while in the "Adopted" group (n=138), it was notably lower at K260.88. The combined dataset of 346 observations had an overall mean expenditure of K393.09. The difference in means between the two groups was 219.91, and the t-statistic was 1.3315. Despite the positive t-value, the associated p-value (0.1839) indicates that the observed difference is not statistically significant at the conventional significance level of 0.05. Therefore, we do not find sufficient evidence to reject the null hypothesis, suggesting that hermetic bags adoption is not significantly associated with differences in the total amount spent on chemicals.

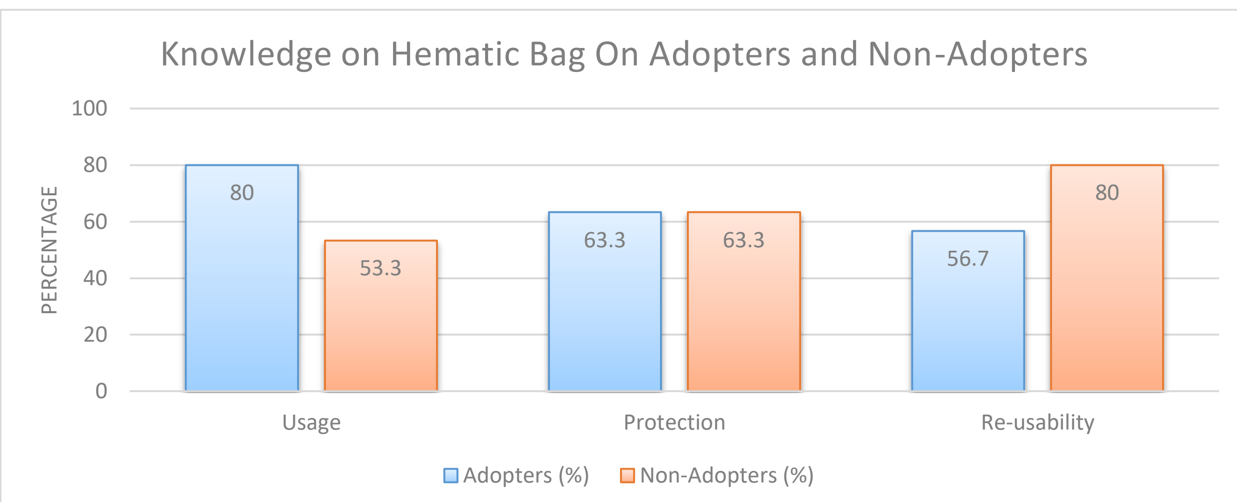
4.2.14 Total Expenditure Used on Hermetic Bags

The study examined the total expenditure used for the hermetic bags. In the "Not adopted" group (n=208), the mean expenditure was $2,932.69, while in the "Adopted" group (n=138), it significantly increased to $40,942.03. The overall mean across both groups was $18,092.49. The difference in means between the two groups was substantially at -$38,009.34, with a highly significant t-statistics of -12.6736 ($p < 0.05$). This compelling evidence supports rejecting the null hypothesis (H0: diff = 0), indicating a significant difference in funds allocated to hermetic bags between adopters and non-adopters. Adopters, on average, invested significantly more funds in hermetic bags than non-adopters.

4.3 Farmers' level of knowledge on Hermetic Bags Technology

Figure 3 shows that 80.0% of the adopters had knowledge about the usage (process on how to use the bags). Non-adopters had 46.7% of the respondents who had no knowledge about the usage. The majority (63.3%) of the adopters had knowledge that the bags provides strong protection to the farm produce stored. Among the non-adopters, 36.7% of them did not have the knowledge about the protection provided by the bags. It was also found that 56.7% of the adopters had knowledge that the bags can be re-used even for three growing seasons. On the other hand, 20% of the non-adopters had no knowledge of re-usability. This indicates that knowledge significantly influences adoption as a higher percentage of informed individuals adopted hermetic bags than uninformed ones. The results suggest that awareness campaigns could enhance adoption rates, improving post-harvest storage practices among users.

Figure 3: Hermetic Bags Knowledge: Adopters vs. Non-Adopters



Based on the participants' knowledge of Hermetic Bags Technology for both adopters and non-adopters the study finds that:

A male adopter aged 45 argued that *"Since I started using hermetic bags, I have noticed a significant reduction in grain losses. My maize stays fresh and free from pests for longer periods."*

However, a 42 years old male non-adopter stated that *"The cost of hermetic bags is too high for me. I have other priorities, and I can't afford to spend money on something I'm not sure will work.*" On the same, the adopter states that *"The initial cost was high, but the savings from reduced spoilage and the ability to sell my produce at better prices have made it worthwhile.*" - Adopter, Female, 38 years old. *"I was skeptical at first, but after attending a demonstration, I realized how easy it is to use hermetic bags. Now, I encourage my neighbours to try them too."* - Adopter, Male, 50 years old. However, non-adopters argue, *"I have heard about hermetic bags, but I don't know much about how they work or where to get them. We need more information and support."* A non-adopter, Female 30 years another non-adopter, added, *"I have seen new technologies come and go. Some work, some don't. I prefer to stick with what I know works, even if it means dealing with some losses."* - Non-Adopter, Female, 55 years old.

4.3.1 Awareness of HBST and Adoption

Table 4 shows the awareness of Hermetic Bag Storage Technology (HBST) amongst farming households and its adoption as post-harvest storage management. Among respondents who were aware of the existence of the technology, 125 (90.58%) adopted it, while 133 (63.94%) non-adopters were also aware of HBST but did not adopt it. Conversely, among those unaware of HBST, only 13 (9.42%) used it, with a more significant proportion of non-adopters at 75 (36.06%). This discrepancy suggests that awareness strongly influences adoption, with a Pearson Chi2 value of 31.04 indicating a significant relationship (Prob = 0.0000). These findings emphasize the importance of increasing awareness to drive the adoption of HBST for efficient post-harvest management.

4.3.2 Perception of Barriers to HBST Adoption

Table 5 presents data on perceptions of barriers to adopting Hermetic Bag Storage Technology. Among those with knowledge of usage, the primary demotivation was the perceived expense (22.84%), scarcity (21.32%), and limited knowledge of use (39.59%). Interestingly, a notable proportion (14.72%) cited "N/A," indicating a complex array of factors. For those with limited knowledge, the key demotivation included a lack of understanding of hermetic bags (5.37%) and perceived expense (14.09%). Furthermore, the data indicate a considerable gap in knowledge, with limited knowledge and understanding contributing significantly to non-adoption. The findings that 40.27% of those who have not adopted HBST cited a limited knowledge of hermetic bags, highlighting an opportunity for targeted educational initiatives.

Table 5: Factors and demotivation of not Adopting Hermetic Bag Storage Technology

Knowledge and Usage Status	Barriers and Information Sources	Percentage (%)
Users (Yes)	**Barriers**	
	Expensive	22.84
	Scarcity	21.32
	Lack of Knowledge on use	39.59
	Lack of Knowledge on HBs	1.52
	N/A	14.72
Non-Users (No)	**Barriers**	
	Expensive	14.09
	Scarcity	28.86
	Lack of Knowledge on use	40.27
	Lack of Knowledge on HBs	5.37
	N/A	11.41
Awareness	**Sources of awareness**	
Aware (74.57%)	Extension Worker	37.28
	Friends	3.47
	Media	1.73
	Lead Farmer	31.5
	N/A	0.58
Not Aware (25.43%)	N/A	25.43

Note: Pearson Chi2 = 335.69, Prob = 0.0000

The table above shows that demotivation underscores the need for comprehensive strategies addressing economic concerns and knowledge gaps. Initiatives that focus on cost-effectiveness and disseminate information about the advantages of Hermetic Bag Storage Technology could be pivotal in overcoming barriers to adoption. This analysis illuminates key areas for intervention, guiding efforts to promote the widespread acceptance of this technology in post-harvest management practices. Table 5 presents a tabulation of awareness regarding the use of hermetic bags for post-harvest management. Among the surveyed farmers, 74.57% are aware of hermetic bags, with the primary sources of awareness being extension workers (37.28%), friends (3.47%), Media (1.73%), and lead farmers (31.50%). Notably, 25.43% of farmers remain unaware. The Pearson Chi2 test indicates a significant association ($p = 0.0000$) between awareness and information sources. This underscores the importance of leveraging extension workers and lead farmers in disseminating knowledge about hermetic bags, potentially enhancing adoption rates and promoting effective post-harvest practices.

4.3.4 Reasons for adopting or not adopting amongst farmers

The findings in Table 6 reveal that 39.9% of farmers use hermetic bags (HB) for post-harvest management, while 60.1% do not. Among users, the primary reasons include seeking strong protection (32.7%), reusing bags (3.5%), and preferring chemical-free storage (3.8%). Interestingly, a significant portion of non-users (60.1%) marked "N/A," indicating a potential lack of awareness or indifference. Non-users cited reasons such as cost (10.1%), scarcity (11.6%), limited knowledge on usage (7.5%), and lack of knowledge about HB (30.9%). These findings underscore the need for targeted education and awareness campaigns to promote hermetic bag adoption among farmers.

