FACTORS INFLUENCING ADOPTION OF HERMETIC STORAGE TECHNOLOGY IN GREEN GRAMS AND ITS IMPACT ON FARMER'S HOUSEHOLD INCOME IN KITUI COUNTY, KENYA

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Declaration

This thesis is my original work and has not been submitted for an award of a degree in any other university.

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Dedication

I dedicate this thesis to my loving family, parents, friends and my siblings for your unwavering support, love and care that made me to be the person I am today. Thank you so much and God bless you.

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Table of Contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

ASALs: Arid and Semi-Arid Lands areas

ATT: Average Treatment on the Treated

ATU: Average Treatment on the Untreated

BH: Base Heterogeneity

CIDP: County Integrated Development Plan

CIMMYT: International Maize and Wheat Improvement Center

ESRM: Endogenous Switching Regression Model

FAO: Food and Agriculture Organization of the UN

FGD: Focus Group Discussion

FIML: Full Information Maximum Likelihood Estimates

GOK: Government of Kenya

HDPE: High-Density Poly-Ethylene

HH: Household Head

HST: Hermetic Storage Technology

IMR: Inverse Mills Ratios

KALRO: Kenya Agricultural and Livestock Research Organization

KI: Key Informants

LR: Likelihood Ratio

NGO: Non-Governmental Organization

PICS: Purdue Improved Crop Storage

PHL: Post-Harvest Losses

SDGs: Sustainable Development Goals

SSA: Sub-Saharan Africa

SPSS: Statistical Package of Social Sciences

TH: Transition Heterogeneity

UN: United Nations

USAID: United States Agency for International Development

VIF: Variance Inflation Factor

WFP: World Food Programme

WPP: Woven Polypropylene

Operational Definition of Terms Used

Small Holder farmer:

- According to Food and Agriculture Organization of the UN there “is no unique and unambiguous definition of a smallholder farmer”, context matters, because such terms as farm size, or income, or even agricultural output have been used to categorize farmers. However, from the study area, a small-scale farm was considered to be between 0.5 acre and 5 acres.

Technology Adoption:

- It is an action accompanied by the intention to use the new technology for as long as the use of the technology offers an advantage over alternative practices.

Farm Household:

- Persons who live together in the same dwelling unit, who acknowledge one adult (male or female) as head of the unit who share same house keeping arrangements, income and considered as one unit.

Land size:

- Refers to the total size of land owned by the farmer in acres that is taken to affect adoption of any given technology.

Study area:

- Kitui County is the geographical area positioned in the former Eastern Province of Kenya and is borders Taita Taveta County to the South, Makueni County to the West, Machakos to the Northwest, Tana River to the East and Embu and Tharaka Nithi to the North. The County has eight sub-counties, namely Kitui Central, Kitui South, Kitui East, Kitui Rural, Kitui West, Mwingi North, Mwingi West and Mwingi Central. It is an arid and semi-arid area with a low-lying topography, and very erratic and unreliable rainfall. The county is characterized by declining food production, water scarcity and poor resilience to climate shocks.

Household income:

- Refers to the total earnings of the households in Kenya shillings.

Off-farm income:

- Refers to income earnings in Kenya shillings from other sources other than the farm.

Extent of use:

- Refers the extent to which farmers are using Hermetic Storage Technology measured by the ratio of the number of bags bought by the household to the quantity of green grams produced.

ABSTRACT

Inadequate and poor post-harvest grain storage is a major constraint to green gram farmers in Kitui County. It has been identified as the key challenge for smallholder green gram growers because it has significantly reduced the quality and quantity of green grams after harvest, resulting in the shortage of food supply and or price manipulation for millions of households in the study area. Resultant food losses have affected green gram trade and have adverse implications on the economy. Hermetically sealed post-harvest storage systems, such as the Purdue Improved Crop Storage (PICS) bags, initially developed by Purdue University for the storage of cowpeas in West Africa, can contribute dramatically to reducing such food losses. In recognition of this, USAID's Kenya Agricultural Value Chains Enterprises (KAVES) project has been a driving force behind the introduction and promotion of Hermetic Storage Technology (HST) that involves the use of the hermetic bags in Kenya since 2013. Hermetic Storage Technology (HST) is intended to reduce post-harvest storage losses and boost household welfare through increased incomes. However, the extent to which the adoption of the HST in Kenya has contributed to reduction of post-harvest storage losses and consequently increased income has not been comprehensively documented. The specific objectives that this study addressed were to: assess the factors that influence the adoption of HST, determine the extent of HST utilization by smallholder green grams farmers, and evaluate the impact of HST utilization on green grams farmers' household income in Mwingi Central and Mwingi West, Kitui county. Primary data were collected from 271 randomly selected farm-households. Descriptive statistics was used for characteristics and basic analyses. Double-hurdle model was used to analyze the factors that influence adoption and the extent of utilization of HST while Endogenous Switching Regression Model (ESRM) was used to analyze the effect of HST adoption and utilization on household income. The results show that the age of the household head, experience in farming, land size, group membership, access to credit facilities, involvement in off-farm activities, years of schooling and occupation of the household head influence the adoption of HST. The extent of adoption, as measured by the ratio of the number of bags bought by the household to the quantity of green grams harvested, was significantly influenced by the age of the household head, experience in farming, land size and access to credit. The rate of adoption was 42% in the study area and this can be assessed as being a medium level of adoption. Unavailability of the HST and its cost of adoption were found to be the major constraint against the adoption as observed in the survey. Despite the average rates of adoption, household income status was found to be positive and statistically significant among the adopters. From the findings, the Average Treatment effect of the Treated (ATT) was kshs.111,899.10 while the Average Treatment Effect of the Untreated (ATU) was Kshs.57,680.10. This result gives an income difference of kshs.54,219.00 (94%) confirms the great indirect impact of HST on improving rural households' welfare. Higher income from improved storage technology translates into lower poverty levels. These findings call for targeted interventions to promote the adoption of HST among the smallholder farmers, given its impact on household income. Both national and county governments should provide subsidies and avail the technology to the farmers. Additionally, the adoption of HST is knowledge-intensive in nature, and one of the strategies to enhance adoption would include strengthening the existing farmer groups to enhance capacity building and sharing of information.

Keywords: Post-harvest storage losses, Hermetic Storage Technology, Adoption, Household income.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Kenya and other Sub-Saharan Africa (SSA) countries face problems associated with post-harvest food storage losses that have led to periodical food shortages. Post-harvest storage losses often lead to reduced smallholder farmers' income, food, and nutrition security among the Sub-Saharan African countries. Food and Agriculture Organization (FAO) of the UN estimates that global post-harvest food losses are about 30%, an amount that could feed up to 1.2 billion people while helping in solving the Sustainable Development Goal (SDG) one that focuses on alleviating hunger (Audi *et al*., 2008).

Approximately 800 million people around the world face abject poverty and hunger (WFP, 2015). According to the United Nations (2013), the current world population is anticipated to rise to 10.5 billion by 2050, with the majority of them being food insecure and thus raising the global food security concerns (Dietz *et al*., 2014). This will require spirited efforts and strategies that target increasing food supply by at least 60% to meet the demands of the populace (Baoua *et al*., 2014). However, such efforts focus mainly on increasing food production and little attention is given to post-harvest management, yet addressing post-harvest storage losses has the potential to improve food and nutrition security and promote the farmers' household welfare. Therefore, there is a need to put more effort and investment in post-harvest food management practices, especially among the developing countries, because appropriate post-harvest food handling significantly improves food and nutrition security (Audi *et al*., 2008). For pulses producers, Post-harvest food management practices would enhance the availability of pulses as food. Pulses are a rich source of protein and contain a substantial amount of minerals, vitamins, and crude fiber.

India is the world's largest producer and consumer of pulses and contributes about 28% to the global production of pulses. Based on the speculated rate of population rise, planet use of pulses is likely to rise by 20% by 2030 from the rate in late 2007, and most of the rapid rise in pulses use is to be expected in Africa and Asia. Pulses farming, consequently, needs to be augmented to meet the predictable world needs for pulses consumption.

In Kenya, pulses are among the most vital staple food ranked closely with cereals, with green grams being the most popular in the Arid lands. Green grams, also known by the name *mung beans* and locally known as *ndengu* (Maina *et al*., 2016), are grown in the ASALs, mainly for sale in both local and export markets. About one million farmers in Kenya cultivate an average of 260,000 hectares of green grams (Ng'ang'a, 2016). Green grams production is essential for enhancing soil fertility and plays a key role in the economy of Kenya. Farming and valuation of chain additions have the potential to boost viable economic activities and improve the smallholder farmer's incomes (Dietz *et al*., 2014). Green grams production in Kenya is faced with many constraints along the postharvest value chain. During postharvest handling of the pulses, at least 30% of the produce is lost. The drivers of these losses are complex and interconnected. For instance, poor handling of the produce at one node in the chain of supply could be the driver of post-harvest losses at a different stage (Maina *et al*., 2016).

Most of the small-scale green grams producers face constraints during post-harvest grain storage. Pulse beetle, weevils, and other insects infest the green grams grain in storage, thus degrading its nutritional and economic value (Bolaji., 2014). Consequently, producers tend to sell the produce at a throw-away price to avoid storage losses. According to Moussa *et al*., (2014), most of these smallholder farmers, specifically in the rural setup, use traditional storage methods that lead to about 25% of production losses. Baribitsa *et al*., (2012) reported that storage insecticides are commonly used to control weevils, but smallholder farmers do not have adequate access to pesticides due to resource constraints. When they access them, they do not utilize the pesticides appropriately, thus posing not only health hazards but also contributing to environmental degradation.

It is on these grounds that development partners, including Purdue University and USAID, came up with a technological package called Hermetic Storage Technology (HST), which is intended to curb losses due to post-harvest storage and boost household welfare through increased incomes. HST was promoted as a safe, proven and cost-effective package for small-scale farmers for the storage of red beans, dried maize, green grams, cowpeas, sorghum, millet, and chickpeas.

The HST practically relies on the use of Hermetic Storage Bags which ensures the dried cereals and pulses are safe without the use of chemical mechanisms. The outer part of the hermetic storage bag is woven with Polypropylene. The same bag protects the inner surface hence providing effective hermetic nature to block moisture (Ndegwa *et al*., 2016). Immediately the same bag is closed as per the manufacturer's instructions, gases and oxygen are blocked from entering or leaking out. This safeguards the already dried grains and pulses from wastage that often occurs during post-harvest food storage by suffocating any living organisms inside (Baoua *et al*., 2014). The grain stored can go up to two years without getting spoil, and the bag can be reused. Thus, the advanced storage pave way for producers to reap the advantages of increased pay by withholding sales till the prices rise.

1.2 Statement of the Research

kitui county is one of the ASAL counties in Kenya and experiences relatively high poverty levels, currently at 47.5% compared to the national average of 36.1 % in 2016 (CIDP, 2018), thus making it one of the poorest counties in Kenya. Farmers in Kitui plant green grams for commercial purposes because they fetch reasonable prices when compared to those for maize and other crops. Smallholder farmers usually expect to realise a plentiful harvest and trade their produce at a fair price. Therefore, storing the crop to trade later is expected to assure reasonable earnings. Also, food traders who buy the grains on wholesale during the harvesting period expect to preserve and maintain the commodity in good condition as they wait for attractive prices. However, this is not always possible, because the traditional and inadequate storage methods often fail to stop wastage from attacks by pulse beetle and other storage insects. Therefore, farmers are exposed to substantial post-harvest storage losses of green grams (and other staple foods), thus posing a major hazard to food security at the household level (De Groote *et al*., 2013).

In recent times, Kenya has been promoting the adoption of food security crops like green grams and the post-harvest loss reduction innovation called Hermetic Storage Technology (HST) through the Kenya Agricultural and Livestock Research Organization (KALRO) and the Ministry of Agriculture (Likhayo *et al*., 2016). The HST is an effective, low-cost, non-chemical grain protection technology that has been able to reserve maize grain with less than 0.5% dry weight loss over a six-month storage period in field tests (Hell *et al*., 2014).

Hermetic Storage Technology is a recent innovation introduced in the agricultural sector in Kenya in 2013, and many farmers continue to adopt this innovation to help in reducing post-harvest food storage losses. Few studies have been undertaken in Kenya on green gram post-harvest storage losses. However, several studies have been done in India and such studies show that the use of technologies that reduce green grams post-harvest food losses leads to increased income levels and food security (Dietz *et al*., 2014). Therefore, an analysis of the adoption of HST among the ASAL green gram farmers in Kenya and its impact in improving household income is warranted because there is limited scholarly information on the impact of HST on household income for Kenya's ASAL areas.

The use of HST by smallholder farmers in Kitui County is relatively recent because they began using it in 2013. Not much has been researched on HST to determine the influence of its adoption in reducing post-harvest storage losses in Kitui County and its impact on farm household income in the county. This study sought to fill the gap in the literature by evaluating the factors that influence adoption, the extent of adoption, and the impact of adopting HST among smallholder farm income in Kitui County in Kenya. A better understanding of the factors that influence the adoption of HST and the impact of adoption on household income can guide in the designing and implementation of more effective policy interventions to stimulate increased uptake of HST among smallholder farmers.

1.3 Research Objectives

Overall Objective

The overall objective of this study was to evaluate the factors influencing adoption and the extent of adoption of HST and its impact on household income for the smallholder green grams farmers in Kitui County.

Specific Objectives

1. To evaluate the social-economic, institutional, and farm-specific factors that influence the adoption of HST among the smallholder green grams farmers in Kitui county;
2. To determine the social-economic, institutional, and farm-specific factors that influence the extent of HST adoption by smallholder green grams farmers in Kitui county;
3. To evaluate the impact of HST adoption on green grams farm household income in Kitui county.

1.4 Hypotheses

The following hypotheses were tested in this study:

1. Socio-economic, institutional, and farm-specific factors do not influence the adoption of HST by smallholder green grams farmers in Kitui County;
2. Socio-economic, institutional, and farm-specific factors do not influence the extent of HST utilization by smallholder green grams farmers in Kitui County;
3. The use of Hermetic Storage Technology does not have any impact on green gram farm household income in Kitui County.

1.5 Justification

Food security is one of the globals focuses under the Sustainable Development Goals (SDGs), as the first two SDGs are on eradication of hunger and poverty and have fueled more policy thrust in Africa on issues affecting poverty and income inequalities. Kenya, being part of the SSA, has focused on food and nutrition security through the 'big four agenda'. To boost food and nutrition security in Kenya, more effort needs to be directed to diversification of stable foods, enhancing reduction of food wastage and food loss, and strengthening the supply chains and linkages to value addition. Food losses along the value chain lead to food insecurity and lower incomes, thus leaving the poor rural households with limited alternatives for survival. Staple crops, such as green grams, have recently received policy attention in Kenya in a bid to actualize the 'national big four agenda'.

Improvement of rural incomes and food security can be enhanced through the adoption of efficient post-harvest storage technologies. This would enable the smallholder farmers to store their farm grains, such as green grams, and sell them when the prices are favorable. This is in line with the achievement of Sustainable Development Goal Number One on poverty eradication. Since there is limited literature so far on the uptake of the available technologies, such as the HST, especially among the smallholder green grams farmers in Kenya, this study sought to contribute to literature as well as provide specific policy options for the promotion of HST among smallholder farmers in the ASALs of Kenya.

1.6 The scope of the Study

The study focused on green gram farmers in Kitui County who have used the HST in storage facilities. Since Kitui County is an expansive area, a sample from Mwingi Central and Mwingi West was selected to ensure representation of the Kitui County.

CHAPTER TWO: LITERATURE REVIEW

2.1 The Concept of Post-Harvest Food Losses

FAO (2011) defined food loss as the decline in viable edible food group along the parts of the chain supply hence contributing to the decline in edible food for human consumption and it takes place at the onset of production, post-harvest and throughout the processing stages along the value chain. Post-Harvest food Loss (PHL) is one of the significant contributors to food insecurity, malnutrition and hunger in developing countries (Lipinski *et al*., 2013). World Food Programme (WFP) in its mission to accomplish zero hunger has listed curbing PHL as a priority. Poor storage technologies at the household level are a significant contributor to high rates of post-harvest food losses (Viola, 2017). With regards to the nature of losses being experienced in developing countries versus leading economies, studies show that higher losses are being encountered with increasing agricultural productivity in sub-Saharan Africa, including Kenya. The losses are mostly quantitative (Kitinoja *et al*., 2011; Kiaya, 2014), which contrast with developed nations whose losses are predominantly measured by deterioration in quality (Kiaya, 2014). What drives these losses at these nodes is arguably attributed to many factors that are feasible for empirical study. Most of the issues that drive post-harvest losses in small economies are often farm-related and associated with a reduction in quantities at pre-harvest, harvest and post-harvest handling points. For instance, poor handling skills, inadequate storage facilities and poor access to financing to augment the use of post-harvest technologies.

In developed economies, studies indicate that post-harvest food losses are driven by myriad of challenges to do with a reduction in quality and wastage associated with highly sophisticated techniques and process (Vilas *et al*., 2007). In Kenya, a farmer may face a similar situation at some procedures, for example reduction in quantity associated with a drying technology. Such means of value addition may reduce weight, but they contribute to improvement in quality (Gathambiri *et al*., 2006). Therefore, such post-harvest technologies as hermetic bags that are not only used for value addition have potential to reduce food losses and are also associated with higher incomes that are reflected in own prices of inputs and opportunity costs (Cassim & Juma, 2018).

2.2 Storage Losses in Developing Countries

According to Kumar & Kalita (2017**),** the maximum amounts of losses are incurred during storage due to poor storage infrastructure and can be classified into two categories, namely direct and indirect losses. The physical loss of the commodity causes direct losses while indirect losses relate to the loss of quality and nutrition. Storage losses are caused by both biotic (insects, pest, rodents and fungi) and abiotic (temperature and humidity) factors (Abedin *et al*., 2012).

Most of the small-scale farmers in developing countries, including Kenya, use traditional structures to store their grains, and due to temperature fluctuations caused by weather changes, there is an accumulation of moisture. Baloch (2010) reported that grains are mostly stored as bulk in improvised stores that are built using materials which are locally available. Majority of these structures are not technically designed and tend to cause harm to kept grains owed to organic, ecological and other aspects. World bank, (2011) stated that approximately 63% of the total post-harvest grain losses incurred by the smallholder farmers are attributed to lack of proper storage facilities or pest infestation. Therefore, there is a need to curb storage-related losses because losing stored grains severely impacts on households (Omotilewa *et al*., 2016).

2.3 Post-Harvest Food Loss interventions

Innovative ways in world's poor rural areas have proven to have a tremendous transformative effect on the living conditions of the households. Improved storage technologies and facilities are a cost-effective way to prevent losses and avoid the pressure to sell the crops after harvest. World Food Programme, (2014) launched an initiative called the Zero Food Loss to curb the post-harvest losses. The programme trains farmers and disseminates Hermetic Grain Storage Equipment (Viola, 2017). It was initially implemented in Uganda with the following outcomes at the household level: (1) Reduction of post-harvest losses by 90-100% through the practice of enhanced packing know-hows and other practices; (2) Improvement in food security and nutrition and (3) A rise in household income through the reduction of losses and the selling of the grains when the price is favourable.

Loss reduction interventions have helped the actors in different ways. For instance, Cowpeas Storage Project by Purdue University led to improved farmers' income (Bolaji, 2014). AGRA through a yam improvement project moved towards an objective to double farmers' incomes and ensure food security. In addition, according to Rockefeller Foundation (2015), USAID project that was carried out on hybrid seeds and post-harvest storage is anticipated to increase yields by 50% and also lead to a decrease in losses by 20%.

Rockefeller Foundation (2015) established an initiative aimed at reducing Post-Harvest Losses (PHL) due to the projection that postharvest loss reduction during harvesting, storage and transportation together with the production initiative will make Africa continent food secure despite the high population growth. Mada *et al*., (2014) postulated that the reduction in PHL would lead to a 15% rise in farmers' income. A loss reduction by 1% is projected to result in an increase in revenue by about 40 million US dollars annually. However, such initiatives have not focused on crops like pulses. Besides, most post-harvest interventions have concentrated on specific parts of the value chain, especially among the perishable crops.

Different know-hows have been advanced hence reducing Post-Harvest Food losses along the pulses value chain. They include Purdue Improved Crop storage (PICs), Metal silos, Super bags, Zero fly, Elite bags and Solar driers (Imaita, 2013; Affognon *et al*., 2015). However, the level of estimated losses has remained relatively high despite the documented literature on the potential loss reduction abilities of these technologies. Hence the need for hermetic storage technologies, whose use can reduce infestation by pests and diseases and thus reduce losses by 20%. The use of plastic crates in Afghanistan as a package of tomatoes was seen to cut losses from 50% to 5% (Lipinski *et al*., 2013). The current study therefore, assessed the aspects upsetting implementation and degree of utilisation of Hermetic Storage Technology (HST) and consequently its impact on household income.

2.4 Green Grams Production in Kenya

Green gram is one of the most common pulses that is consumed in Kenya. Majority of the people consume it as a whole grain while others ground it into flour and mix it with cereals to make porridge (Kihoro *et al*., 2016). According to FAO (2010), the contribution of pulses in Kenya is about 20% of crop-based proteins. Consumers both in countryside and built-up areas, however, are inhibited by challenges in availability, with excess throughout harvest periods and scarcity during off-peak periods (Olwande, 2012). The question is whether improved storage technologies would be able to solve this problem. Nevertheless, HST is needed due to the fact that there has been an increase in the production of green grams in Kenya since the year 2008 to date (GoK, 2013), this being attributed to various interventions, like the Promotion of High-Value Traditional Crops that was employed by Kenya Agricultural and Livestock Research Organization (KALRO) in 2010. The aim of such initiatives was to promote drought-tolerant crops in ASALs to curb food shocks, green grams being one of the crops.

Table 1 shows the trends in green grams production in Kenya from 2013 to 2017. The growth of pulses in Kenya picked up again in recent years. Today, pulses are an important food source for the Kenyan population owing to their nutritional value, protein content and relatively low cost when related with meat. Pulses are gaining popularity among farmers due to their hardiness and resistance to drought, which makes them ideal in Kenya, where rainfall is sporadic because it is governed by the erratic movement of the intertropical convergence zone (FAOSTAT, 2015). Further complicating the matter, weather has been particularly unpredictable in recent years due to climate change. This has led many farmers to abandon wheat production in favor of pulses, especially green grams, which mature quickly and can thrive with limited rainfall.

Table 1: Green gram production trends in Kenya (2013-2017)

Year	**Area(ha)**	**Production (MT)**	**Yield (MT/ha)**
2013	147352	61125	0.41
2014	159910	70225	0.44
2015	188416	91024	0.49
2016	258407	96799	0.37
2017	259167	121076	0.47

[*]Source: Ministry of Agriculture (MOA), Economic Review of Agriculture (2018).

2.5 Green gram Storage Methods

Storage of green grams is a vital marketing function that should be carried out along the green gram value chain by the actors involved in the handling process. It ensures that the role of the agricultural sector in guaranteeing food security for the growing population is met. Several methods are used by the smallholder farmers depending on their attributes, for instance:

2.5.1 Chemical Methods

Most of the small-scale farmers use insecticides to control pest infestation during grain storage. Use of chemical insecticides has been suggested to guard against pests and other pathogen attack throughout storage period (Gitonga *et al*., 2015). Though, pesticides are regularly absent or are too exclusive for subsistence farmers in emerging countries. A study carried out in Nigeria by Asogwa & Dongo (2009) shows that some of the smallholder farmers use more than one chemical at the same time and this may lead to health complication such as blindness and skin irritation which might culminate to death. This can be credited to inappropriate routine application of storage chemicals. Safe storing of green grams at the farm level is vital, as it directly influences on poverty improvement, food and income safety of the small-scale farmers.

2.5.2 Traditional Methods

Smallholder farmers have several traditional methods of storage at the farm level which include: (a) ash method; (b) clay pots method and (c) basket method.

Ash Method: It**'s** a common traditional technique used to fight post-harvest insects and it involves mixing of green gram grain with sieved ash from cooking fires before storage. However, as traditionally used, the amount of ash and how it was mixed with the grain varied greatly from farmer-to-farmer.

Clay pots method: This mean is partly active for storage of small quantity of green gram grain for use as seed the succeeding year. According to Hayma (2003), grains has been kept in clay pots with minor openings, such as those used for holding water, with a layer of ash or sand to stop entry of insects. However, majority of these methods are not operative and this encouraged farmers to consume or trade most of their grains within two months of harvest (Scheepens *et al.,* 2006).

Basket method: Baskets are particularly usable in the dry tropics. In the humid tropics' ventilation is sufficient, so the baskets are separated from one another. They are raised off the ground on a platform, to prevent rodents attacking the basket. This method does not give enough safety against insects, but this can be enhanced by applying mud and clay (Scheepens *et al., 2006*).

Traditional storage techniques in African countries does not assure protection against main storage pests of grains (Gitonga *et al*., 2015). Inadequate storage structures for grain storage and the lack of storage management knowhows often push the smallholder farmers to trade their grains directly after harvest. Thus, producers take poor market prices for any surplus grain they may produce to evade post-harvest storage losses from pests and diseases (Tefera *et al*., 2011). Farmers also cannot use their harvest as collateral to access credit. Therefore, it's crucial that proper and reasonably priced storage technologies are readily available to farmers for them to securely store and preserve the quality of their grains (Thamaga-Chitja *et al*., 2004).

Abera *et al*., (2018) carried out a study in Ethiopia on the effectiveness of traditional and hermetic storage methods and found that hermetic bags prevent pest infestation and prolong the life span of the grains without grain quality losses compared to traditional methods.

2.5.3 Sun drying Method

In sun drying methods, the natural heat of the sun is collected in human-made prototype heaters to raise the temperature of the grain to the thermal death point necessary to kill all stages of the pulse beetle (Murdock *et al*., 2003; Mishili *et al*., 2011). However, according to research conducted by Bolaji (2014), the author reported that farmers comment on the extra labor required for solarization technique compared to hermetic storage.

2.5.4 Metal Silos method

Metal Silos was introduced by the International Maize and Wheat Improvement Center (CIMMYT) through a funded project titled “Effective Grain Storage for Sustainable Livelihood of African Farmers.” The programme aimed at reducing post-harvest maize grain losses and other grains in Africa. The project fruitfully introduced the advance and fabrication of metal silo technique in Kenya and Malawi (Ndegwa *et al*., 2013). The technique is a cylindrical structure, made from a galvanized iron sheet and hermetically sealed. It has proven to be efficient and effective in preventing the harvested grains from insects and pests’ infestations (Tefera *et al*., 2011). However, metal silos are hard to find and very expensive. Therefore poor smallholder farmers cannot afford to buy them which limits the spread of the Metal Silo Technology (Murdock *et al*., 2003).

2.5.5 Hermetic Storage Technology (HST)

HST consists of sealed storage with a modified atmosphere that develops deficient oxygen (O_2) and high carbon dioxide (CO_2). It has led to the use of safe, pesticide-free storage appropriate for several commodities, especially in a hot and humid climate(Villers, Bruin, & Navarro, 2005). It has been used mainly in Africa, Asia and South and Central America for a rising range of different types of commodities. High-quality brands of HST available in Kenya include; PICS, Grain Pro-Super Grain, Zero Fly, Agro-Z and Elite bags. A sensitization campaign in Kenya was conducted from November 2016 to April 2017. The campaign was targeting households and especially the small-scale farmers and schools. It included road shows across the counties, television and radio messages, hermetic storage technology field days, village demonstrations and school sessions.

Purdue Improved Crop Storage (PICS) is a triple-layer Hermetic Storage Technology that contains two layers made of 80µm Thick High-Density Polyethylene (HDPE) liners inserted in an outer woven polypropylene sack. PICS bags were initially introduced for the protection of cowpeas from cowpea weevil, *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) in West Africa (Murdock *et al*., 2003). This type of hermetic bag has attracted attention as being a better option for grain preservation, and it is even more attractive to smallholder farmers (Baributsa *et al*., 2012). The HDPE liners have low permeability to air and are therefore able to secure modified low oxygen and high carbon dioxide atmosphere. It is created by respiration of the grain, insects and other life-forms bounded when the bag is sealed, thus stopping the harm of the stored grains by insect pests and moulds (Njoroge *et al*., 2014).