Table 6: Reasons for using HBST

Category	Description	Percentage (%)
Reasons for using HB	Strong Protection	32.7
	Re-Used	3.5
	Chemical Free	3.8
	N/A	60.1
Reasons for not using HB	Expensive	10.1
	Scarcity	11.6
	Limited knowledge on usage	7.5
	Lack of knowledge of HB	30.9
	N/A	39.9

4.3.5 Adoption Motivations and Duration of Hermetic Bag Use

Table 6 illustrates farmers' motivations for using hermetic bags (HB) in post-harvest management and the corresponding duration of adoption. Strong protection emerged as the predominant reason, constituting 34.10% of responses, followed by re-usability (2.02%) and chemical-free storage (3.76%). Notably, 60.12% of respondents selected "N/A" for motivations, indicating a potential gap in understanding or being aware of the technology. Regarding the duration of adoption, a significant proportion (60.12%) reported "N/A," emphasizing the need for targeted interventions and education on the benefits and duration of HB utilization. The findings underscore farmers' diverse motivations and awareness levels in adopting hermetic bag technologies.

Table 7: Period participants used the hermetic bag as post-harvest storage Technology

Why using hermetic bags?	**How long have you been using hermetic bags**					
	N/A	**1 Year**	**2 Years**	**3 Years**	**4 Years**	**Total**
Strong protection	0.00	17.05	5.20	10.69	1.16	34.10
Re-usable	0.00	1.73	0.29	0.00	0.00	2.02
Chemical free	0.00	3.47	0.00	0.29	0.00	3.76
N/A	60.12	0.00	0.00	0.00	0.00	60.12
Total	60.12	22.25	5.49	10.98	1.16	100.00

Pearson Chi2 = 376.11 Prob = 0.0000

4.3.6 Sources of Information on Hermetic Bags

Table 8 outlines farmers' diverse sources of information on hermetic bags (HB) for post-harvest management and identifies the sponsoring institutions or organizations, particularly for extension workers and research scientists. Notably, the government emerged as a significant source (36.99%), followed by NGOs (33.24%). Friends and lead farmers also played notable roles, contributing 22.54% and 6.94%, respectively. However, 25.72% of respondents indicated "N/A," underscoring the need for enhanced awareness campaigns specifying the responsible institutions and organizations disseminating HB-related information. The findings highlight the importance of targeted information sources to enhance farmers' knowledge and adoption of hermetic bag technologies.

Table 8: Tabulation of Information Source on HBST

Source of Information	Government (%)	NGO (%)	Other (%)
Extension Worker	26.59	13.58	0
Friends	4.34	17.63	0.29
Media	0.29	0.58	3.76
Lead Farmer	5.2	1.45	0.29

Pearson Chi2 = 637.74 Prob = 0.0000

4.4 Analyzing the Factors influencing Adoption of Hermetic Bags

Table 9: Factors influencing adoption of Hermetic Storage Technology

Hermetic Bags Use	Coef.	St.Err.	p-value	Sig
Age	0.045	0.015	0.002	***
Marital Status	-0.346	0.564	0.539	
Gender	-1.305	0.475	0.006	***
Household Head	-0.088	0.590	0.881	
Household Size	-0.741	0.135	0.000	***
Income Level	0.000	0.000	0.237	
Education	8.0181	0.324	0.018	**
Farm size	-0.507	0.340	0.136	
Harvest size	0.035	0.075	0.642	
Total Harvest	-0.721	0.433	0.096	*
Farming & Carpentry	1.053	1.422	0.459	
Farming & Tailoring	-1.344	1.362	0.324	
Farming & business	0.345	0.737	0.640	
Extension Worker	0.777	0.376	0.039	**
Friends informed	0.138	0.847	0.871	
Constant	0.386	1.225	0.753	
Mean dependent var	0.281			
Pseudo r-squared	0.261			
Chi-square	77.192			
Akaike crit. (AIC)	250.626			
SD dependent var	0.450			
Number of obs	249.000			
Prob > chi2			0.000	
Bayesian crit. (BIC)	306.905			

**** p<.01, ** p<.05, * p<.1*

The Binary logistic regression model's pseudo-R-squared value of 0.166 indicates that the included variables collectively explain 16.6% of the variance in hermetic bag adoption. The chi-square value of 77.472, with a p-value of 0.000, supports the model's overall significance. Notably, the positive coefficient for Harvest-Storage (1.056) suggests a strong positive association between effective harvest storage practices and hermetic bag adoption. However, surprisingly, income level shows no significant impact. The findings highlight the multifaceted nature of adoption determinants, emphasizing the need for targeted interventions addressing factors like age, literacy, awareness methods, and specific agricultural practices to enhance hermetic bag adoption among farmers.

4.4.1 Age

Age shows a statistically significant positive relationship with hermetic bag use. For each year increase in age, the likelihood of using hermetic bags increases by 0.045 units. The low p-value (0.002) and high t-value (3.030) indicate a robust relationship, suggesting that older individuals are more likely to adopt this agricultural storage technology, potentially due to greater experience and risk awareness.

4.4.2 Gender

Gender demonstrates a significant negative association with hermetic bag use. The highly significant p-value (0.006) and negative coefficient (-1.305) suggest that gender plays a considerable role in technology adoption. This could indicate differential access to information, resources, or decision-making power between genders in agricultural technology implementation.

4.4.3 Education

The results indicate a significant positive relationship between farmers' education and the adoption of hermetic bag storage technology, with a coefficient of 8.0181 and a p-value of 0.018, which is statistically significant at the 10% level (denoted by **). This suggests that higher education among farmers positively influence their decision to adopt hermetic bag storage technology. The findings highlight the importance of education and awareness in promoting the adoption of innovative agricultural practices, which can enhance food security and reduce post-harvest losses in farming communities.

4.4.4 Household Size

The results reveal a significant negative relationship between household size and the adoption of hermetic bag storage technology, with a coefficient of -0.741 and a p-value of 0.000, which is statistically significant at the 1% level. The coefficient and extremely low p-value suggest that larger households are less likely to use hermetic bags. This might relate to resource constraints, competing priorities, or risk management strategies in, more prominent families.

4.4.5 Total Harvest

The results show a negative relationship between total harvest and the adoption of hermetic bag storage technology, with a coefficient of -0.721 and a p-value of 0.096, which is statistically significant at the 10% level (denoted by *). This suggests that farmers with larger harvests are less likely to adopt hermetic bag storage technology, possibly due to higher costs associated with scaling the technology for larger quantities.

4.4.6 Extension Worker

Extension worker interaction shows a significant positive relationship with hermetic bag use. The positive coefficient (0.777) and low p-value (0.039) suggest that engagement with agricultural extension services increases the likelihood of adopting hermetic bag technology, highlighting the importance of knowledge dissemination. On the other hand, some variables were not statistically significant and therefore could not influence the level of adoption or non-adoption among respondents in the study. These variables include; Marital status, household head, income level, farm and harvest size.

4.4.7 Model Statistics

The model demonstrates good explanatory power with a pseudo-r-squared of 0.261, indicating that the variables explain approximately 26.1% of the variation in hermetic bag usage. The significant chi-square value (77.192) and very low p-value (0.000) suggest the model is statistically robust overall.

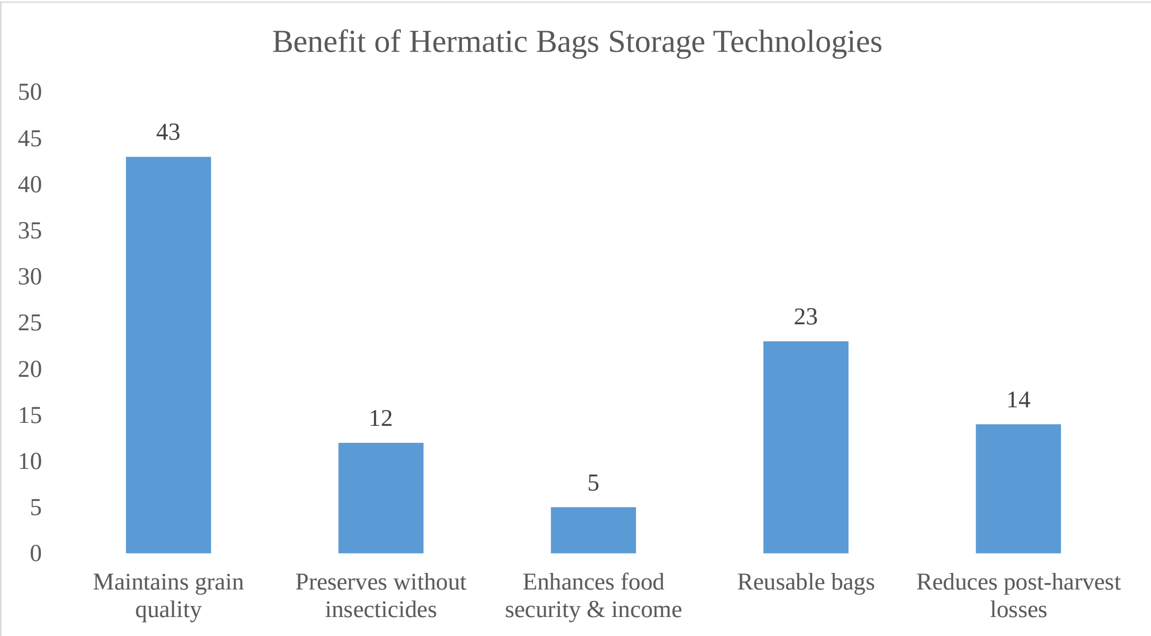
4.5 **The benefits and challenges that farmers face in using Hermetic bags.**