2.6 Review of Economic Impact Studies on Agricultural Technologies

This section provides a summary of the selected studies that aimed at investigating the economic impact of agricultural technology adoption. The use of improved agricultural technologies has been circulated due to their returns. Nevertheless, there is an empirical evidence of income gaps between possible and actual achievements, and that net gains achievable from improved storage technologies have not been fully exploited by farmers in developing countries due to a number of reasons such as poor extension services, institutional and economic constraints (Alene and Manyong, 2007).Therefore, to evaluate the actual economic impact on household outcomes, econometric studies are needed that analyze the impact of agricultural technologies under farmers' conditions.

Studies by Asfaw *et al*., (2012) estimated the causal impact of Agricultural technology adoption in rural Ethiopia and Tanzania by using endogenous switching regression and propensity score matching methods to evaluate results robustness. The results concluded that adoption of improved technologies have a substantial positive impact on income.

Abdulai & Huffman (2013) assessed the factors affecting farmers 'decisions to adopt soil and water conservation technology in Africa and how this technology impacts on farm yields and net returns. The output of Endogenous Switching Regression model reveals that farmers' years of schooling, capital and extension services, and farm soil conditions majorly determine adoption of Soil and water conservation technology. The use of the technique improves rice yields and net gains significantly.

Shita *et al*., (2020) analyzed the effect of agricultural technology utilization on income disparity in Ethiopia. Propensity score matching method was used to analyzed the collected data. The results revealed that the utilization of agricultural technologies such as chemical fertilizer and improved seeds meaningfully improves household income but degrade income distribution. The positive impact occurred as a result of increased accessibility of extension and credit services by smallholder farmers.

Shiferaw *et al*., (2014) assessed the impact of the adoption of improved wheat varieties on food security in Ethiopia. They used endogenous switching regression treatment effects supplemented with a binary propensity score matching methodology to check the robustness of the results and reduced selection bias stemming from both observed and unobserved features. They found a consistent result across models showing that adoption boost food security and farm households that did not utilize the technique would also have benefited significantly had they adopted improved varieties.

2.7 Empirical Studies on the Impacts of PICS Technology

Previous research on PICS bags has investigated their effectiveness in storing products (Baoua *et al*., 2014; Mutungi *et al*., 2014; Njoroge *et al*. 2014). In the case of insect pest control, hermetic condition induces a fungistatic effect when oxygen concentration drops to 1% or below (Bernárdez & Pastoriza, 2013). Thus, stored products could be free from moulds infection and aflatoxin accumulation during storage if initial moisture content is safe for long term storage (Williams *et al*., 2014).

Yakubu (2014) carried out a study on the effects of PICS on household income in Jigawa, Kano and the Katsina States of Nigeria. The study used the gross margin analysis to determine the incomes of adopters and non-adopters in the three states. The study found that PICS farmers, that is the adopters made more profit than the non-adopters.

A study was also carried out by Jones *et al*., (2011) to examine the profitability of hermetic PICS bags for African common bean producers. The study found that PICS bags can give significant returns to storage for marketing producers. An impact assessment of the bean/cowpeas CRSP project by Moussa *et al*., (2014) found that, because of the introduction of hermetic storage technology in the study area, over 500,000 additional tons of cowpeas were being preserved per year, leading to $100 million in annual extra cowpeas income. The findings from such studies have prompted the researchers and other developmental partners to experiment with the storage of other commodities like pulses. Ognakossan *et al*., (2010), reported that PICS bags show 50% lower storage losses in cassava compared to other storage structures. Research studies by Bolaji, (2014) found that farmers and traders who stored their grains using improved storage technologies generated more income for their households.

2.8 Methods for Measuring Impacts of Improved Storage Technologies

The Impact Assessment Methods are classified into three broad categories, namely: Quantitative, qualitative and the combination of both (Jervis & Drake, 2014). Quantitative methods include social experiments, econometrics, propensity score matching and double difference estimator. The modest method to scrutinize the influence of acceptance of improved know-hows on well-being outcomes would be to include on welfare calculation, a mock variable equal to one if the farm-household accepted new know-how, and then, to apply ordinary least squares. This method, however, might yield unfair estimates because it assumes that acceptance of improved technology is exogenously strong-minded while it is possibly endogenic. The choice to adopt or not is voluntary and may be based on specific self-selection.

Difference in Difference analytical tool is a quantitative method often used to measure impact assessment study. The Difference in Difference estimator according to Nkonya *et al*., (2007), compares changes in outcome measures (changes from before to after the programme) between adopters and non-adopters rather than basically linking outcomes levels at one point in time. In order to use the estimator in question, there must be information on both adopters and non-adopters and all individuals must be observed both before and after the program (Verner, 2005). Difference in Difference Method can be used to reject assortment bias as it allows time invariant differences in outcomes between adopters and non-adopters. But it requires two sets of data for pre-treatment time period which were not available (Conley and Taber, 2011; Heckman *et al*., 1998).

Propensity score matching is a device for causal inference in non-randomized studies that allow for conditioning on large sets of covariates (Thoemmes, 2012). The PSM method compares observable outcomes between adopters and non-adopters of Hermetic Storage Technology (HST). According to studies by Mwansakilwa *et al*., (2017), PSM has been used in preceding studies to correct the self-selection bias and to evaluate the average treatment effect (ATE) of technology utilization. The objective of this technique is to account for selection bias on observables. The drawback is that selection on unobservable remains unaccounted for. According to Khandker *et al*., (2010), the tool is only used if the assumptions of conditional independence and common support hold.

Adopters have systematically different features from non -adopters, and they may have chosen not to adopt based on anticipated net gains. Unobservable features of farmer and their farm may have an impact on both the adoption choice and the well-being outcome, leading to unreliable estimates of the impact of utilization of agricultural techniques on household welfare. For example, if only the most motivated or skilled farmers decides to adopt and we do not account for skills, then an upward biased will be incurred. The solution is to use simultaneous equation models that explicitly controls for such endogeneity (Hausman, 1978).

2.9 Organization of the Thesis

This thesis has been organized as follows. Chapter two provides a review of the relevant literature, while the theoretical and analytical frameworks are discussed in chapter three. In addition, sampling techniques and data needs are explained in this chapter. Chapter four gives the results from data analysis. The final chapter (five) gives a summary of the main findings, conclusions, policy implications and offers some suggestions for further research.

CHAPTER THREE: METHODOLOGY

3.1 Background

Hermetic Storage Technology (HST) is one of the improved storage practices that reduce post-harvest pest infestation, specifically by insects such as weevils and grain borers. It is a modern improved storage technology that reduces the exchange of gasses between the stored grains and the environment. According to Baoua *et al*., (2014), oxygen gets depleted causing the insects to suffocate and die. In addition to that, metabolism is slowed down, and fungal growth is stopped, hence the preservation of grain quality is improved. Therefore, the adoption of hermetic bags by the smallholder farmers will enable them to have more and quality grain, either for consumption or for sale.

3.2 Conceptual Framework

The conceptual framework in Figure 1 demonstrates the interrelationships between the primary variables used in the study. Both socio-economic attributes, institutional factors and farm-specific factors influence the adoption of Hermetic Storage Technology. Adoption leads to utilisation of improved storage technologies which in turn leads to increased household income.

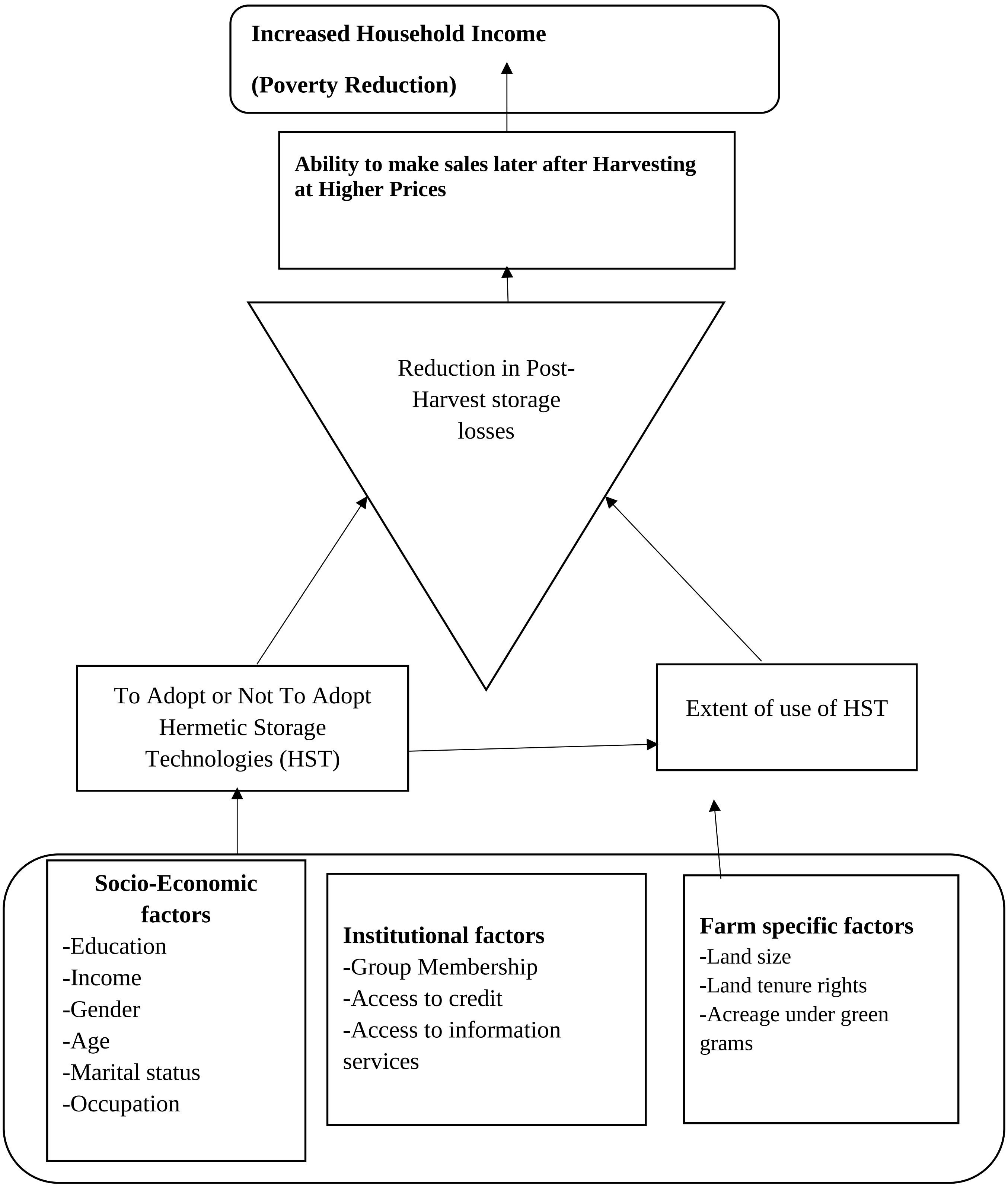

Figure 1: Conceptual Framework
Source: Author's (Own) Conceptualization

3.3 Theoretical Framework

The study was anchored on the theory of Expected Utility as developed by Daniel Bernoulli. According to Cooper (1997) & Hanemann (1984), a farmer's choice on whether or not to adopt a technique is modelled using expected utility framework. Every single farmer is faced with two choices with regards to the expectation that the utility of adopting is greater than that for non-adoption. Let Y be an observed outcome for the use of HST and it is binary represented by Y=1 for adopter and Y=0 for non-adopter. These outcomes are assumed to be influenced by the socio-economic characteristics of the farmer, farm specific characteristics and the institutional factors.

In the case of Hermetic Storage Technology (HST), a farmer *i* will choose to adopt the technology if the utility derived from it (U_{1i}) is greater than the utility (U_{0i}) of not adopting the technology. The assumption is that the farmer will only adopt the technology that gives him/her the largest possible utility. However, we do not observe its utility, but only its choice of technology. The utility of each alternative is in turn determine by a set of exogenous variables and error term. Adoption was assumed to occur if the utility of using HST was higher than the utility of using other storage techniques.

Let Y= Adoption decision, where Y=1 if the farmer chooses to adopt

Y=0 if the farmer chooses not to adopt

The green grams farmer will choose to adopt the Hermetic Storage Technology if

$(U_{1i}) > (U_{0i})$.

Thus, $Y^* = U_{1i} - U_{0i} > 0$……………………………………………………… (3.3.1)

Y^*=latent variable associated with the benefits of adopting HST.

According to Asfaw *et al*., (2012), utility derived from adopting HST can be demonstrated as a link between adoption decision and the expected benefits. Moreover, a rational farmer will adopt HST if the utility from adoption (U_{1i}) is greater than utility from non-adoption (U_{0i}). Nevertheless, utility is unobservable, thus adoption decision is modelled based on farm and farmer characteristics as shown:

$$Y_i^* = Z\beta + \varepsilon \qquad with\ HST = \begin{cases} 1\ if\ Z\beta + \varepsilon > 0 \\ 0 \quad Otherwise \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3.2)}$$

Where Z represents the observable characteristics that influence HST adoption, β is a vector of parameters to be estimated and ε is a vector of normally distributed error terms.

The probability of i^{th} household adopting the HST is given by:

$$P_i = P(Y_i = 1) = P_i(U_{1i} > U_{0i}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3.3)}$$

Which is estimated from the following equations:

$$P_i = P((\delta_1)F(Z_{1i}, W_{1i}) + \varepsilon_{1i} > (\delta_0)F\{Z_{0i}, W_{0i}) + \varepsilon_{0i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3.4)}$$

$$= P(\varepsilon_{1i} - \varepsilon_{0i}) > F(Z_i, W_i)\{\delta_0 - \delta_1\}$$

$$= P(\mu_i) > -F(Z_i, W_i, \beta)$$

$$= F_i(\beta X_i) or Y_i(\beta X_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.3.5)}$$

Where:

$P(\mu_i)$ = Probability function

X= Explanatory/exogenous variables

$\mu_i = \varepsilon_{1i} - \varepsilon_{0i}$ =Random Disturbance Term

$\beta = \delta_0 - \delta_1$ =Vector of coefficients

$F_i(BX_i)$ =Cumulative distribution function for μ_i evaluated at βX. Therefore, the probability of the i^{th} household to adopt the hermetic storage technique is the probability that the utility of the improved technology is higher than the utility of traditional storage methods or the cumulative distribution Function F_i evaluated at βX (Ngugi *et al*., 2003).