Farmers expressed appreciation for the improved quality of stored grains. One farmer remarked, "*Our maize stays fresh and tasty even after months of storage. Buyers prefer our grains now."* This sentiment was echoed by a local trader who stated, *"Grains from Hermetic bags fetch better prices in the market due to their superior quality."* One farmer stated, *"These bags have been a game-changer for us. We can store our grains for months without worrying about pests or moisture."* Another key informant, a local agricultural officer, noted, *"Hermetic bags have significantly reduced post-harvest losses in our community."* However, challenges were also identified. A farmer explained, *"The initial cost of these bags is high for some of us. It's a big investment."* A community leader added, *"There's a need for more training on proper usage. Some farmers aren't sealing the bags correctly, which reduces their effectiveness."* A female farmer highlighted accessibility issues: *"These bags aren't always available in our local markets. We have to travel far to get them."* Additionally, a focus group discussion revealed concerns about reusability. An elder farmer explained, *"We're unsure how long these bags last. If they're damaged, we don't know how to repair them."* The study also found that proper usage remained a challenge. An agricultural extension officer observed, *"Some farmers struggle with the sealing process. If not done correctly, it compromises the effectiveness of the bags."* This was corroborated by a farmer who admitted, *"The first time I used the bag, I didn't seal it properly. I lost a significant portion of my harvest to pests."*

4.5.1 Benefits of Hermetic Bags Storage Technology

The data illustrates the multiple benefits of Hermetic Bag Storage Technology. Primarily, it maintains grain quality (44.51%), preserving produce without insecticides (12.72%), thereby enhancing food security and income (4.34%). Additionally, farmers appreciate the bags' reusability (25.14%) and their effectiveness in reducing post-harvest losses (13.29%). These findings underscore the multifaceted advantages of Hermetic bags in maintaining produce quality and promoting sustainability, economic stability, and food security, making them a valuable tool for agricultural practices aiming for efficient post-harvest management.

Figure 4: Benefits of Hermetic Bags Storage Technology



4.5.2 Challenges preventing the use of Hermetic Bags

The table 10 presents a cross-tabulation between the presence of challenges preventing using Hermetic Bags and the specific reasons for these challenges

Table 10: Challenges preventing the use of Hermetic Bags

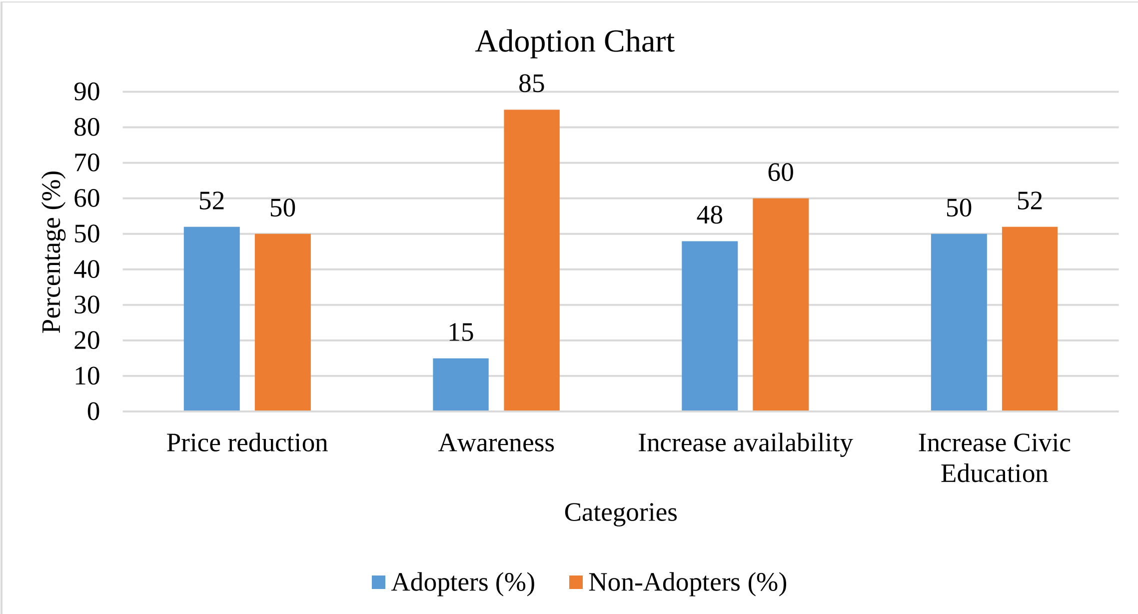
Challenge Type	Yes	No	Chi-square
Expensive	154 (100.00%)	0 (0.00%)	4.8***
Lack of information on Hermetic bags	84 (96.55%)	3 (3.45%)	2.66***
Lack of Shops selling close by	46 (100.00%)	0 (0.00%)	1.46***
Scarcity	44 (100.00%)	0 (0.00%)	1.39***
Limited Knowledge of the use	14 (93.33%)	1 (6.67%)	0.44***

Among respondents facing challenges, the most common barriers include the expense of Hermetic Bags (154), limited information on their use (84), and scarcity (44). However, among those not facing challenges, only 1 respondent reported a lack of knowledge. The Pearson chi-squared test indicates a significant association between challenges and their specific reasons ($\chi^2 = 10.8403$, $p = 0.028$). This suggests that the reasons for challenges vary significantly among respondents.

4.5.3 How can the adoption of Hermetic bags be improved

The graph in Figure 5 reveals key insights into strategies for improving hermetic bag adoption. Price reduction is the most emphasized strategy among adopters (52.17%) and remains significant for non-adopters (47.83%), highlighting affordability as a critical barrier. Awareness campaigns are crucial, particularly for non-adopters (82.57%), who may have limited knowledge about the benefits and use of hermetic bags. Both groups value increased availability, though it is slightly more important for non-adopters (56.86%) than adopters (43.14%). Civic education is least influential, with both adopters and non-adopters equally recognizing its importance (50%). These findings suggest prioritizing affordability and awareness to drive adoption.

Figure 5: Suggested strategies for promoting adoption of Hermetic bags



4.7 Chapter Summary

This chapter presented findings from 346 respondents across Mitole and Kalambo EPAs in Chikwawa District. The results revealed that 39.9% of farmers adopted hermetic bags, with significant determinants including age, gender, education, household size, and extension worker contact. Knowledge levels significantly influenced adoption, with 90.58% of adopters being aware of the technology. Key barriers identified were high initial cost, scarcity and limited knowledge. Benefits included grain quality preservation and reusability.

CHAPTER FIVE: DISCUSSION

5.1 Introduction

This chapter discusses the findings of the study objectives which were to assess farmers level of knowledge about adoption of hermetic bags as post-harvest management storage technologies, to determine farmers' awareness of hermetic bags, to analyze the determinants of adoptions and to find out the benefits and challenges for using hermetic bags.

5.2 To determine farmers' level of knowledge on Hermetic Bags Technology

Figure 3 shows that 80.0% of the adopters had knowledge about the usage of HBST (process on how to use the bags). About 46.7% of the non-adopter respondents had no knowledge of the usage. The majority (63.3%) of the adopters had knowledge that the bags provide strong protection to the farm produce stored. Among the non-adopters, 36.7% of them did not have the knowledge on the protection provided by the bags. It was also found that 56.7% of the adopters had knowledge that the bags can be re-used even for three growing seasons. On the other hand, 20% of the non-adopters had no knowledge about re-usability. These results underscore the critical role of knowledge in driving adoption decisions, suggesting that knowledge of HBT is a prerequisite for adoption.

Hermetic storage technologies have emerged as crucial solutions for mitigating post-harvest losses among smallholder farmers in Sub-Saharan Africa. The adoption of these technologies, such as the Purdue Improved Crop Storage (PICS) bags, has been shown to significantly reduce grain losses caused by pests and moisture, leading to improved food security (Benimana et al., 2023;

Murdock & Baoua, 2014). Studies indicate that using hermetic bags can decrease aflatoxin contamination and mold infection, which are prevalent issues in maize storage (Akumu et al., 2020; Okori et al., 2022).

Furthermore, the economic implications of adopting hermetic storage are substantial. Research has demonstrated that farmers utilizing these technologies experience increased incomes due to reduced losses and enhanced marketability of their stored products (Ndegwa et al., 2016; Baributsa & Njoroge, 2020). In Kenya, a randomized controlled trial revealed that the effectiveness and economics of hermetic bags for maize storage resulted in notable financial benefits for smallholder farmers (Ndegwa et al., 2016; Muriuki et al., 2023).

5.3 Farmers awareness of HB as post-harvest management storage technologies

The results from table 5 showed that among the surveyed farmers, 74.57% were aware of hermetic bags, with the primary sources of awareness being extension workers (37.28%), friends (3.47%), Madia (1.73%), and lead farmers (31.50%). Notably, 25.43% of farmers remain unaware. The Pearson Chi2 test indicates a significant association (p = 0.0000) between awareness and information sources. This underscores the importance of leveraging extension workers and lead farmers in increasing awareness about hermetic bags, potentially enhancing adoption rates and promoting effective post-harvest practices. This result revealed that those households who were aware about hermetic bags were more likely to adopt HBST than those households who were not aware about this technology. This suggests that the awareness of farmers for the hermetic bags technology was used as an information dissemination tool, and this leads to higher probability of using the hermetic bag technology than respondents with no awareness about hermetic bags. This finding is consistent with the findings of Mengist (2019), who found that awareness was an important factor influencing individual behaviour to adopt technology. The results also agree with the study made by Jones and Brown (2022) whose findings suggest that awareness campaigns play crucial roles in influencing adoption of a given technology.

5.4 Understanding factors influencing adoption of Hermetic Bag Adoption

The binary logistic regression model highlights key determinants influencing farmers' adoption of Hermetic Bag Storage Technology (HBST). The pseudo-R-squared value of 0.166 indicates that the independent variables explain 16.6% of the variance in adoption which is statistically significant (Chi-square = 77.472, $p = 0.000$). Age emerges as a critical factor, with a significant positive coefficient ($p = 0.002$), suggesting that younger farmers are more likely to adopt HBST. Literacy also shows a strong influence, aligning with findings by Adebo and Shittu (2022), which emphasize the role of education in adopting sustainable agricultural technologies. Surprisingly, income levels and marital status were non-significant, indicating that awareness and targeted interventions might play a more substantial role than economic or social factors.

Further analysis underscores the importance of awareness campaigns and extension services, with positive coefficients for extension workers' influence ($p = 0.039$). The findings resonate with studies like Manda et al. (2021), which stress that tailored awareness and effective extension services enhance adoption rates. Gender also showed significant effects with men more likely to adopt HBST, highlighting potential gender-specific barriers. These insights suggest that policy efforts should focus on improving literacy, engaging younger farmers, and deploying targeted awareness campaigns to address the obstacles and enhance the use of HBST in agricultural practices.

5.4.1 Gender

The regression model identified gender as one of significant factors influencing adoption of hermetic bag storage technology, with a positive coefficient indicating higher adoption rates among certain genders, emphasizing the need to address potential gender disparities in technology uptake (Chegere et al., 2022). This suggests that targeted interventions and extension services should consider gender-specific approaches to enhance adoption rates and promote equitable access to hermetic bag technology. This agrees with the study made by Ogunsumi (2017) on the socio-economic conditions of peasant farmers that showed that decisions on agricultural activities were influenced by males. Boateng (2008) also reported that the majority of the farmers who participated in Agroforestry were males based on the perception that the majority of females do not own land.

5.4.2 Age

The regression model identified age as a significant factor influencing hermetic bag storage technology adoption ($p = 0.009$). The "Adopted" group was significantly younger (mean age = 37.46) compared to the "Not adopted" group (mean age = 41.14), indicating that younger farmers are more likely to adopt new technologies (Faizal et al., 2020). This finding is consistent with previous studies that have shown a positive relationship between youth and technology adoption (Kassie et al., 2020). Targeting younger farmers with extension services and training may enhance adoption rates and promote sustainable agricultural practices.

5.4.3 Literacy level

The regression model reveals a significant association between farmers' literacy levels and HBST adoption (Chi2 = 8.0181, p = 0.018**). Literate farmers, particularly those who can both read and write, exhibit a higher adoption rate (23.70%) compared to those who can only read (7.80%) or are illiterate (10.69%). This suggests that literacy plays a role in HBST adoption, which is consistent with previous findings that literate farmers are more likely to adopt new technologies (Adebayo et al., 2017). Enhancing literacy among farmers may increase adoption rates and promote sustainable agricultural practices. Literacy level significantly influences adoption, underscoring the importance of education in promoting technological uptake (Chegere et al., 2022).

5.4.4 Occupation

The binary logistic regression analysis reveals that occupation is a significant predictor of hermetic bag storage technology adoption (β=2.12, $p<0.01$). Farmers who are full-time farmers are more likely to adopt hermetic bags storage technology compared to part-time farmers (Kassie et al., 2020). This suggests that occupation influences adoption decisions, with full-time farmers having a higher propensity to adopt new technologies (Adebayo et al., 2017). Targeting full-time farmers with extension services and training may enhance adoption rates and promote sustainable agricultural practices.

5.4.5 Awareness method

The binomial logistic regression analysis reveals that awareness is a significant predictor of hermetic bag storage technology adoption (β=1.85, $p<0.05$). Farmers who are aware of hermetic bags are more likely to adopt them compared to those who are not aware (Faizal et al., 2020). This suggests that awareness is a crucial factor in adoption decisions, consistent with previous studies that highlight the importance of awareness in technology adoption (Kassie et al., 2020). Increasing awareness through extension services and training may enhance adoption rates and promote sustainable agricultural practices.

5.4.6 Relationship with household head

The binary logistic regression analysis reveals that the relationship with the household head is a significant predictor of hermetic bag storage technology adoption ($\beta=1.62$, $p<0.05$). Specifically, household members who are the heads of the households or have a close relationship with the head are more likely to adopt hermetic bags compared to those who are not (Adebayo et al., 2017). This suggests that decision-making authority and influence within the household play a crucial role in adoption decisions, and this is consistent with previous studies on technology adoption in agricultural households (Kassie et al., 2020). Overall, the model's goodness-of-fit statistics indicate its reliability in explaining adoption behaviour, providing valuable insights for designing targeted interventions to enhance the adoption of Hermetic Bag Storage Technology in agricultural contexts (Chegere et al., 2022).

5.5 The benefits and challenges that farmers face in using Hermetic bags

Analyzing the adoption of HBST involves understanding its benefits, challenges, and strategies for improvement. Benefits include maintaining grain quality, enhancing food security, and reducing post-harvest losses. Challenges encompass the high cost, lack of information, and scarcity. Strategies for improvement entail price reduction, awareness campaigns, availability enhancement, and civic education. Addressing these factors collectively can facilitate widespread

HBST adoption, optimizing post-harvest management and contributing to agricultural sustainability and food security. The qualitative findings from the study on the use of hermetic storage bags among farmers' highlight both the benefits and challenges associated with this technology, emphasizing its impact on grain quality and post-harvest losses while also identifying barriers to effective implementation.

Farmers overwhelmingly expressed satisfaction with the improved quality of stored grains, with one remarking, "Our maize stays fresh and tasty even after months of storage. Buyers prefer our grains now." This aligns with existing literature that supports the notion that hermetic storage can enhance grain quality, thereby increasing marketability (Adebayo et al., 2021). The positive feedback from local traders reinforces this perspective, as they noted that "Grains from Hermetic bags fetch better prices in the market due to their superior quality," suggesting that improved storage methods directly contribute to higher economic returns for farmers (Mwanza et al., 2022). Another significant advantage cited by farmers was the reduction in post-harvest losses due to pests and moisture. One farmer stated, "These bags have been a game-changer for us. We can store our grains for months without worrying about pests or moisture." This observation supports findings from previous studies indicating that hermetic storage effectively mitigates post-harvest losses, a critical issue in many agricultural settings (Badu et al., 2023). A local agricultural officer collaborated this by stating, "Hermetic bags have significantly reduced post-harvest losses in our community," highlighting the potential for such innovations to improve food security.

Despite these advantages, challenges remain that may hinder widespread adoption. One farmer expressed concern about the "high initial cost of these bags," indicating that financial barriers could limit access for some farmers. This observation resonates with the research of Abass et al. (2020), who noted that initial investments in improved storage technologies can be prohibitive for smallholder farmers.

Training and education on the proper use of hermetic bags emerged as another critical issue. A community leader pointed out the necessity for "more training on proper usage," suggesting that inadequate knowledge about sealing techniques could undermine the effectiveness of the bags. This was further illustrated by an agricultural extension officer's observation that "some farmers struggle with the sealing process." The importance of training is underscored by prior research indicating that effective implementation of agricultural innovations often depends on proper knowledge transfer (Suleiman et al., 2021).

Accessibility of hermetic bags also poses a challenge. A female farmer lamented, "These bags aren't always available in our local markets. We have to travel far to get them." Accessibility issues have been documented in various studies, indicating that logistical constraints can limit farmers' ability to adopt beneficial agricultural practices (Khan et al., 2020). Concerns about the reusability of hermetic bags were also raised. An elder farmer expressed uncertainty regarding the longevity of the bags, stating, "If they're damaged, we don't know how to repair them." This highlights a gap in knowledge regarding maintenance and sustainability of such storage solutions. Previous studies emphasize the need for clear guidelines on the longevity and maintenance of agricultural tools to promote their effective use (Mathews & Tobi, 2022).

5.5.1 Benefits of Hermetic Bag Storage Technology

The benefits of Hermetic Bag Storage Technology (HBST) are evident from the data, with various advantages identified by farmers. A total of 44.51% of the respondents, especially adopters, said that Hermetic bags help maintain grain quality. This agrees with Baributsa (2020) who stated that farmers who store their produce in hermetic bags managed to maintain its grain quality for at least 6 months without any loss in quality. In addition, 25.14% of the adopters said that Hermetic bags can be reused for about three years while maintaining grain quality, hence saving money for buying sacks in the subsequent years. This was found during the focus group discussions and the individual interviews that were conducted among the respondents.