The current study assumes a normal distribution function for μ_i, which in turn influences the distribution for F. Therefore, the probit model is as shown below:

$$p(y = 1) = aZ_i + bW_i + \varepsilon_i \qquad (3.3.6)$$

Where:

Z and W= Explanatory variables

-+ ε_i=Random error

a and b=Unknown parameters to be estimated

P=Probability of adopting HST

3.4 Empirical Analysis

The study was accomplished by analyzing three objectives and these were achieved as follows:

3.4.1 Objectives 1 and 2: Adoption and extent of HST utilization

Berhanu and Swinton (2003) argued that adoption and extent decisions are not necessarily made jointly. The decision to adopt may precede the decision on the extent of use, and the factors affecting each decision may be different. With this reasoning, the appropriate model to analyze factors that affect adoption and extent of adoption is the double hurdle model. The Double hurdle model was first suggested by Cragg (1971) to solve the restriction of too many zeros in Tobit model and has been used by several authors (Burke, 2009; Olwande et al., 2009; Mignouna et al., 2011). The underlying assumption in the double-hurdle approach is that individuals make two decisions about their willingness to adopt Hermetic Storage Technology. The first decision is whether they will adopt the technology while the second decision is about the amount of the technology they will buy, conditional on the first decision. The importance of treating the two decisions independently lie in the fact that factors that affect one’s decision to adopt may be different from those affecting the decision on how much to adopt. Implying that households must cross two hurdles to adopting and therefore, the first hurdle needs to be met to be a potential adopter. Furthermore, this model approach allows us to understand characteristics of a class of households that would never adopt Hermetic Storage technology. Thus, the probability of a household to belong to a particular category depends on a set of household’s characteristics. To address Objectives 1 and 2, the researcher made use of a double hurdle model. It is comprised of two hurdles representing two continuous decision-making process. In the first hurdle, the researcher run a probit model to identify the factors that affect the decision to adopt using all sample population. The model was chosen since it assumes that the error term is normally distributed, the dependent variable will take two options (adopt= 1 and not adopt= 0), and it will be able to overcome the assumption of a linear probability model (Wooldridge, 2015).

For the second hurdle, the researcher used a truncated regression model to determine the extent of utilisation of HST by the smallholder farmers. Consequently, the model analysed the factors influencing the adoption of HST. The extent of Hermetic Storage Technology utilization was the dependent variable and factors affecting extent of use of the technology was taken as the explanatory variables. The equation of the first hurdle was presented as follows (Mignouna *et al*., 2011):

$y_i = 1\ if y_i^* > 0\ and\ 0\ if\ y_i^* \leq 0$

$y_i^* = x_i'\alpha + \varepsilon_i$…………………………………………………………………… (3.4.1)

Where: $y_i^* = Dependent\ dichotomous\ \ adoption\ choice\ variable$ that takes 1 if a household adopts HST and 0 otherwise, X' is a vector of household characteristics and α represents a vector of parameters for the first hurdle and ε_i represents the error term.

The second hurdle is expressed as follows:

$t_i = t_i^* > 0\ and\ y_i^* > 0$,

$t_i^* = 0\ otherwise$

$t_i^* = x_i'\beta + \mu_i$ ……………………………………………………………………. (3.4.2)

where: t_i=Dependent variable for the extent of adoption of HST conditional on y_i=1

X=Vector of household characteristics

β =Vector of the parameter of the second hurdle

μ_i=Error term

According to Goodwin & Smith (2003), the errors μ_i and ε_i are assumed to be independent and normally distributed as shown: $\mu_i \sim N(0,1), \varepsilon_I \sim N(0, \partial^2)$ and the observed variable in the double model is as shown: $t_i = y_i t_i^*$

The dependent adoption variable refers to whether a farmer has bought or not bought hermetic storage technologies.

From the first hurdle, the empirical adoption model is as follows:

$$y_j = \sum_{i=i}^{n} x_i \, \alpha_i + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4.3)$$

For j=1 or 0

The empirical model for the extent of adoption is estimated as follows:

$$t_i = \sum_{i=1}^{n} x_i' \, \beta_i + \mu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.4.4)$$

The dependent variable in the second hurdle (extent) refers to the ratio of the number of bags bought by the household to the quantity of green grams produced.

The equation for the current study was presented as follows:

$$\boldsymbol{in(HST) = \beta_0 + \beta_1 X_1 + \cdots + \beta_{16} X_{16} + \varepsilon} \ldots\ldots\ldots\ldots\ldots \quad \textbf{(3.4.5)}$$

Where:

X_1=Marital status, X_2=Years-school, X_3=Age, X_4=Farm experience, X_5=Off-farm Act, X_6=Membership, X_7=Household Size, X_8=Extension services, X_9= Gender, X_{10}=Market Distance, X_{11}= Occupation X_{12}= Land size, X_{13}= Credit Access, X_{14}= Market information, X_{15}= Plot tenure, X_{16}=Purpose of growing green grams.

3.4.2 Impact of use of HST on HH income

Due to observable and unobservable features, a farm household self-selects adopting agricultural techniques. To address the impact of use of Hermetic Storage Technology on Household Income, the researcher made use of Endogenous Switching Regression Model (ESRM).

3.4.2.1 Model Specification

A review of current literature shows that the majority of impact assessment studies grounded on cross-sectional data have used Endogenous Switching Regression Model (ESRM) (Alene *et al*., 2007; Asfaw *et al*., 2012; Abdulai & Huffman, 2013; Kassie *et al*., 2014; Murtazashvili & Wooldridge, 2016). ESRM is anchored on the assumption that, in addition to the observed features, there might be unobservable factors that could potentially influence both the adoption of HST and household income. Estimating the impact of technology adoption on household income without accounting for this problem might lead to endogeneity bias so that the estimated results may over- or under-estimate impacts compared to the actual impact. To correct for this problem, endogenous switching regression analysis was used with selectivity being modeled using a Probit model. The overall econometric modeling framework used is as described hereafter.

The switching regression was modeled in two stages (Di Falco *et al*., (2011); Gorst *et al*., (2018)). The first stage endogenous switching regression method involves the modelling of adoption into a binary model, and the equations for the outcome of interest, in this case household income, are modelled for both groups, conditional on selection. Following Asfaw *et al*., (2012), the utility from adopting HST can be modelled as a connection between adoption decision and the expected benefits. A green gram farmer (i) adopts improved storage technologies if the expected utility from adoption (U_a) is greater than the corresponding utility from non-adoption (U_{na}), i.e., $U_a - U_{na} > 0$. Let A_i^* be the latent variable that captures the benefit from adopting Hermetic Storage Technology by the i^{th} farmer, and this is given as:

$$A_i^* = Z_i\alpha + \varepsilon_i \; Where \; A_i = \{1 \; if \; Z_i\alpha + \; \varepsilon > \; 0 \; , 0 \; otherwise \; \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (3.4.6)$$

Equation (3.4.6) represents a probit model of adoption of Hermetic Storage Technology, where Z= Parameters to be estimated, α=Vector of household’s, farm and technology characteristics that affect the decision to adopt and/or not to adopt HST and ε= Error term (unobservable hence assumed to be normally distributed).

The second stage of the endogenous switching regression method (ESRM) involves the specification of the Full Information Maximum Likelihood (FIML) endogenous switching regression model (ESRM), say FIML-ESRM. Adopters and non-adopters are not directly comparable because of potential self-selection bias, and the FIML-ESRM is needed to correct for this self-selection bias so as to obtain unbiased estimates of the impact of Hermetic Storage Technologies on household income (Lokshin & Sajaia, 2004; Semykina &Wooldridge, 2010). This method enables us to obtain an estimate of the impact of the technology by using conditional expectations, that is, the hypothetical case of the outcome for adopters had they not adopted. This anticipated outcome is compared with the actual case, which provides a self-selection bias corrected estimate of the impact of the technology (Heckman, 2017).

The choice of this ESRM method for the current study is based on the fact that the model takes observed and unobserved characteristics into account when estimating the impact of HST. Propensity score matching, which could also be useful to a cross-sectional dataset, does not account for unobserved factors. This method assumes that selection is on observable characteristics only and should therefore only be used if this assumption is binding (Heckman *et al*., 1998; Dehejia & Wahba, 2002). To account for selection bias, an endogenous switching regression model of welfare outcome (i.e., household income) was adopted, where green grams farmers face two regimes 1= To adopt, and 2=Not to adopt (Rees and Maddala,1985). The model was defined as follows:

$$Regime\ 1: y_{1i} = X_{1i}\beta_1 + \varepsilon_{1i} \quad if\ A_i = 1(HST\ adopters) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3.4.7a)$$

$$Regime\ 2: y_{2i} = X_{2i}\beta_2 + \varepsilon_{2i} \quad if A_i = 0(Nonadopters\ of\ HST) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4.7b)$$

Where y_i is a binary household income status of household *i* under regime 1(adopter of HST) and 2 (Non-adopter of HST). X_i is a vector of household and farm characteristics that affect adoption, β is a vector of parameters to be estimated and ε is a vector of error terms.

According to Asfaw *et al*., (2012), self-selection into adoption may result in a trivariate normal distribution, with zero mean and non-singular covariance matrix as shown:

$$cov(\varepsilon_i\varepsilon_1\varepsilon_2) = \Sigma = \begin{matrix} {\sigma^2}_{\varepsilon i} & \sigma_{\varepsilon i\varepsilon 1} & \sigma_{\varepsilon i\varepsilon 1} \\ \sigma_{\varepsilon 1\varepsilon i} & {\sigma^2}_{\varepsilon 1} & \sigma_{\varepsilon 1\varepsilon 2} \\ \sigma_{\varepsilon 2\varepsilon i} & \sigma_{\varepsilon 2\varepsilon 1} & {\sigma^2}_{\varepsilon 2} \end{matrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4.8)$$

Where ${\sigma^2}_{\varepsilon i}$ ${\sigma^2}_{\varepsilon 1}$ and ${\sigma^2}_{\varepsilon 2}$ are variances of the error terms from the selection and outcome equations respectively, $\sigma_{\varepsilon 1\varepsilon i}$ is the covariance between εi and ε_i and $\sigma_{\varepsilon 2\varepsilon i}$ is the covariance between εi and ε_2.The $\sigma_{\varepsilon 2\varepsilon 1}$ is the covariance between ε_1 and ε_2 but is never defined because Y_1 and Y_2 are not observed simultaneously. Therefore, the expected values of the error terms for equation (3.4.7a) and (3.4.7b) are given by:

$E(\varepsilon_1|A_i = 1) = E(\varepsilon_1|\varepsilon_i > -Z_i\alpha = \sigma_{\varepsilon 1\varepsilon i}\frac{\theta(Z_i\alpha)}{\phi(Z_i\alpha)} = \sigma_{\varepsilon 1\varepsilon i}\lambda_{1i}$ ………………………………… (3.4.9a)

$E(\varepsilon_2|A_i = 2) = E(\varepsilon_2|\varepsilon_i \leq -Z_i\alpha = \sigma_{\varepsilon 2\varepsilon i}\frac{\theta(Z_j\alpha)}{1-\phi(Z_j\alpha)} = \sigma_{\varepsilon 2\varepsilon i}\lambda_{2i}$ …………………………... (3.4.9b)

Where ϕ is a standard normal probability density function and Φ is standard normal cumulative function. While $\lambda 1$ and $\lambda 2$ are ratios representing the Inverse Mills Ratios (IMR) for adopters and non-adopters that is to be included in the outcome equations (3.4.7a) and (3.4.7b) to correct for selection bias in the endogenous switching regression (Wooldridge, 2015).

The adoption choice of HST could be endogenous in the outcome equation (household income), hence the need to correct for the potential endogeneity. Therefore, identification of the outcome equation from the selection equation using an instrumental variables method is crucial. For the outcome equation to be identified, exclusion restrictions were used, where some variables affecting the selection equation but not the outcome equation are excluded from the outcome equation (Asfaw *et al*., 2012; Di Falco *et al*., 2011; Kassie *et al*., 2014; Shiferaw *et al*., 2014). However, getting a true instrument is empirically challenging, and membership was used as an instrumental variable. Falsification test was used to check for the admissibility of these instruments. Accordingly, the falsification test on the selected instrumental variable shows that it was statistically significant in affecting the selection equation but not the outcome equation.

3.4.2.2 Conditional Expectations, Treatment, and Heterogeneity Effects

From Equation (3.4.9a) and (3.4.9b), the Inverse Mills ratios derived from the selection equation in the outcome equation was incorporated to get;

$y_{1i} = X_{1i}\beta_1 + \varepsilon_{1i} + \sigma_{\varepsilon 1\varepsilon i}\lambda_1$ if A_1=1…………………………………………………... (3.4.10)

$y_{2i} = X_{2i}\beta_2 + \varepsilon_{2i} + \sigma_{\varepsilon 2\varepsilon i}\lambda_2$ if A_2=0…………………………………………………… (3.4.11)

The FIML estimates of the parameters of the endogenous switching regression model were generated by using *movestay* Stata command by Lokshin & Sajaia (2004).

The conditional expectations and average treatment effects under actual and counterfactual scenarios are estimated from equations (3.4.10) and (3.4.11) as follows:

$E(y_{1i}|A_i = 1) = X_{1i}\beta_1 + \delta_{\varepsilon 1\varepsilon i}\lambda_{1i}$………………………………………………….... (3.4.12a)

$E(y_{2i}|A_i = 0) = X_{2i}\beta_2 + \delta_{\varepsilon 2\varepsilon i}\lambda_{2i}$ …………………………………………………. (3.4.12b)

$E(y_{2i}|A_i = 1) = X_{1i}\beta_2 + \delta_{\varepsilon 2\varepsilon i}\lambda_{1i}$………………………………………………….... (3.4.12c)

$E(y_{1i}|A_i = 0) = X_{2i}\beta_1 + \delta_{\varepsilon 1\varepsilon i}\lambda_{2i}$ …………………………………………………. (3.4.12d)

Cases (3.4.12a) and (3.4.12b) along the diagonal of Table 2 represent the actual expectations of the observed outcomes. Case (3.4.12c) is the counterfactual outcome for non-adopters had they adopted, while case (3.4.12d) represents the counterfactual outcome for adopters had they not adopted. Counterfactual outcomes denote the expected outcomes for HST adopters had they not adopted and for non-adopters had they adopted.