As if this was not enough, 15% of the adopters said that hermetic bags help improve farmers' income and food security as they sell the grain that did not lose its quality and quantity. During the Focus Group Discussion, adopters said that they get income after selling surplus maize (Table 16). These findings are consistent with previous research highlighting the effectiveness of Hermetic Bags in preserving grain quality and reducing losses due to pests and mold (Baributsa et al., 2019). The multifaceted benefits of HBST underscore its significance in sustainable agriculture, aligning with the goals of food security and economic stability (FAO, 2018). By mitigating post-harvest losses and enhancing food security, Hermetic Bags play a crucial role in improving livelihoods and agricultural productivity in resource-constrained settings (Maheshwari et al., 2020).

5.5.2 Challenges associated with the Use of Hermetic Bags

Despite the benefits, several challenges prevented the widespread adoption of Hermetic Bags among farmers in the study area. In table 15, a total of 46.25% of the non-adopters said that they do not use hermetic bags because the bags are expensive hence they cannot afford to buy them. These findings were in agreement with the study made by Baributsa (2019) who conducted the studies on hermetic bags adoption and promotion. The study showed that some farmers did not use hermetic bags because of its high price. The other challenge that was identified was that the non-adopters (25%) do not know how to use hermetic bags. Lack of knowledge on the importance (function) of hermetic bags was also one of the challenges raised by 24.56% of non-adopters. About 44% of the non-adopters stated that scarcity of hermetic bags was a major constraints to its adoption. This matches with the findings of Soni and Kurmvanshi.

For poor adoption of improved storage systems in India, where 18.5% complained of high costs of the improved systems and nonavailability of the technology. In the study by Moussa et al. [19], lack of local availability of bags was the most often cited reason for not using PICS bags. These challenges are consistent with previous studies highlighting high costs, limited awareness, and access constraints as significant obstacles to adopting agricultural innovations (Braun et al., 2019; Mogotsi et al., 2020). Addressing these challenges requires targeted interventions, such as price subsidies, training programs, and extension services, to enhance farmers' knowledge and access to hermetic bags (Birner et al., 2018). By overcoming these barriers, policymakers and development practitioners can facilitate the widespread adoption of hermetic bags storage technology, thereby improving post-harvest management and food security outcomes (FAO, 2021).

5.5.3 Strategies for Improving the Adoption of Hermetic Bags

Respondents proposed several strategies that would help improve the adoption of hermetic bags storage technology for post-harvest storage. These include price reduction, increasing awareness, enhancing availability, and providing civic education. Price reduction initiatives, such as subsidies or bulk purchasing schemes, can make hermetic bags more affordable for smallholder farmers, increasing adoption rates (FAO, 2019). Increasing awareness through targeted communication campaigns and extension services can enhance farmers' understanding of the benefits and usage of hermetic bags (Cunguara et al., 2018). Moreover, strengthening availability through market development initiatives and partnerships with agribusinesses can improve farmers' access to hermetic bags (Magrini et al., 2021). Additionally, providing civic education on sustainable agriculture practices and the importance of post-harvest management can foster a supportive environment for the adoption of hermetic bag storage technology (FAO, 2020). By implementing these strategies in a coordinated manner, stakeholders can promote the widespread adoption of hermetic bags storage technology, contributing to sustainable agricultural development and food security.

The respondents also highlighted some perceptions of existing policy gaps in post-harvest management support compared to production support through the Farm Input Subsidy Programme (FISP). The data reveals a stark policy imbalance: while 78.32% of respondents acknowledged adequate support for production inputs through FISP, 60.12% reported complete absence of support for post-harvest storage technologies. An agricultural extension officer from Mitole EPA stated: *"Government policy heavily emphasizes production of fertilizer subsidies, improved seeds but there's virtually nothing for helping farmers preserve what they've produced. We lose so much to storage pests that the production gains are undermined."*

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the culmination of findings from the study on the adoption of hermetic bags storage technology among smallholder farmers in Chikhwawa District. Drawing upon the analysis of data, this chapter provides a comprehensive conclusion that synthesizes key insights and outlines actionable recommendations to promote the widespread adoption of hermetic bags storage technology and enhance post-harvest management practices in the region.

6.2 Conclusion

In conclusion, this study has examined the determinants and barriers of the adoption of hermetic bags storage technology as one of the post-harvest management technologies among smallholder farmers in Chikhwawa. The study used a mixed methods approach, combining quantitative data from semi-structured questionnaires and qualitative data from FDGs and in-depth interviews with key informants. The study has found that the most substantial influence came from harvest-storage practices (coefficient=1.056, p=0.001) demonstrating that farmers with better storage practices were more likely to adopt HBST.

6.2.1 Farmers' level of knowledge on Hermetic Bags Technology

The study reveals significant insights into the adoption and knowledge of Hermetic Bag Storage Technology (HBST) among farming households. The findings indicate that 57% of farmers were knowledgeable about hermetic bags, though only 39.9% had adopted the technology. This gap between knowledge and adoption is primarily attributed to myriad factors such as high costs

(10.1%), scarcity (11.6%), and limited knowledge about usage (7.5%), among others. Notably, strong protection emerged as the primary motivation for adoption, with 32.7% of users citing this benefit.

The study's findings emphasize the need for comprehensive interventions to boost HBST adoption. The substantial proportion of farmers with limited knowledge about hermetic bags (30.9%) suggests an opportunity for targeted educational initiatives. The testimonials from adopters indicate positive experiences with the technology, particularly in reducing grain losses and maintaining produce quality. However, the concerns raised by non-adopters about cost and uncertainty point to the necessity of addressing both economic barriers and knowledge gaps through coordinated efforts between government agencies, NGOs, and agricultural extension services.

6.2.2 Awareness of hermetic bags technology

Information dissemination channels played a crucial role in HBST adoption, with extension workers being the most influential source (37.28%), followed by lead farmers (31.50%). The government (36.99%) and NGOs (33.24%) were identified as the primary institutional sources of information about hermetic bags. This highlights the importance of institutional support in promoting agricultural technologies. The significant association between awareness and information sources (Pearson Chi2 = 335.69, p = 0.0000) underscores the effectiveness of structured awareness campaigns and strategies.

6.2.3 Factors influencing Adoption of Hermetic Bags

The binary logistic regression analysis uncovered significant determinants influencing the adoption of Hermetic Bag Storage Technology (HBST) among farming households. The statistical model demonstrated robust explanatory power, with a pseudo-R-squared value of 0.166 and a chi-square value of 77.472 ($p=0.000$), which indicates a statistically significant relationship between the examined variables and technology adoption.

Demographic characteristics emerged as crucial factors in farmers' technology adoption decisions. Gender showed a positive and significant association (coefficient=0.584, $p=0.015$), suggesting that gender plays a meaningful role in HBST adoption. Age also exhibited a positive and significant relationship (coefficient=0.02, $p=0.035$), indicating that age influences technology acceptance. Similarly, literacy level demonstrated a significant positive correlation (coefficient=0.567, $p=0.011$), highlighting the importance of education in technology adoption.

Knowledge and experience constitute the most significant influence in the adoption of the technology for the post-harvest storage practices, showing a strong positive correlation (coefficient = 1.056, $p = 0.001$). This indicates that farmers with advanced existing storage methods are significantly more inclined to adopt Hermetic Bag Storage Technology. This finding highlights the critical role of current agricultural practices in driving the adoption of new technologies.

Occupation exhibited a negative relationship with the adoption of Hermetic Bag Storage Technology (HBST) (coefficient = -0.471, $p = 0.002$), suggesting that specific occupational backgrounds may hinder technology adoption. On the other hand, the relationship to the household head showed a slightly positive influence (coefficient = 0.604, p = 0.097), indicating that household dynamics may play a subtle yet meaningful role in the acceptance of this technology.

These findings illuminate the complex interplay of socio-economic and demographic factors in Hermetic Bag Storage Technology adoption. The results emphasize the critical need for targeted, nuanced interventions that carefully consider the multifaceted determinants influencing farmers' technology adoption decisions. Policymakers and agricultural extension services should design strategies that address the specific challenges and opportunities revealed by this comprehensive analysis.

The research underscores the importance of a holistic approach to technology dissemination, taking into account gender, age, literacy, existing storage practices, awareness strategies, and household dynamics. By understanding these intricate relationships, stakeholders can develop more effective methods to promote the adoption of innovative agricultural storage technologies.

6.2.4 Benefits and challenges for using hermetic bags

The study revealed significant benefits of Hermetic Bag Storage Technology (HBST), with maintaining grain quality emerging as the primary advantage (44.51% of respondents). Other notable benefits included the ability to reuse bags (25.14%), reduction in post-harvest losses (13.29%), and preservation of grain without insecticides (12.72%). Qualitative findings from farmers and agricultural officers reinforced these benefits, with testimonials highlighting improved grain quality, better market prices, and reduced post-harvest losses. The technology's ability to maintain grain freshness and quality without chemical preservatives represents a significant advancement in sustainable agricultural practices.

However, several challenges impede widespread adoption of HBST. Cost emerged as the most significant barrier, with 154 respondents citing expense as a primary concern. Other major challenges included lack of information on proper usage (84 respondents), limited availability in local markets (46 respondents), and general scarcity (44 respondents). The Pearson Chi-square test ($\chi^2 = 10.8403$, $p = 0.028$) confirmed the significance of these challenges. Potential solutions identified by both adopters and non-adopters include price reduction (emphasized by 96 adopters and 88 non-adopters), increased awareness campaigns, and improved availability. The significant association between these improvement strategies (Pearson $Chi^2 = 34.82$, $p = 0.0000$) suggests that a multi-faceted approach addressing both economic and knowledge barriers is necessary for increasing HBST adoption.

6.3 Recommendations

Based on the study findings, here are the key recommendations:

On the farmers' level of knowledge of hermetic bags storage technology adoption, the study recommends that agricultural extension services should be strengthened to provide continuous support and monitoring of HBST adoption. This includes establishing regular follow-up mechanisms to ensure proper usage and maintenance of hermetic bags. Extension officers should be equipped with updated knowledge and resources so that they are able to impart knowledge, skills and competences to farmers as regards to hermetic usage, its functionality and their sources. This includes demonstration trainings on hermetic usage.

On the farmers' awareness of hermetic bags, the government and agricultural stakeholders should prioritize recruiting and increasing number of extension workers in order to frequently visit farmers thereby enhancing awareness and education about Hermetic Bag Storage Technology (HBST).

The study also stresses that supply chain improvements are crucial for increasing HBST accessibility. Therefore, local agricultural input suppliers should be incentivized to stock hermetic bags, and distribution networks should be expanded to reach remote areas. Partnerships between manufacturers, distributors, and local agro-dealers should be fostered to ensure consistent availability. This could include establishing local storage facilities and coordinating bulk purchases to reduce transportation costs.

In order to address the economic barriers, financial institutions, NGOs, and government agencies should develop subsidized programmes to make hermetic bags more affordable for farmers. These financial interventions should be coupled with demonstrations of long-term cost benefits to justify the investment.

6.3 Areas for further research

The researcher suggests the following;

1. Longitudinal studies tracking the long-term impact of Hermetic Bags Storage Technology adoption on crop yields, post-harvest losses, and farmers' livelihoods would provide valuable insights into the sustainability and scalability of this technology.
2. Qualitative research focusing on the socio-cultural factors influencing technology adoption and usage behaviors could deepen our understanding of the contextual nuances shaping farmers' decision-making processes.

REFERENCES

Aboagye, D., Darko, J. O., & Banadda, N. (2017). Comparative study of hermetic and non-hermetic storage on quality of cowpea in Ghana. *Chemical and Biological Technologies in Agriculture*, *4*(1), 1–6. https://doi.org/10.1186/s40538-017-0091-y

Abrehet, F. (2018). Post-harvest loss vs food and nutrition Insecurity: challenges and Strategies to overcome in Ethiopia. *Int J Food Sci Nutr Eng*, *8*(4), 95–102. https://doi.org/10.5923/j.food.20180804.02

Adeola, E. H. (2020). Post-Harvest Management Practices among Rice Farmers in Imo State Nigeria. *European Journal of Biology and Biotechnology*, *1*(4). https://doi.org/10.24018/EJBIO.2020.1.4.32

Akumu, G., Atukwase, A., Tibagonzeka, J. E., Apil, J., Wambete, J. M., Atekyereza, P. R., Kiyimba, F. L., & Muyonga, J. H. (2020). On-farm evaluation of effectiveness of improved postharvest handling of maize in reducing grain losses, mold infection and aflatoxin contamination in rural Uganda. *African Journal of Food, Agriculture, Nutrition and Development*, *20*(5). https://doi.org/10.18697/AJFAND.93.19790

Anghileri, D., Chibarabada, T., … A. G.-T.-A., & 2024, undefined. (n.d.). Understanding the maize yield gap in Southern Malawi by integrating ground and remote-sensing data, models, and household surveys. *Elsevier*. Retrieved February 21, 2025, from https://www.sciencedirect.com/science/article/pii/S0308521X24001124

Atkari, V. T., Pawar, K. R., & Patil, S. C. (2022). Hermetic Storage Technology for Food Grains: New Beginning of Organic and Safe Storage for Farmers and Consumers: A Review. *Bhartiya Krishi Anusandhan Patrika*, *Of*. https://doi.org/10.18805/bkap278

Bank, T. W. (2022). *World Bank SME Finance: Development news, research, data World Bank*. https://www.worldbank.org/en/topic/smefinance

Baoua, I. B., Amadou, L., Baributsa, D., & Murdock, L. L. (2014). Triple bag hermetic technology for post-harvest preservation of Bambara groundnut (Vigna subterranean (L.) Verdc.). *Journal of Stored Products Research*, *58*, 48–52. https://doi.org/10.1016/j.jspr.2014.01.005

Baoua, I. B., & others. (2013). Side by side comparison of GrainPro and PICS bags for postharvest preservation of cowpea grain in Niger. *Journal of Stored Products Research*, *54*, 13–16. https://doi.org/10.1016/j.jspr.2013.03.003

Baributsa, D. (2019). Empowering the private sector to reduce hunger - PICS Sales crossed 5 million bags per year in 2018. *PICS. Newsletter*, *5*(1).

Baributsa, D., Bakoye, O. N., Ibrahim, B., & Murdock, L. L. (2020). Performance of five postharvest storage methods for maize preservation in Northern Benin. *Insects*, *11*(8). https://doi.org/10.3390/insects11080541

Baributsa, D., Díaz-Valderrama, J. R., Mughanda, D., Lubanzadio, A., Nshombo, J. P. C., Sperling, L., & Baoua, I. B. (2021). Grain handling and storage in lubero and rutshuru territories in the North Kivu Province, the democratic Republic of Congo. *Sustainability (Switzerland)*, *13*(17). https://doi.org/10.3390/SU13179580

Baributsa, D., & Njoroge, A. W. (2020). The use and profitability of hermetic technologies for grain storage among smallholder farmers in Eastern Kenya. *Journal of Stored Products Research*, *87*. https://doi.org/10.1016/j.jspr.2020.101618

Benimana, G. U., Ritho, C., & Irungu, P. (2021). Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda. *Heliyon*, *7*(10). https://doi.org/10.1016/j.heliyon.2021.e08235

Benimana, G. U., Ritho, D. C., & Irungu, D. P. (2023). Impact of adopting maize hermetic storage technologies on smallholder farmers' income in Gatsibo District, Rwanda. *Heliyon*, *9*(3). https://doi.org/10.1016/j.heliyon.2023.e14592

Benson, T., & Weerdt, J. (2023). *Employment options and challenges for rural households in Malawi: An agriculture and rural employment analysis of the fifth Malawi Integrated Household Survey*. https://cgspace.cgiar.org/items/dede2d3e-b3c0-4c3a-a280-2575e243641c

Blessed, M., Austin, M., Windu, M., Joseph, C., Onward, C., Robbson, M., Golden, M., Richie, N., & Nizah Mutambo. (2022). Research Methodological Choice: Explaining Research Designs; Qualitative and Quantitative Sample Size Determination, Sampling, Data Collection, and Analysis Techniques. *Journal of Marketing and Consumer Research*. https://doi.org/10.7176/JMCR/87-06

Butenko, A. A., Mozgovyi, A. O., Butnik, S. V., & Spirande, K. V. (2022). Increasing of strength-rigidity parameters of bases of metallic silos. *IOP Conference Series: Earth and Environmental Science*, *1049*(1). https://doi.org/10.1088/1755-1315/1049/1/012049

Charry, A., Vargas, A., Narjes, M., & Gonzalez, C. (2023). *Agroecological transitions in value chains: Main findings, challenges, and opportunities for the agroecological transition of the value chains in the agroecological living landscapes*. https://hdl.handle.net/10568/137773

Coeurderoy, R., Guilmot, N., & Vas, A. (2014). Explaining factors affecting technological change adoption: A survival analysis of an information system implementation. *Management Decision*, *52*(6). https://doi.org/10.1108/MD-10-2013-0540

Cohen, L., Manion, Lawrence., & Morrison, K. (Keith R. B.). (2007). *Research methods in education*. Routledge.

Creswell, J. W., & Plano-Clark, V. (2011). *Designing and Conducting Mixed Methods Research* (2nd ed.). Sage Publications Ltd.