Table 2. Conditional Expectations, Treatment, and Heterogeneity Effects

	Decision Stage		
Subsamples	**To adopt HST**	**Not to adopt HST**	**Adoption Effects**
Adopters of HST	(a)$E(y_{1i}\|A_i = 1)$	(c)$E(y_{2i}\|A_i = 1)$	**ATT**
Non-adopters of HST	(d)$E(y_{1i}\|A_i = 0)$	(b)$E(y_{2i}\|A_I = 0)$	**ATU**
Heterogeneity Effects	BH_1	BH_2	**TH**

Note: (a) and (b) represents observed expected outcome, and: (c) and (d) represent counterfactuals

A_i=1 if household i adopted HST; and A_i=0 if household i did not adopt the HST

Y_{1i}=Household income if a household adopt HST

Y_{2i}=Household income if a household did not adopt HST

ATT: Average Treatment effect on treated

ATU: average treatment effect on untreated

BH_i: the effect of base heterogeneity for non-adoption of HST

TH= (ATT-ATU), i.e., transition heterogeneity

Situations (a) and (b) are obtained from the survey data, but (c) and (d) are the expected situations (counterfactual outcome) where the treated happened to be untreated, and the untreated happened to be treated. Moreover, the expected change in the level of household income for adopters, i.e., ATT (Heckman, 2017), is given as;

$$ATT = (a) - (c) = E[y_{1i}|X, A_i = 1] - E[y_{2i}|X, A_i = 1] \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3.4.13)$$

Equally, the expected change in the level of household income of a household that did not adopt had they adopted HST, i.e., the average effect on the untreated households (ATU) is given as:

$$ATU = (d) - (b) = E[y_{1i}|X, A_i = 0] - E[y_{2i}|X, A_i = 0] \dots \quad (3.4.14)$$

where X1 and X2 are set of explanatory variables affecting HST adoption in regime 1 and 2, respectively. β_1 and β_2 are parameters to be estimated.

It might be the case that households that adopt HST have had better household income than non-adopter households, regardless of the fact that these households are using HST, due to unobservable factors that could potentially affect the level of household income. According to Carter & Milon (2005) and Di Falco *et al.*, (2011), one can also define the effect of base heterogeneity for households using HST (i.e., BH1) as:

$$BH_1 = (a) - (d) = (X_{1i} - X_{2i})\beta_1 + \sigma_{1\varepsilon}(\lambda_{1i} - \lambda_{2i}) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3.4.15)$$

Also, the base heterogeneity for non-adopters (BH2) is given as:

$$BH_2 = (c) - (b) = (X_{1i} - X_{2i})\beta_2 + \sigma_{2\varepsilon}(\lambda_{1i} - \lambda_{2i}) \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (3.4.16)$$

Lastly, transitional heterogeneity (TH) is arrived at by having a close look at whether the effect of using improved storage technologies, i.e.HST, on household income is larger for households that have adopted HST than for households that did not adopt, focusing on the counterfactual case that they would have adopted HST, that is, the difference between equations (3.4.15) and (3.4.16) (ATT and ATU).

3.5 Study Area

The research was carried out in Mwingi Central and Mwingi West Sub Counties in the Kitui county of Kenya. The two Sub-counties were chosen due to their high levels of production of green grams by the smallholder farmers who unfortunately experience high levels of post-harvest storage losses of green gram while being faced with high levels of poverty. A study by Wangui (2017) indicated that approximately 90% of farmers in Mwingi Central and 80% in Mwingi West grow green grams. Kitui County is positioned in the former Eastern Province of Kenya and is borders Taita Taveta County to the South, Makueni County to the West, Machakos to the Northwest, Tana River to the East and Embu and Tharaka Nithi to the North. The County has eight sub-counties, namely Kitui Central, Kitui South, Kitui East, Kitui Rural, Kitui West, Mwingi North, Mwingi West and Mwingi Central. The county covers an area of 30,570.30 square kilometres (Km^2), of which 6,369 km^2 is occupied by Tsavo East National Park as shown in Figure. 2(CIDP2013-2017).

The total population is 1,012,709 (approx. 205,491 households) according to the 2019 population census. Mwingi Central has a population of 141,207 and Mwingi West 139,967. Kitui County has two main livelihood zones as shown in Figure 3.

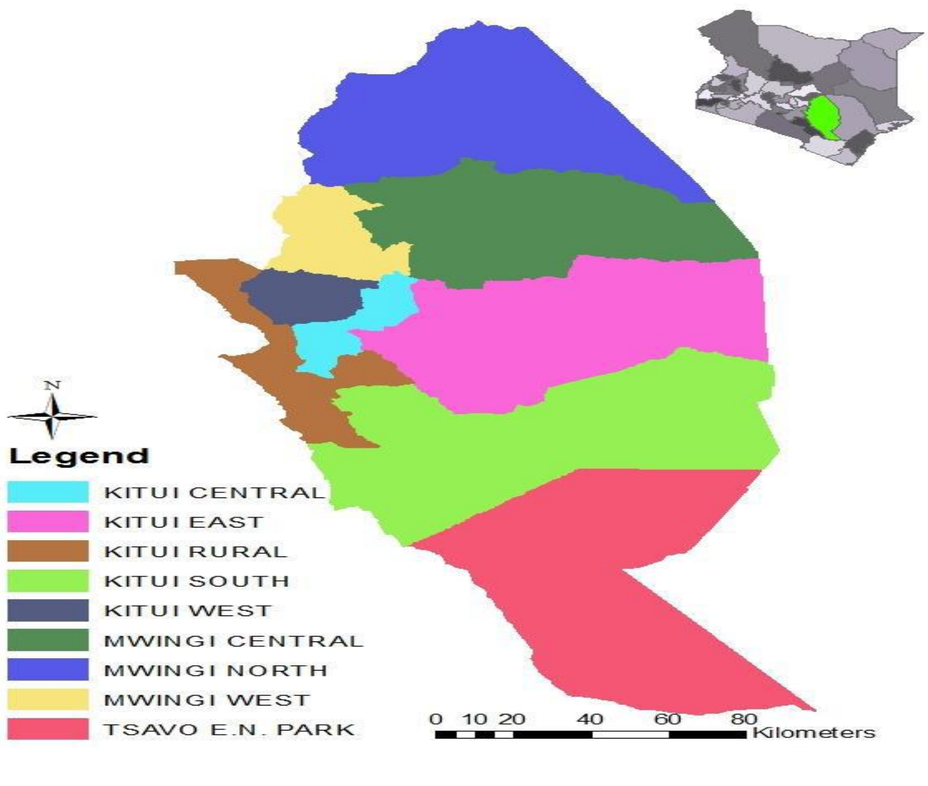

Figure 2: Kitui County and its Sub-Counties

Source: CIDP (2013-2017)

Figure 3: Population of Kitui County by Livelihood Zones
Source: CIDP (2013-2017)

Kitui County is an arid land with a low-lying topography, and very erratic and unreliable rainfall. It receives rains twice a year with high variability, ranging between 500-1050mm. Over the last three decades, it has encountered severe droughts, which have led to livestock deaths and food shortages (Wangui, 2017).

The county is characterized by declining food production, water scarcity and poor resilience to climate shocks**.** Mixed farming areas grow maize, beans, pigeon peas and cowpeas for consumption and fruits, cotton and vegetables as cash crops. The marginal mixed farming areas, where the rainfall is more erratic, grow cowpeas, millet, cassava and sweet potatoes for consumption, and green grams, sorghum and vegetables as cash crops**.**

3.6 Research Design, Sample Size and Sampling technique

Research design is a structure of investigation used to obtain answers to a research problem. It entails a blue print for collection, measurement and analysis of data (Gall *et al*., 2003). The study was based on both qualitative and quantitative research designs.

The sample size for the study was determined using the Cochran (1963) formula. It is specified below:

$$n = \frac{z^2 pq}{e^2}$$

$$n = \frac{(1.96)^2(0.5)(0.5)}{0.05^2} = 384$$

Where n is the sample size, e is the desired level of precision, Z^2 is the standard normal deviate at the selected confidence level (which is 95 percent confidence interval), p is the estimated proportion of an attribute that is present in the population, and q is 1-p.

The study applied a multi-stage sampling technique that entailed a combination of purposeful and systematic random sampling procedures to obtain a representative sample of HST adopters and non-adopters with regard to green grams farmers. The first stage entailed a non-random sampling procedure where the study purposively selected Kitui county because it is the leading producer of green grams in the Eastern part of Kenya. Secondly, the study purposively selected Mwingi Central and Mwingi West sub-counties of the Kitui County, based on their high concentrations and potential of green grams production. In the third stage, Sub- County wards were visited with the help of the Sub-County Agricultural Officers and a random sample of 271 green gram farmers, comprising both HST adopters (114) and non-adopters (157) were selected using a systematic random sampling technique. The goal was to select and interview a random sample of 384 green gram farmers, comprising both HST adopters and non-adopters, but owing to time and financial constraints, only 271 households were interviewed. The survey was conducted through face-to-face interviews which is an ideal method of data collection because it gives room for clarification of issues by both the interviewer and the respondent (Bateman *et al*., 2002). The interviews were carried out with the help of five well-trained enumerators and field guides who aided with the translation of questions into the local dialect.

3.7 Data Collection

Both primary and secondary data were collected. The secondary data were obtained from journals, government reports and the internet. Primary data were obtained through the face-to-face interviews with the individual farmers using semi-structured questionnaires. The face-to-face interview allowed clarification of concerns that any individual respondents had.

3.8 Data Analysist

The qualitative and quantitative data collected for objectives one, two and three were entered into a statistical package of social sciences (S.P.S.S) and analysed using STATA version 14 to estimate the Double Hurdle and the Endogenous Switching Regression models. Data cleaning and error checks were addressed by generating and evaluating robust standard errors that take care of heteroskedasticity. The results were presented in graphs and Tables.

3.9 Description of Variables and their Expected Signs

3.9.1 Dependent Variable for Probit and Truncated Regression Models

The dependent variable of the probit model takes a binary value, depending on the farmers' decision either to adopt or not to adopt the Hermetic Storage Technology. However, the truncated regression model would have a continuous value, which is the intensity of the use of HST bags. In this case, it refers to the ratio of the number of bags bought by the household to the quantity of green grams produced. Adopters are the farmers who use the HST bags. Non-adopters are the farmers who did not use the HST bags during the survey period.

3.9.2 Independent Variables

Majority of the adoption literature gives an extensive list of the factors that may influence the adoption of improved storage technologies. Commonly, farmers' decision to use improved storage technologies and the intensity of their use in a given period of time are conjectured to be influenced by a joint effect of various factors, such as household characteristics, socio-economic and physical environments in which farmers exist. Based on the previous studies on the adoption of improved storage technologies in the study area, Table 3 gives the explanatory variables that were selected for this study.

Table 3: Measurement Units and Expected Signs for Independent Variables

Variable	**Description**	**Units of Measurements**	**Expected sign**
Marital status	The marital status of the respondent	**Dummy (1=Married,0=Otherwise**	+
Farming experience	Number of years one has been involved with green gram production	**Years**	+
Membership	Membership to farmer groups	**Dummy (1=Yes, 0=No)**	+
Off-farm Activities	Any activities done outside farming i.e. charcoal burning	**Dummy (1=Yes, 0=No)**	+
Distance to market	Average Distance to the Market	**Kilometres**	-
Credit access	The ability of the farmer to access credit facilities	**Dummy (1=Yes, 0=No)**	+
Land size	The average land size a farmer has	**Acres**	+
Extension Services	Whether you received extension services or not during the last 12 months.	**Dummy (1=Yes, 0=No)**	+
Household Size	Number of people dependent on the household for food	**Number**	+/-
Plot tenure	Whether the farmer owned the land	**Dummy (1=Yes,0=Otherwise)**	+
Purpose	The reason why the farmer is growing green-grams	**Dummy (1=Sale, 0=Otherwise)**	-
Gender	Sex of the household head	Dummy (1=male,0=female)	+/-

Occupation-HH	The main occupation of the head of the household	**Categorical;**1=Formal employment,2=Casual employment,3=Farmer 4=Business person,5=others	+/-
Years of schooling	Number of years in school	**Years**	+

Marital Status

Marital status was hypothesized to have a positive sign. This can be attributed to the fact that; married respondents possibly have more properties than the unmarried or divorced. They also probably have a bigger household size. Both would force married respondents to be more likely to seek out improved storage technologies so as to be able to store their grains and be food secure.

Farming Experience

Experience in farming was hypothesized to have a positive influence on adoption of improved storage technologies. It was captured as a continuous variable.

Membership

In this study, it was hypothesized that membership in a farmer organization would positively influence both adoption and intensity of HST utilization among green grams farmers in Kitui County. The variable was captured as a dummy variable if any of the household members was a member in a famer organization.

Off-farm Activities

Off-farm activities as a variable was hypothesized to influence adoption positively, because it leads to increased off-farm income. Off-farm income represents the amount of income the farmers earn in the year on other than on-farm activity. For instance, income from petty trading, charcoal selling, firewood selling and others. Therefore, it is expected that the availability of off-farm income is positively related with adoption of Hermetic storage technologies.

Market Distance

The distance to the nearest market was captured in kilometers and hypothesized to negatively influence the adoption and intensity HST utilization among green grams producers.

Land size

The size of land owned by a household was captured in hectares as a continuous variable and hypothesized to be positively related to adoption and extent of HST utilization among green gram growers. This means that farmers who have relatively large farm size will be more initiated to involve in adopting the new agricultural production technologies, and the reverse is true for small size farm land.

Credit Access

Access to credit was captured as a dummy variable indicating whether the household had received any formal credit in the past 24 months or not. Access to credit is important with regard to technology adoption because it enables households to purchase hybrid seed, fertilizer and improved storage technologies which increase the likelihood of producing a marketable surplus. In this study, access to credit was hypothesized to be positively associated with adoption and extent of technology utilization.