Debebe, S. (2022). Post-harvest losses of crops and its determinants in Ethiopia: tobit model analysis. *Agriculture and Food Security*, *11*(1), 1–8. https://doi.org/10.1186/S40066-022-00357-6/TABLES/2

Díaz-Valderrama, J. R., Njoroge, A. W., Macedo-Valdivia, D., Orihuela-Ordóñez, N., Smith, B. W., Casa-Coila, V., Ramírez-Calderón, N., Zanabria-Gálvez, J., Woloshuk, C., & Baributsa, D. (2020). Postharvest practices, challenges and opportunities for grain producers in Arequipa, Peru. *PLoS ONE*, *15*(11 November). https://doi.org/10.1371/JOURNAL.PONE.0240857

Dilipan, E., Sharma, J., Jha, M. K., Markandey, D. K., Purewal, S. S., & Yuvraaj, A. (2022). Maize protein : Extraction, quality, and current scenario. *Maize*, 183–210. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003245230-6/maize-protein-dilipan-jaya-sharma-manas-jha-dilip-kumar-markandey-sukhvinder-singh-purewal-arihant-yuvraaj

Hengsdijk, H., & de Boer, W. J. (2017). Post-harvest management and post-harvest losses of cereals in Ethiopia. *Food Security*, *9*(5), 945–958. https://doi.org/10.1007/S12571-017-0714-Y

Ignacio, M. C. C. D., Maier, D. E., & Vorst, K. L. (2023). Engineering Properties of Commercially Available Hermetic Storage Bag Liners. *Journal of the ASABE*, *66*(3), 601–615. https://doi.org/10.13031/JA.15366

Irfan, M., Kumar, P., Ahmad, M. F., & Siddiqui, M. W. (2023). Biotechnological interventions in reducing losses of tropical fruits and vegetables. In *Current Opinion in Biotechnology* (Vol. 79). https://doi.org/10.1016/j.copbio.2022.102850

Kaur, M., Kaur, G., Birwal, P., Kaur, R., & Sandhya. (2022). Storage of maize and its products. *Maize*, 325–356. https://doi.org/10.1201/9781003245230-10/STORAGE-MAIZE-PRODUCTS-MANINDER-KAUR-GURVEER-KAUR-PREETI-BIRWAL-RAMANDEEP-KAUR-SANDHYA

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, *6*(1), 1–22. https://doi.org/10.3390/FOODS6010008

Kumari, V. V., Balloli, S. S., Kumar, M., Ramana, D. B. V., Prabhakar, M., Osman, M., Indoria, A. K., Manjunath, M., Maruthi, V., Chary, G. R., Chandran, M. A. S., Gopinath, K. A., Venkatesh, G., Rao, M. S., Singh, V. K., & Timsina, J. (2024). Diversified cropping systems for reducing soil erosion and nutrient loss and for increasing crop productivity and profitability in rainfed environments. *Agricultural Systems*, *217*, 103919. https://doi.org/10.1016/J.AGSY.2024.103919

Kuyu, C. G., Tola, Y. B., Mohammed, A., Mengesh, A., & Mpagalile, J. J. (2022). Evaluation of different grain storage technologies against storage insect pests over an extended storage time. *Journal of Stored Products Research*, *96*. https://doi.org/10.1016/j.jspr.2022.101945

Lane, B., Sharma, S., Niu, C., Maina, A. W., Wagacha, J. M., Bluhm, B. H., & Woloshuk, C. P. (2018). Changes in the fungal microbiome of maize during hermetic storage in the United States and Kenya. *Frontiers in Microbiology*, *9*(OCT). https://doi.org/10.3389/FMICB.2018.02336

Marcos Valle, F. J., Gastón, A., Abalone, R. M., de la Torre, D. A., Castellari, C. C., & Bartosik, R. E. (2021). Study and modelling the respiration of corn seeds (Zea mays L.) during hermetic storage. *Biosystems Engineering*, *208*, 45–57. https://doi.org/10.1016/J.BIOSYSTEMSENG.2021.05.009

Marti, L. (2024). *The role of international agricultural trade in facilitating food security and climate adaption: a case of trade in Maize in Malawi and Zambia*. https://digitalcollection.zhaw.ch/bitstream/11475/31257/1/2024_Marti_Lena_BA_UI.pdf

Mlambo, S., Mvumi, B. M., Stathers, T., Mubayiwa, M., & Nyabako, T. (2017). Field efficacy of hermetic and other maize grain storage options under smallholder farmer management. *Crop Protection*, *98*. https://doi.org/10.1016/j.cropro.2017.04.001

Moussa, B., Lowenberg-DeBoer, J., & Baributsa, D. (2010). *Adoption of hermetic storage for cowpea in Niger and Burkina Faso in 2010*.

Moussa, B., Lowenberg-DeBoer, J., Fulton, J., & Boys, K. (2011). The economic impact of cowpea research in West and Central Africa: A regional impact assessment of improved cowpea storage technologies. *Journal of Stored Products Research*, *47*(3), 147–156. https://doi.org/10.1016/j.jspr.2011.02.001

Moyo, G., Zimusi, L., Ncube, S., & Kupfurwa, M. (2022). Factors affecting adoption and usage of mobile money services by artisan gold miners: Case of Umzingwane District in Zimbabwe. *International Journal of Research Publications*, *105*(1). https://doi.org/10.47119/IJRP1001051720223654

Mugenda, O. M., & Mugenda, A. G. (2003). Research methods: Quantitative and. *Qualitative. Approaches. Nairobi*. https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1917785

Muriuki, N. N., Munyua, C. N., & Odero-Wanga, D. A. (2023). Effectiveness of Extension Communication Channel in the Adoption Process of Hermetic Bag Storage Technology in Nakuru, Kenya. *Asian Journal of Agricultural Extension, Economics & Sociology*, *41*(10). https://doi.org/10.9734/ajaees/2023/v41i102180

Mwinuka, L., & Hyera, E. O. (2022). Effect of socio-cultural factors on gendered decision-making in the adoption of improved maize storage technologies. *Cogent Food and Agriculture*, *8*(1). https://doi.org/10.1080/23311932.2022.2132849

Ndegwa, M. K., De Groote, H., Gitonga, Z. M., & Bruce, A. Y. (2016). Effectiveness and economics of hermetic bags for maize storage: results of a randomized controlled trial in Kenya. *Crop Protection*, *90*, 17–26. https://doi.org/10.1016/j.cropro.2016.08.007

Negede, B. M., De Groote, H., Minten, B., & Voors, M. (2024). Does access to improved grain storage technology increase farmers' welfare? Experimental evidence from maize farming in Ethiopia. In *Journal of Agricultural Economics* (Vol. 75, Issue 1). https://doi.org/10.1111/1477-9552.12546

Ngoma, T. N., Monjerezi, M., Leslie, J. F., Mvumi, B. M., Harvey, J. J. W., & Matumba, L. (2024). Comparative utility of hermetic and conventional grain storage bags for smallholder farmers: a meta-analysis. In *Journal of the Science of Food and Agriculture* (Vol. 104, Issue 2). https://doi.org/10.1002/jsfa.12934

Ngwenyama, P., Mvumi, B. M., Stathers, T. E., Nyanga, L. K., & Siziba, S. (2022). How different hermetic bag brands and maize varieties affect grain damage and loss during smallholder farmer storage. *Crop Protection*, *153*. https://doi.org/10.1016/j.cropro.2021.105861

Njoroge, A. W., Baoua, I., & Baributsa, D. (2019). Postharvest Management Practices of Grains in the Eastern Region of Kenya. *Journal of Agricultural Science*, *11*(3), 33. https://doi.org/10.5539/JAS.V11N3P33

Okolo, C. A., & Adejumo, B. A. (2017). Hermetic Storage Technology : The Way forward in Solving Numerous Cereal Grains Storage Challenges in Developing Countries. *International Journal of Engineering Research & Technology (IJERT)*, *6*(07).

Okori, F., Cherotich, S., Abaca, A., Baidhe, E., Adibaku, F., & Onyinge, J. D. (2022). Grain Hermetic Storage Adoption in Northern Uganda: Awareness, Use, and the Constraints to Technology Adoption. *Agricultural Sciences*, *13*(09). https://doi.org/10.4236/as.2022.139061

Okori, F., Cherotich, S., Baidhe, E., Komakech, A. J., & Banadda, N. (2022). Grain Hermetic Storage and Post-Harvest Loss Reduction in Sub-Saharan Africa: Effects on Grain Damage, Weight Loss, Germination, Insect Infestation, and Mold and Mycotoxin Contamination. In *Journal of Biosystems Engineering* (Vol. 47, Issue 1). https://doi.org/10.1007/s42853-022-00130-4

Osei-Asibey, R. K., Wireko-Manu, F. D., Aidoo, R., Boakye-Achampong, S., Mills-Robertson, F. C., & Baributsa, D. (2022). Farmers' Perception of the Use and Benefits of Cowpea Storage Methods in Northern Ghana. *Sustainability (Switzerland)*, *14*(9). https://doi.org/10.3390/SU14095129

Östlund, U., Kidd, L., Wengström, Y., & Rowa-Dewar, N. (2011). Combining qualitative and quantitative research within mixed method research designs: A methodological review. *International Journal of Nursing Studies*, *48*(3), 369–383. https://doi.org/10.1016/j.ijnurstu.2010.10.005

Roberts, D., & Khattri, N. (2015). *The World Bank Group A to Z 2016*. The World Bank. https://doi.org/10.1596/978-1-4648-0484-7

Rono, V. K., Ogema, V., & Chesambu, A. (2018). Factors Affecting Adoption Of Hermetic Bags Technology Among Smallholder Farmers In Busia County, Kenya. *Pdfs.Semanticscholar.Org*, *5*(3).

Tesfaye, A., Jenber, A. J., & Mintesnot, M. (2021). Survey of storage insect pests and management of rice weevil, Sitophilus oryzae, using botanicals on sorghum (Sorghum bicolor L.) at Jawi

District, Northwestern Ethiopia. *Archives of Phytopathology and Plant Protection*, *54*(19–20), 2085–2100. https://doi.org/10.1080/03235408.2021.1970976

Upendram, S., Regmi, H. P., Cho, S. H., Mingie, J. C., & Clark, C. D. (2023). Factors affecting adoption intensity of climate change adaptation practices: A case of smallholder rice producers in Chitwan, Nepal. *Frontiers in Sustainable Food Systems*, *6*. https://doi.org/10.3389/fsufs.2022.1016404

Westerman, G., Bonnet, D., & McAfee, A. (2014). *Leading digital: Turning technology into business transformation*. Harvard Business Press.