Extension Services

Access to extension service was captured as a dummy variable, that’s whether a household received extension services in the last 12 months or not. Farmers that are in contact with extension agents have better understanding on new improved technologies such as Hermetic Storage

Technologies. In this study, access to extension service was hypothesized to be positively related to adoption and extent of HST utilization among green grams farmers in Kitui County.

Household Size

Household size was captured as a continuous variable indicating the number of members who were directly dependent on the household. In this study, therefore, an indeterminate relationship between household size and the adoption and extent of HST utilization was hypothesized.

Gender

Gender of the household head was captured as a dummy variable indicating whether the household was headed by a male or female and an indeterminate relationship with adoption and extent of HST utilization was hypothesized.

Age

Age of the household head was captured as a continuous variable. Older farmers may have more resources to access improved storage technologies, but risk averseness increases with age. According to Olwande & Mathenge (2011), the age of the household head negatively influenced the choice of adoption, but did not influence extent of adoption while Martey *et al*., (2012) found age to positively influence market participation among maize producers. Based on this evidence, age of the household head was hypothesized to have an indeterminate relationship with adoption and extent of HST utilization.

Years of Schooling

Education level of the household head was captured as a continuous variable, indicating the number of years spent in formal school by the household head. Therefore, education was hypothesized to have a positive sign.

3.10 Model Diagnostic Tests

A number of tests were done as shown below.

3.10.1 Testing for Multicollinearity

A test was done to check for the existence of multicollinearity between the explanatory variables. Multicollinearity arises when a linear relationship exists between the independent or explanatory variables and it increases the probability of making type 1 error. To check for multicollinearity in the data, the variance inflation factor (VIF) of the variables included in Double Hurdle Model were calculated by running 'Artificial Ordinary Least Squares' between each explanatory and other explanatory variable. Gujarati (2009) states that for any variable with VIF values greater than 10, this is a sign of multicollinearity. There was no evidence of multicollinearity across the models estimated in the study (Appendix 1).

3.10.2 Testing for Heteroscedasticity

The other test done was to check for the existence of heteroscedasticity, which arises when the variance of the error term differs across observations. Following Woodridge (2010), the Breusch Pagan test was used to check if the variance across the error terms in the Double Hurdle was constant. The results (Appendix 2) show that there is no constant variance across the error terms in the models, hence we fail to reject the null hypothesis. To correct for heteroscedasticity, we utilized robust standard errors in the model.

3.10.3 Correlation Test

A Pearson pair-wise correlation test was generated in STATA 14 (see Appendix 3). According to Gujarati (2007), if the pair-wise correlation is above 0.5, then the two variables are correlated hence they jointly influenced the dependent variable. After running the test, it was found that group membership and extension service were correlated above 0.5 and so extension service was dropped. From the results in Appendix 3, no variables had a pair-wise correlation above 0.5, which shows that the data was free from correlation after dropping extension service.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Introduction

Green gram has recently become an important crop in *Kitui County* because of its high economic returns and short growing season. This chapter deals with the presentation of the results obtained from data analysis. The results are presented in two sections. In the first section, a description of the socio-economic characteristics of the sample households comparing adopters and non-adopters for both Mwingi West and Mwingi Central, Kitui County, is presented. In the second section, the econometric results on the adoption, extent and impact of Hermetic Storage Technology utilization on household income are presented.

4.2 Socio-Economic characteristics of sampled green grams farmers

In this study, the focus was on the dynamics of household welfare, in particular how household incomes change with the adoption of Hermetic Storage Technology (HST). The socio-economic characteristics of the adopters and non-adopters of Hermetic Storage Technology were examined in this study. Table 4 presents the results of differences between means of characteristics describing HST adopters and non-adopters.

The results show that there was a significant difference in age and education of the household head with regard to adopters and non-adopters—the adopters were significantly younger. Farm size was significantly higher for adopters compared with non-adopters, while the quantity of green grams harvested per acre/hectare was comparable between the two groups, but higher for adopters. Also, majority of HST adopters had better access to credit facilities and extension services when compared with non-adopters.

Table 4: Socio-Economic Characteristics of Households

Variable		Pooled Mean (std dev)	Adopters Mean (std dev)	Non-adopters Mean (std dev)	t-value
Age of farmer		46.89(12.83)	43.99(10.71)	49(13.82)	3.23***
Years of schooling		8.5(4.42)	11.49(3.21)	6.45(3.96)	11.19***
Years of Experience		12.77(8.33)	16.47(8.10)	10.08(7.43)	6.73***
LogIncome		11.06(1.12)	11.46(1.04)	10.78(1.10)	5.09***
Land size		4.53(3.47)	5.26(3.44)	3.99(3.41)	3.01***
Quantity harvested		5.34(0.72)	5.66(0.68)	5.21(0.69)	5.38***
Proportion of green gram farming		1.71(1.40)	2.13(1.60)	1.41(1.15)	4.29***
Market distance		4.40(4.73)	3.78(4.06)	4.85(5.13)	-1.85*
Household size		5.87(2.51)	5.82(2.55)	5.91(2.49)	-0.28
			Percent	Percent	χ^2
Gender of the household head	Male	76.38	75.44	77.07	- 0.27
	Female	23.62	24.56	22.93	- 0.15
Credit Access	Yes	43.17	84.21	13.38	6.51***
Membership to Farmer Groups	Yes	45.76	92.98	11.46	-8.18***
Extension Services	Yes	41.70	87.72	8.28	6.57***
Off-farm Activities	Yes	77.12	76.32	77.71	0.24

Source: Survey Data 2019

Table 4 shows that the age distribution of the adopters and non-adopters of HST ranged from a minimum of 22 years and a maximum of 89 years. The mean ages of adopters and non-adopters were 43 years and 49 years respectively as shown in Table 4. This shows that in Mwingi central and Mwingi West, adopters are relatively younger and hence are in active labour force when compared to non-adopters. An implication for this is that, risk aversiveness increases with age. Mukasa (2016) found similar results in Tanzania and Uganda.

The average number of years of schooling for the adopters and non-adopters were 11 years and 6 years respectively. Imonikhe (2004) reported that education would significantly improve farmer's ability to make accurate and useful farming decisions, such as decision to adopt improved farming techniques. Education is one of the major decision factors in the adoption of high yielding technologies and improved storage structures. The average number of years of schooling for adopters was higher than for the non-adopters. This shows that the majority of adopters are in a better position to be aware of, understand and adopt improved storage technologies. This may be one of the reasons why adopters of Hermetic bags understood the need to use HST.

Additionally, the literate farmers will be able to adopt improved technologies that will impact on their household income and food security while those not educated may find certain farm practices too complex to understand. The findings were also in agreement with the findings of Elemasho *et al*., (2017).

The average household size was 5.8 for adopters and 5.9 for non-adopters. The household size refers to the number of people residing and eating from the same pot for each household interviewed. The mean household size was not found to be significantly different between adopter and non-adopter households in Mwingi Central and Mwingi West. The nearest local market was about 3.78 km for adopters and 4.85km for non-adopters.

At least 92.98 percent of the adopters and 11.46 percent of the non-adopters belonged to an agricultural group. This can be attributed to the fact that majority of the adopters were residing closer to shopping centers compared to non-adopters and had better access to farmer organizations. Further, 84.21 percent of the adopters and 13.38 percent of the non-adopters had access to agricultural credit while 87.72 percent of the adopters and 8.28 percent of the non-adopters reported having accessed extension services.

The average land owned by adopters (5.26 acres) was slightly higher than the average land owned by non-adopters (3.99 acres). These results show that farmers owning large farms have more freedom in allocating new crops and can produce more compared to those owning small land sizes. These findings are in line with the findings of Kiiza *et al*., (2011) & Mukasa (2016) who observed that the average size of land for adopters is larger than that of non-adopters.

The study revealed that the mean average of green grams farming experience was 16.47 years for the adopters and 10.08 years for the non-adopters. The implication here is that most of the farmers were highly experienced in green grams production and as such could thus manage their production process to get better output and income. There was a significant statistical difference between the two categories (adopters and non-adopters) at 1% level of significance with regard to farming experience in years.

Respondents' distribution by gender as shown in Table 4 showed that 76.38 percent of the households were male headed, so that 23.62 percent of the households were female headed. Of the adopters, 75.44% were male while 24.56 % were female. Of the non-adopters, 77.07% were male while 22.93% were female. The adoption and non-adoption proportions thus closely followed the household headship profiles.

4.2.1 Occupation of the Household head

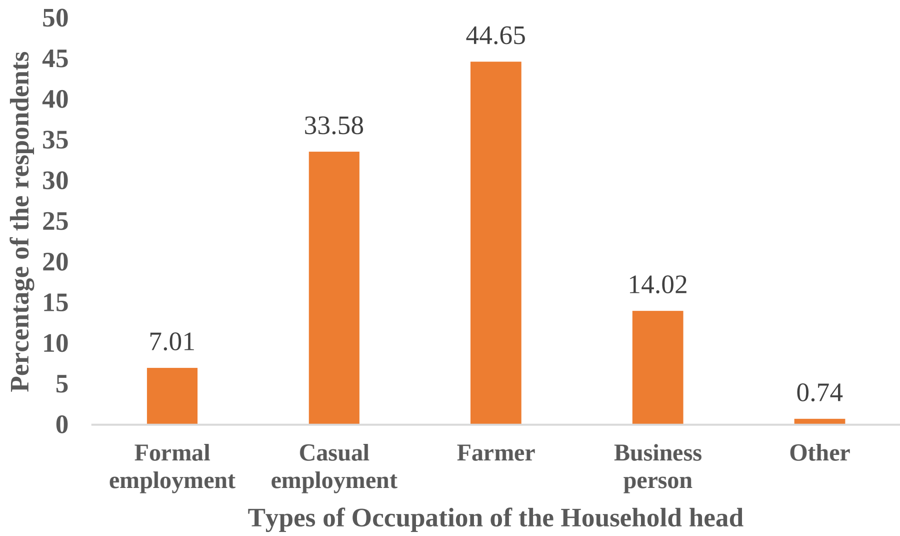

Figure 4: Occupation of the Household head

Source: Survey Data (2019)

From Figure 4, 44.65% of the respondents had farming as their main occupation while 33.58% were involved in casual employment. Agriculture is the backbone of Kitui County since, majority of the people are engaged in subsistence farming.

4.2.2 Sources of information about Hermetic Storage Technology

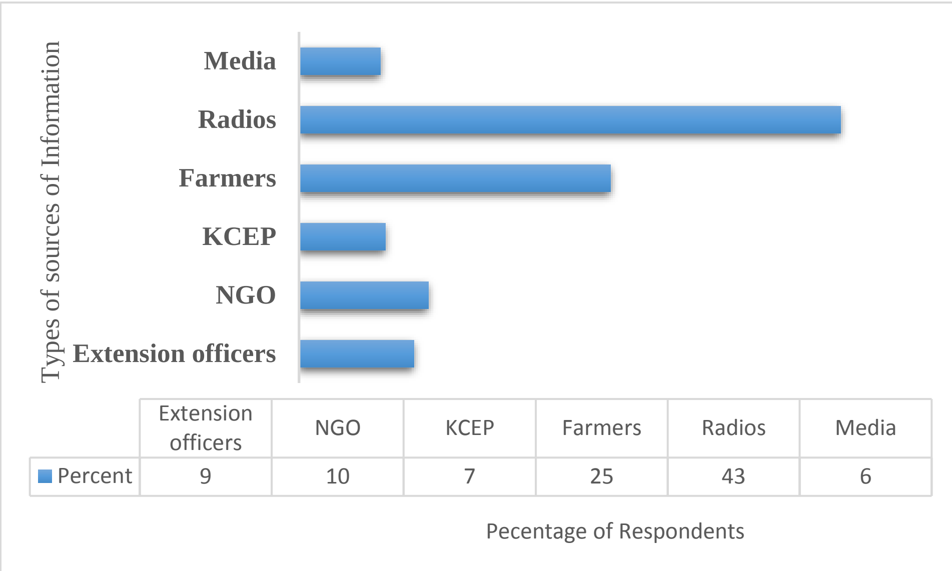

Figure 5: Sources of Information About HST
Source: Survey Data (2019)

The study findings revealed that most of the respondents (43%) said that they had learnt about Hermetic Storage Technology through the radios and this is consistent with the results of Elemasho *et al*., (2017). The second source of information often used by 25% of the farmers was their co-farmers and this finding is in agreement with Nwabeze *et al*., (2012) who reported that interpersonal method is an effective source of information.

Other popular sources of information for learning about HST included NGO, i.e., Adventist Development and Relief Agency (ADRA), and government initiative called Kenya Cereal Enhancement Programme (KCEP) through seminars and community meetings. About 6% of the respondents sourced information from the media. This low percent can be attributed to inadequate supply of electricity in the rural areas and lack of enough funds to buy television (Nenna, 2011).

4.2.3 Constraints Associated with the use of HST

Figure 6 depicts the constraints hindering farmers from adopting Hermetic Storage Technology in Mwingi central and Mwingi West Sub-counties. Although the majority of the surveyed households are aware about the HST, not all of them have adopted the technology. During the survey, 54.74% of the farmers cited the high cost of HST as the major factor which hinders adoption. Other factors include insect infestation of the bag caused by negligence during storage (11.58%), unavailability of the bag (8.42 %) and lack of knowledge on how to use the bag (8.42%).

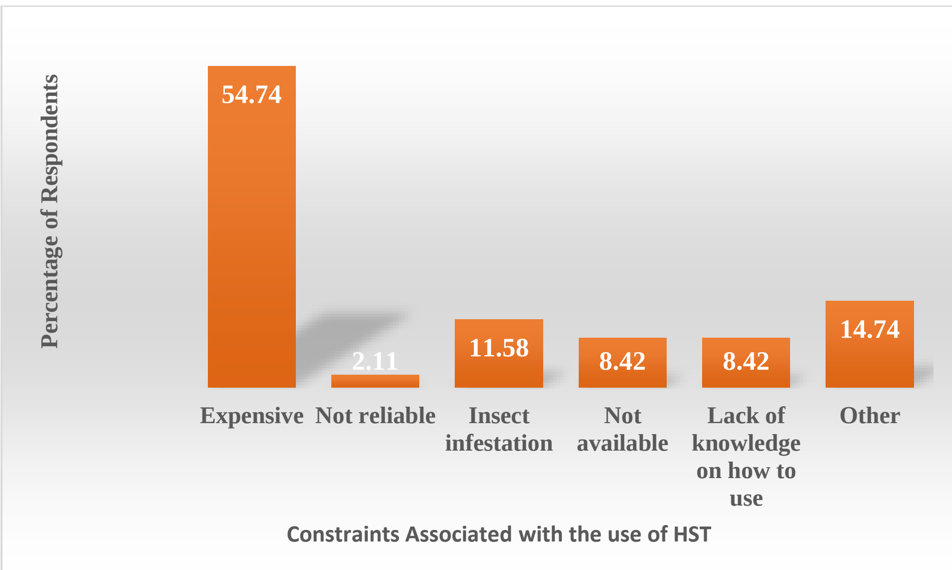

Figure 6: Constraints Associated with the use of HST
Source: Survey Data (2019)

4.2.4 Extent of Satisfaction with HST utilization

Based on a Likert scale of 1-5, from 'very dissatisfied' (1) to 'very satisfied' (5), the results (Figure 7) showed that 42.11% of the adopters of HST reported that they were very satisfied while 38.6% were satisfied with the hermetic bag. The dissatisfaction was attributed to lack of proper knowledge on how to use the bag, leading to poor handling by the farmer and pest infestation.

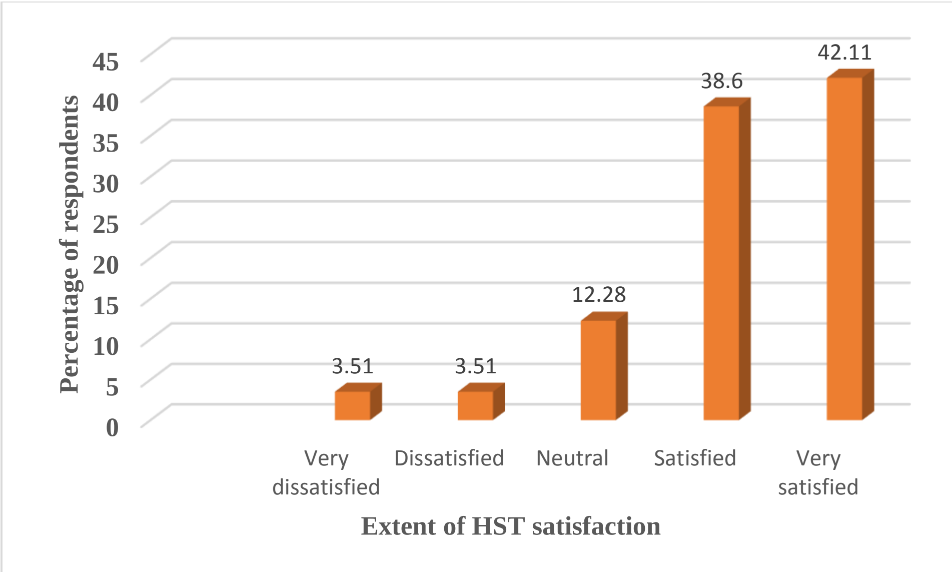

Figure 7: Extent of Satisfaction with HST utilization

Source: Survey Data (2019)

4.2.5 Types of other storage structures currently being used

Results from Figure 8 show that, apart from Hermetic Storage bags, 61.625% of the households growing green grams still use local gunny bags while 27.31 % use sisal sacks**.** In their review of literature, Affognon *et al*., (2015) found that farm household adoption of improved post-harvest storage techniques in SSA ranges from 12.7% to 74%, with majority of the studies reviewed revealing adoption rates of less than 50%. Also, high non-adoption rates of 56% to 73% were reported in the same study. Besides limited access to finance by farmers, the other reasons indicated as being causes of low adoption and high non-adoption were limited technical know-how and inappropriate technologies (at times) due to inadequate involvement of beneficiaries in selecting technology (Mutambuki Ngatia, 2006; Obeng-Ofori, 2011).

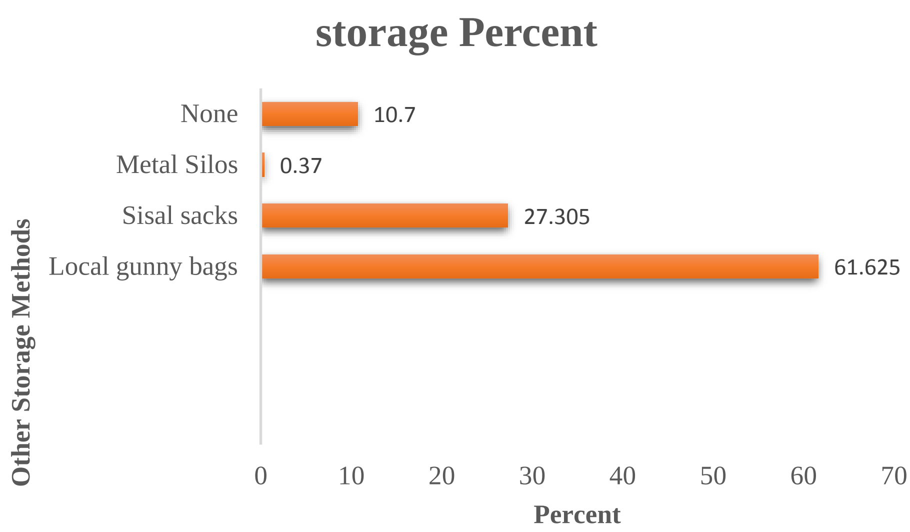

Figure 8: Percentage of farmers using Other Storage Methods

Source: Survey Data (2019)

4.3 Factors Influencing the Adoption and Extent of HST utilization

Table 6 is the result of the Craggit command in Stata use for the double hurdle model assumption in the study. The assumption of conditional independence which implies that both decisions to adopt and the extent of adoption are independent and unique decisions, is upheld as a basic assumption when using a Craggit command to determine both decisions to adopt and the extent of adoption. The maximum likelihood estimate is revealed to have a chi squared significance of 1%, showing that the model fits the variables properly.

The double hurdle model was estimated using STATA 14 econometric software. Diagnostic tests for presence of multicollinearity and heteroscedasticity were conducted using Variance Inflation Factor (VIF) (Gujarati, 2004) and the White test (White, 1980) respectively. The mean VIF was 1.42 and the critical value is 5 according to Ringle *et al*., (2015). Therefore, Multicollinearity was not a problem among the continuous variables. Heteroskedasticity was found to be a problem but it was corrected for by using the robust standard errors. This entails computing the weighted least squares estimator using a hypothesized specification for the variance.

Table 6: Double Hurdle Model Results

	Adoption Probit			**Extent of Adoption Truncated**		
Variables	Coefficient	Robust std. errors	Marginal Effect	Coefficient	Robust std. errors	Marginal Effect
Age of Household head	-0.049**	0.017	-0.226	0.063*	0.038	0.063
Gender of Household Head	-0.805	0.534	-0.05	-0.521	0.779	-0.518
Experience in greengram farming	0.073***	0.028	0.005	-0.120***	0.044	-0.119
Land size	0.109**	0.048	0.0068	-0.248**	0.075	-0.247
Group Membership	0.266***	0.441	0.042	0.841	1.007	0.839
Credit access	0.270***	0.339	0.142	-1.696*	1.146	-1.69
Market Distance	-0.013*	0.03	-0.001	0.06	0.091	0.06
Off-farm Activities	-1.243**	0.479	-0.078	0.488	0.842	0.487
Household size	-0.056	0.063	-0.004			
Marital Status	0.755	0.512	0.047			
Years of schooling	0.271***	0.52	0.017			
Occupation of HH	-0.676**	0.352	-0.042			
Purpose	0.352	0.333	0.022			
Plot tenure	0.629	0.298	0.039			
_cons	-2.216	1.458		13.22	2.463	
Observations	271					
Log Likelihood	-338.74					
Wald=Chi2	53.56					
Prob>Chi	0.0000					

Source: Survey Data (2019)

4.3.1 Econometric Results of Hermetic Storage Technology Adoption Model

Double Hurdle Model was used in estimating factors that influence adoption and extent of Hermetic Storage Technology Utilization among the smallholder green grams farmers in Mwingi Central and Mwingi West. The results are presented in table 6. The log likelihood function is statistically significant at 1% level of significant. This indicates that the variables (farmers socio-economic characteristics, institutional, and other policy variables) included in the Double Hurdle model are conjointly significant in determining the farmers' adoption and extent of adoption of HST decision. However, only nine out of the fourteen variables and four out of the eight variables are individually statistically significant in the first hurdle and second hurdle respectively.

The results of the analyses also revealed that the rate of adoption and extent of adoption of Hermetic Storage Technology were influenced by different factors at different levels of significance. In the first stage of the Double Hurdle model, dependent variable equals 1 if the farmer adopts HST and 0 otherwise. The discussion of the results about the significant factors is presented hereafter.

The age of household head variable was found to be negative and significant in the adoption decision at 5% level, but it was positive and significant at 10% level in the extent of adoption decision. The result reveals that as farmer's age increases by one year, the probability of adopting improved storage technologies decreases by 22.6%. This could be attributed to the fact that risk aversion increases with age. The results are consistent with the findings by Sadati *et al*., (2010) & Velandia *et al*., (2009) who reported that the farmers' age influenced adoption of crop insurance negatively. Nevertheless, a positive relationship between age and adoption of crop insurance was reported by Sherrick *et al*., (2004).

Years of schooling was found to be positive and statistically significant at 1% in influencing HST adoption. The result shows that as the years of schooling increase by one year, the probability of adopting HST increases by 1.7%. This is probably because education increases the capacity of farm households to acquire information and knowledge of improved storage technologies and thus promotes the decision to use them on their farms. Similar results were found in studies of the adoption of improved storage structures for maize in Benin (Adegbola *et al*., 2011, as cited in

Affognon *et al*., 2015), and metallic grain silos in Malawi (Maonga *et al*., 2013). The results are also consistent with the findings of Doss &Morris (2001); Abay & Assefa (2004). In the majority of the studies on agricultural technology, education was taken as a vital explanatory factor that positively affected the decision of households to adopt new agricultural technologies. For instance, Abay & Assefa (2004); Salasya *et al*., (2007) and Alene & Manyong (2007) studied the effect of education on agricultural productivity under traditional and improved technology in northern Nigeria using an endogenous switching regression analysis. The researchers found that education had a positive and significant influence on agricultural technology adoption. The analysis by Beshir *et al*., (2012) using double-hurdle method also showed a positive and significant result on the role of education on chemical fertilizer technology adoption in Northern Ethiopia. The findings of the current study in Kitui County are thus consistent with previous findings.

The results of this study showed that occupation of the household head was negative and statistically significant at 5% in influencing the adoption of HST. However, it was negative and not significant in influencing the extent of adoption. The model results reveal that being a non-farmer decreases the probability of adopting HST by 4.2%.

The results showed that experience in green grams farming was positive and significant at 1% level in influencing the adoption of HST. This variable was also found to be negative and statistically significant at 1% level in influencing the extent of adoption. The implication is that farmers with more farming experience are more likely to perceive and adopt improve storage technologies as compared to farmers with less farming experience. Simply because, with increase in working year the farmer gets more understanding about the system of post-harvest storage losses and how to curb them. Farmers with higher experience appear to have full information and better knowledge and are able to evaluate the advantage of the technology.

As anticipated, the size of land owned by green grams farmers was found to be significant at 5% level and had a positive effect on the adoption of HST. The results show that a one unit increase in land size increases the probability of adopting HST by 0.6%. This was in line with the findings from Simtowe *et al*., (2012) who found a significant relationship between land size and adoption of improved technology and stated that there was a positive correlation between farm size and adoption of improved technology. Idrisa *et al*., (2012) analyzed the determinants of the likelihood of adoption and extents of adoption in Nigeria and found that farm size influenced the adoption and extent of soya bean seed. Farm size was found as one of the most important factors that significantly affected adoption decision (Akudugu *et al*., 2012; Salasya *et al.*, 2007; Saleem *et al.*, 2011). A plausible explanation is that larger farms strengthen farmer's capacity to produce more, which makes them interested in preserving their produce from post-harvest storage losses. Land size, was however, found to negatively influence the extent of adoption at 10% level of significance. This is simply because, farmers with large sizes of land tend to diversify their production.

Membership to a group by the household head was positive and significantly (1% level) increased the probability of adopting Hermetic bags. This showed that adoption increased by 49.3% when a farmer belonged to a group. Membership to a group is a proxy for social capital which enables social networks to facilitate flow of information relevant to improved storage technologies. This might be an indication that organized farmers are empowered (through enhanced diffusion of knowledge and information about new technologies) and have improved bargaining power for cost-effective technology acquisition when compared to their non-member counterparts (Bahta & Lombard, 2017). Quisumbing (2003) suggests that social groups act as informal insurance in crisis periods such as those common in the study area caused by low and erratic rainfall. The findings are consistent with those of Kassie *et al*., (2015) who found that farmers organized in groups are likely to adopt sustainable intensification practices such as fertilizer and improved varieties. It does this through improved access to inputs, increasing bargaining power for better factor and product prices as well as increasing access to improved storage technologies. It also allows producers to reach economies of scale by bulking (Mathenge *et al*., 2014).

The results show that access to credit had a positive effect on the adoption of HST at 1% level of significance. Agricultural credit services are the major sources of capital to solve financial constraints. If farmers can get access to credit, they can purchase improved storage technologies. The result is consistent with the findings of Abay & Assefa (2004); Teklewold *et al*., (2013). However, credit access had a negative and significant effect on the extent of adoption. A plausible explanation for this can be that farmers that have access to agricultural loans have enough capital to adopt other capital-intensive practices such as irrigation.

The estimated coefficient for market distance was found to be negative and statistically significant at 10% level in adoption hurdle but insignificant in the extent of adoption. This show that farmers who are closer to the market have a higher probability to adopt HST than those that are far away. The probability marginal effects of the distance to the market variable were noted to be statistically significant at 10%. This indicated that expected adoption of *HST* decreased by 0.1% as the distance to the market increased by one-kilometer. The findings were in line with the finding of Tey *et al*., (2014). Distance to the market can be utilized as a proxy to access to information and technology (Kassie *et al*., 2015); thus, the farmers nearer to the market had access to information regarding HST and its benefits thus explaining their adoption rate. Dhivya *et al*., (2019) found out that, households that were in urban centers adopted more than those that were in rural areas because the former could access markets at lower transportation and transaction costs than the latter.