Yewle, N., Charpe, A. M., Gupta, S., Patil, B., Tushir, S., & Mann, S. (2020). Impact of hermetic packaging on green gram (Vigna radiata) insect and microbial damage under environmental storage condition. *Journal of Entomology and Zoology Studies*, *8*(5), 1883–1887. https://doi.org/10.22271/J.ENTO.2020.V8.I5Z.7766

Yewle, N. R., Stroshine, R. L., Ambrose, R. K., & Baributsa, D. (2023). Short-Term Hermetic Storage of Wet Maize and Its Effect on Quality. *Foods 2023, Vol. 12, Page 891*, *12*(4), 891. https://doi.org/10.3390/FOODS12040891

Appendix 1: Interviewer Administered Questionnaire

DETERMINANTS AND BARRIERS OF ADOPTION OF HERMETIC BAGS AS POST-HARVEST MANAGEMENT STORAGE TECHNOLOGIES AMONG SMALLHOLDER FARMERS IN CHIKWAWA DISTRICT

SECTION A: SOCIO-DEMOGRAPHIC PROFILE

A. Identification Information

1.Name of Interviewer…………………………………………………………………

2. Name of respondent…………………………………………………………………

3. District…………………………………………T/A…………………………………

4. EPA……………..................Section………………………Village…………………

B: Demographic Characteristics of respondent

Name of member……………………………………Age………………………………

Gender: a. Male

b. Female

Marital status: a. Married

b. Divorced

c. Widowed

Educational level: a. Primary

b. Secondary

c. Tertiary

d. None of above

e. Others (specify)

Household Head: a. MHH

b. FHH

c. CHH

Relationship to Household head

a. Head

b. Spouse

c. Child

d. Others (specify)…………….

Number of household members………………Occupation……………………………

Farmer's literacy: Are you able to read and write?

a. Only read (   )   b. Both read and write (   ) c. none

Are you a household head?   a. Yes (   )   b. no (   )

If no, mention the relationship to the family…………………………..

C. Knowledge of farmers on the use of hermetic bags as post-harvest management storage technologies

1. Are you aware that *hermetic bags* can be used as post-harvest management storage technologies

   a. yes (   ) b. No (   )

2. How did you become aware that *hermetic bags* can be used as post-harvest management storage technologies?

………………………………………………………………………………………………

…………………………………………………………………………

3. Have you ever tried using hermetic bags as post-harvest management storage technologies?

Yes (   ) b. no (   )

4. What motivated you to start using hermetic bags as post-harvest management storage technologies?

………………………………………………………………………………………………

…………………………………………………………………………

5. If no why:……………………………………………………………………………

6. Why do you use hermetic bags as post-harvest management storage technologies?

……
……………………………………………………………………………

7. How many years have you been using hermetic bags as post-harvest management storage technologies `?

………………………………………………………………………………………………..

D. Farmers awareness of hermetic bags as post -harvest management storage technologies

1. Where did you get the information for the use of hermetic bags as post-harvest management storage technologies?

a. Extension worker ( ) b. Researcher ( ) c. Friends d. Both ( ) e. others (specify) ………………………………………….

2. If extension worker or research scientist, from which institution or organization?

a. Government ( ) b. NGO (specify) ………………………………………

c. Others (specify) ……………………………………………………………………

3. How often do you meet the extension workers on the use hermetic bags as post-harvest management storage technologies

a. Don't meet ( ) b. fortnightly ( ) c. weekly ( ) d. Once a month ( )

e. Others (specify) …………………………………………………………..

E. Factors that determine the adoption of hermetic bags as post-harvest management storage technologies

14. Why do you adopt *hermetic bags as post-harvest management storage technologies*?

……
……………………………………………………………………………..

15. Would you encourage other farmers to start using hermetic bags as post-harvest management storage technologies?

a. Yes ( ) b. No ( )

16. Give reason(s) for your answer to question above.

…………………………………………………………………………………………

17. What is your general opinion on the use of hermetic bags as post-harvest management storage technologies?

……

……………………………………………………………………………

F. Benefits for using hermetic bags as post-harvest management storage technologies

18. Why do you use hermetic bags?

……

………………………………………………………………………………………

19. What are the advantages of using hermetic bags?

……

…………………………………………………………………………………………………

G. Challenges (Reasons) for farmers' low adoption of *hermetic bags as post-harvest management storage technologies*

H. Are there any challenges that prevent you from using hermetic bags?

a. Yes ( ) b. no ( )

20. If yes, what are these challenges? ……………………………………………………….

……

……………………………………………………………………………………..

21. What are the possible ways of improving the situation? ……………………………….

……

…………………………………………………………………………….....

22. What have you learnt on the use of hermetic bags as post-harvest management storage technologies? ………………………………………………………………………………………

Thank you for your time!!

Appendix 2: Research Ethics Approval Letter

MZUZU UNIVERSITY

DIRECTORATE OF RESEARCH

Mzuzu Un
Private Ba
L u w i
M z u z
M A L A
TEL: 01 3

MZUZU UNIVERSITY RESEARCH ETHICS COMMITTEE (MZUNIREC)

Ref No: MZUNIREC/DOR/22/83 29/08/22

Kennedy Kapulula,
Mzuzu University,

P/Bag 201,

Mzuzu.
kapululaken@gmail.com

Dear Kennedy,

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL REF NO: MZUNIREC/DOR/22/83: ANALYSIS OF ADOPTION OF HERMETIC BAGS AS POST-HARVEST MANAGEMENT STORAGE TECHNOLOGIES AMONG SMALLHOLDER FARMERS IN CHIKWAWA DISTRICT

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the Mzuzu University Research Ethics Committee (MZUNIREC) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee with a final report of the study. The Committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Wishing you a successful implementation of your study.
Committee Address:

Secretariat, Mzuzu University Research Ethics Committee, P/Bag 201, Luwinga, Mzuzu 2;
Email address: mzunirec@mzuni.ac.mw

Yours Sincerely,

Gift Mbwele

SENIOR RESEARCH ETHICS ADMINISTRATOR
For: CHAIRMAN OF MZUNIREC

Appendix 3: Mzuzu University Research Ethics Committee Informed Consent Form (English)

Mzuzu University Research Ethics Committee (MZUNIREC)

Informed Consent Form for Research in

Agri-Sciences

Introduction

I am **Kennedy Cristiano Kapulula** from the Department of Agri-Sciences in the Faculty of Environmental Sciences at Mzuzu University. We are doing research on **Determinants and barriers of Adoption of Hermetic Bags as Post-Harvest Management Storage Technologies among Smallholder Farmers in Chikwawa District, *Malawi***. This consent form may contain words that you do not understand. Please ask me to stop as we go through the information and I will take time to explain. If you have questions later, you can ask them of me or of another researcher.

Purpose of the research

This research aims to analyse adoption of Hermetic Bags as post-harvest management storage technologies among smallholder farmers.

Type of Research Intervention

This research will involve your participation in answering a questionnaire and/or individual interview**.**

Participant Selection

You are being invited to take part in this research because of your capacity as Extension Workers, agro-dealers.

Voluntary Participation

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. If you choose not to participate nothing will change. You may skip any question and move on to the next question.

Duration

The research takes place from the month of June 2022 to September 2022.

Risks

You do not have to answer any question or take part in the discussion/interview/survey if you feel the question(s) are too personal or if talking about them makes you uncomfortable.

Reimbursements

You will not be provided any incentive to take part in the research.

Sharing the Results

The knowledge that we get from this research will be shared with you and your community before it is made widely available to the public. Following, we will publish the results so that other interested people may learn from the research.

Who to Contact?

If you have any questions, you can ask them now or later. If you wish to ask questions later, you may contact: Mr. Christopher Mbukwa, (Supervisor and postgraduate coordinator), Department of Agri-Sciences, Mzuzu University, Private Bag 201, Luwinga, Mzuzu 2. Phone: 0992782100, Email: chrismbukwa@yahoo.co.uk

This proposal has been reviewed and approved by Mzuzu University Research Ethics Committee (MZUNIREC) which is a committee whose task it is to make sure that research participants are protected from harm. If you wish to find about more about the Committee, contact Mr. Gift Mbwele, Mzuzu University Research Ethics (MZUNIREC) Administrator, Mzuzu University, P/Bag 201, Luwinga, Mzuzu 2, Phone: 0999404008/0888641486

Do you have any questions?

Part II: Certificate of Consent

I have been invited to participate in research about ***Analysis of Adoption of Hermetic Bags as post-harvest management storage technologies among smallholder farmers in Chikwawa district.***

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions I have been asked have been answered to my satisfaction. I consent voluntarily to be a participant in this study

Print Name of Participant___________________

Signature of Participant ____________________

Date ____________________________

Day/month/year

If illiterate [1]

[1] A literate witness must sign (if possible, this person should be selected by the participant and should have no connection to the research team). Participants who are illiterate should include their thumb print as well.

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Print name of witness_____________ Thumb print of participant

Signature of witness **_____________**

Date _________________________

Day/month/year

Statement by the researcher/person taking consent

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands the research project. I confirm the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Signature of Researcher /person taking the consent__________________________

Date __________________________

____