From the results, gender of the household head, household size, plot tenure, purpose of growing green grams and marital status had no significant influence on both adoption and the extent of adoption of Hermetic Storage Technology. Gender of the household head having an insignificant effect on the adoption of HST is consistent with earlier studies in Nepal (Gauchan *et al*., 2012). For the gender not being significant here is possibly because, in general, most of the household decisions in farming operation (including technology adoption) are made by men in consultation with female members, so that men are not the sole decision makers for the choice of post-harvest storage technologies to be used.

Engagement in off-farm activities was found to positively influence adoption at 5% level of significance. This was in line with the findings of Wake & Habteyesus (2019) who found a positive and significant effect of off-farm activities on chemical fertilizer technology adoption in North eastern highlands of Ethiopia. The households engaged in off-farm activities are better endowed with additional off-farm income to purchase initial improved storage technologies or other essential agricultural inputs for seed or seedling production.

4.4 Impacts of HST Utilization on household income

Postharvest storage losses are a major factor that affects household income and food security in rural areas of Kitui County. During the late 1980s, Purdue University introduced the use of Hermetic bags which aimed at reducing smallholder farmers' post-harvest storage losses, with the Purdue Improved Crop Storage (PICS) one being the most commonly used. This study evaluated the determinants of the adoption and the impact of the use of HST on the household income of rural households in Mwingi West and Mwingi Central, Kitui County.

4.4.1 Results and discussions of Actual and Counterfactual Comparisons

To separate the impact of Hermetic Storage Technology Utilization on the household incomes of the smallholder green grams farmers from the impacts of unobserved heterogeneities between the households who adopted and those who did not, a counterfactual analysis was built from the endogenous switching regression estimates. The first stage of the Endogenous Switching Regression Model is a selection equation on adopting HST or not. The second part is the outcome equation (on household income) under adopter and non-adopter households. Group membership was used as the identifying instrument because this variable is expected to affect adoption of HST but not the outcome variables of interest directly.

Table 7: Factors influencing Adoption of HST

Variables	Decision (Probit model)	
	Coef.	Std. error
Age of the household head	-0.04**	0.02
Marital status	-0.12	0.7
Years of Schooling	0.29***	0.09
Household size	-0.01	0.08
Land size	0.19	0.41
Plot tenure	0.83	0.54
Credit Access	0.72***	0.42
Off-farm Activities	-0.94*	0.56
Sex of the Household head	0.08	0.66
Quantity Harvested	0.0005	0.001
Group Membership	2.32***	0.47
Market Distance	-0.05	0.39
Purpose of growing green grams	0.61	0.4
Experience in green grams farming	0.068**	0.03
Cons	-4.79***	1.71
Number of observations		
Wald $Chi^2(8)$ =34.46		
Prop>Chi^2=0.0000		
Log likelihood=-394.829		

***, ** and * represents significance at 1%, 5% and 10% probability levels respectively

Source: Survey Data 2019

The coefficient for age is negative and significant at 10% level of significance. This implies that older farmers are less likely to adopt HST than younger farmers. This result agrees with the findings of Kuntashula *et al*., (2014), an adoption study that was done in Zambia.

The coefficient for years of experience in green grams farming is positive and significant at 5% level. This shows that farmers who have more experience in green grams production are more likely to adopt HST. Additionally, the results show that access to credit had a positive effect on the adoption of HST at 1% level of significance. This implies that there is need for credit facilities be made available to farmers so as to increase the likelihood of technology adoption in the study area.

The coefficient for group membership was positive and significant at 1% level, implying that membership to a social group increases the probability of adopting HST. The findings are in agreement with the findings of Kassie *et al*., (2015) which indicated that farmers who were in social groups were more likely to adopt sustainable intensification practices, such as improved crop varieties and fertilizer. Years of schooling was found to be positive and significant at 1% level. This means that an increase in the number of years of schooling before one becomes an adult and takes into farming increases the probability of adopting HST. From the findings, involvement in off-farm activities was found to be negative and significant at 10% level.

4.4.2 Full Information Maximum Likelihood Estimates of the switching regression model

The Results of the second stage endogenous switching regression that aimed to explain if there are any differences in the household incomes are presented in Table 8. The estimate of the coefficients of correlation between the error terms in the selection equation and the outcome equation given by ($\rho 1$, $\rho 0$) is significant and negative for both the correlation between adoption equation and household income for adopter's equation, and adoption equation and household income for non-adopter's equation. This finding implies that both the adopters and the non-adopters are worse off. However, one cannot make a final conclusion from this test because the significance of the two systems of equations (r1r2) suggests that there is evidence of self-selection in the adoption of HST. This result justifies the use of endogenous switching model to correct self-selection. Additionally, the likelihood ratio test for selection and outcome equations is significant, implying that there is dependence between the two system equations.

Table 8: Full Information Maximum Likelihood estimates of the switching regression model for household income

Variables	Adopters		Non-adopters	
	Coef.	Std. err	Coef.	Std. err
Age of the Household head	0.001	0.009	-0.007*	0.006
Marital status	-0.02	0.233	0.439	0.212
Years of schooling	0.060**	0.034	-0.031	0.22
Household size	-0.049**	0.036	-0.02	0.34
Land size	0.080***	0.026	0.130***	0.025
Plot tenure	-0.25	0.185	-0.13	0.17
Credit Access	0.089	0.343	-0.28*	0.26
Off-farm Activities	0.47**	0.22	0.73*	0.2
Cons	9.98***	0.84	9.94***	0.53
r1r2	-0.219**	0.806	-0.649**	0.341
ρ1ρ0	-0.216**	0.769	-0.571*	0.229
LR test for joint indep.	6.88***			
Log likelihood		-394.829		
Number of observations		270		

***, ** and * represents significance at 1%, 5% and 10% probability levels respectively

r1r2: Transformation of the correlation of the error terms in the adoption choice equation and outcome equation

ρ1ρ0: Correlation coefficient between error terms of the system equations

Source: Survey Data 2019

From the findings, age of the household head, years of schooling, household size, land size, credit access and off-farm activities affect adopters and non-adopter's household income differently at different levels of significance. Such differences in the signs of coefficients reflect the presence of heterogeneity between adopters and non-adopters (Di Falco *et al*., 2011; Khanal *et al*., 2018).

The results show that land size has a positive and significant effect on the outcome variable for both adopters and non-adopters. Age of the household head has a negative and significant impact on the outcome variable for the non-adopters only. Involvement in off-farm activities has a positive and significant impact on the outcome variable for both adopters and non-adopters.

Years of schooling was found to influence the outcome variable for adopters positively at 5% level of significance. However, the variable was insignificant for the non-adopters.

The model estimates for the household size show a negative and significant impact on the household income for adopters and insignificant impact for non-adopters.

Accessibility to credit was found to have a negative and significant impact on household income for non-adopters.

4.4.3 Average Treatment Effect of Adopting HST

Table 9 presents the average household income for Adopters and Non-adopters. To determine if the household income is greater or smaller for adopters had they not adopted or non-adopters had they adopted, the transitional heterogeneity effect was computed from the difference in household income for Adopters and Non-adopters (ATT & ATU).

ATT is the difference between how much adopters earned and what non-adopters would have earned had they adopted, whereas ATU is the difference between what adopters would have earned had they not adopted and what non-adopters actually earned without adoption (Ngoma, 2018).

Table 9: Impact of Adoption of HST on household income

Subsample	Decision stage		
	To Adopt HST	**Not to Adopt HST**	**Treatment Effects**
Adoption	150654.8 (77827.26) ***	140978.9 (77939.18) ***	ATT=111899.1 (52873.53) ***
Non-adoption	38755.75 (52800.97) ***	83298.85 (49689) ***	ATU=57680.1 (60141.94) ***
Heterogeneity Effects	111899.05	57680.05	TH=54219

***, ** and * represents significance at 1%, 5% and 10% probability levels respectively. The figures in parenthesis are standard deviations.
ATT: Treatment effects on the treated
ATU: Treatment effects on the untreated
TH: Transitional Heterogeneity
Source: Survey Data 2019

The transitional heterogeneity (TH) is positive (Ksh 54,219), implying that there are systematic differences in income among the farmers. Farmers who actually adopted Hermetic Storage Technology had higher household income than non-adopter farmers. These results imply that the adoption of Hermetic Storage Technology leads to an increase in household welfare as measured in terms of household income. Moreover, the transition heterogeneity effect for household income is positive, and this shows that the effect is bigger for the farm households that did adopt with respect to those that did not adopt.

The third objective of this research states that adoption of HST has not significantly improved the household's income in Kitui County. The results of ESRM show that the marginal adoption impact on household's income equals to Kshs.54,219. Therefore, based on these findings, it was concluded that the HST had significantly impacted on household's income and thus hypothesis 3 was rejected.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the study findings

With farming as the primary source of livelihood in Kitui County, there is need for promotion and adoption of improved food storage technologies. The aim of this study was to determine the factors that influence the adoption and extent of adoption of Hermetic Storage Technology and its impact on household income among smallholder green grams farmers in Mwingi West and Mwingi Central Sub-Counties of Kitui County.

This study shows that adoption and extent of use of Hermetic Storage Technology in Kitui County is influenced by socio-economic, institutional and farm specific characteristics. It also shows that the HST adoption has a positive impact on the household income, hence impacting on the farmers' welfare. This is reflected by the differences in household incomes of the adopters and non-adopters. Adopters had on an average increased their income by Ksh.54,219 when compared to the income of the non-adopters.

5.1.1 Findings on Farmer Socio-Economic, Institutional and Farm Specific Factors on Adoption and extent of adoption of HST

The study determined the factors that influence adoption and extent of HST utilization by using the double hurdle model. The empirical results indicated that the age of the household head, Land size, Group membership, Credit access, farming experience, distance to the nearest market, off-farm activities, occupation of the household head, and years of schooling significantly influence the adoption of HST. Some of these factors show a clear and positive effect on HST adoption and these include access to credit, years of schooling, group membership, land size, and farming experience. The extent of HST utilization was influenced by age of the household head, farming experience, land size and credit access. Therefore, the study concludes that social economic factors, institutional factors and farm specific characteristics are the main factors that influence the adoption and extent of adoption of the HST.

It can be argued that credit access and group membership affect adoption and utilization of HST because increased funds can permit higher investments in improved storage facilities, hence leading to reduction in post-harvest storage losses, while group membership enhances social networks that facilitate the flow of information about storage facilities.

Research findings showed that land size was positively significant in adoption such that farmers who have large tracts of land easily adopted the technology because land can act as collateral security in getting funds to acquire the new technology. Additionally, other occupations that farmers engaged in (other than green gram production) were negatively significant. This shows that the farmers' attention is diverted to other activities, hence leading to reduced production and less pressure to adopt storage facilities.

Years of schooling and farming experience were also found to have a positive effect on adoption and utilization of HST. Farmers who were more educated were better adopters and users of HST than illiterate farmers. This finding can be attributed to the fact that educated farmers could analyze the benefits and were better risk takers than the less educated.

5.1.2 Findings on the impact of HST utilization on household incomes

The findings showed that the adoption of HST had significantly and positively impacted on household income for the smallholder green gram farmers in Kitui County**.**

5.2 Conclusion

The results validated the contribution of social-economic factors, farm specific characteristics and institutional factors to adoption and extent of adoption of the HST. The adoption and extent of adoption proved to be knowledge-intensive, based on the positive influence of literacy level and agricultural group membership. This showed that training programs should be conducted to improve the knowledge of the farmers about the advantages of adopting HST so that they can reduce post-harvest storage losses and hence have more grains for sale that in turn lead to increased household income.

Land size that a farmer owned positively influenced adoption. Farmers adopted HST to enhance grain storage and thus ensure better prices leading to improved household income and food security. This signifies the need to encourage the promotion of HST by educating farmers on the economic losses due to pests that attack their stored grains, especially green grams. Therefore, the promotion of hermetic bags seems to provide a path for sustainable social and economic development, which should be considered when evaluating policy.

Considering a group of economic and social indicators of household well-being, the adopter households had experienced a significantly higher improvement in their well-being than non-adopters since 2013 when they started using HST.

Given the critical role of group membership and distance to market, more farmer organization should be formed, especially in areas where hermetic bags are not accessible so as to increase adoption and utilization. The County government should also channel credit facilities to remote areas to allow farmers purchase the technology.

5 .3 Recommendations

The results of the study allow for major policy implications to be made. Based on the findings of this study, access to credit facilities and extension services specific to HST are some of the key policy options that can raise the benefits and attractiveness of HST for smallholder farmers at household, community and national levels.

The findings of this study show that credit accessibility has influence on the adoption of HST. However, majority of the non-adopters cited little knowledge on credit service. A joint programme approach between agricultural extension officers and credit service provider institutions should educate farmers on this aspect.

The findings of this study also show that the farmers-agricultural extension officer interaction is very minimal especially for the non-adopters. When the farmers were asked to give their suggestions on what should be done for them to facilitate the adoption of HST**,** knowledge provision on HST was among the top ranked suggestions. This is a challenge for government to recruit more extension officers. One extension officer per ward is not enough. However, having more extension officers is one thing, but ensuring good performance is another thing.

Also, government and NGOs could offer more training on how to properly use hermetic bags to avoid negligence during handling which can leads to pest infestation.

The county government of Kitui together with the national Government need to strengthen the existing farmers' groups so that they can be used to relay information on the advantages of adopting HST. Strengthening of farmer groups will provide a great platform where farmers can share experiences on the practices that they deem best, thus creating a feedback loop to researchers and local government extension agents.

As regards the high cost of Hermetic bags, the study calls for subsidies to farmers. Policies that will encourage the expansion and distribution of suitable agricultural technologies to farmers will ease the attainment of the SDGs of reducing poverty and hunger in the ASALs; such as Kitui County.

5.4 Areas for Further Research

Future research can focus on how to improve farmers' access to green grams market. Additionally, future research could also focus on analyzing the impact of adopting HST on household food security by considering household data over time in the study area.

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APPENDICE

Appendix 1: Multicollinearity Test

Variable	**VIF**	**1/VIF**
Membership	2.21	0.453095
Credit access	1.97	0.507951
Years of schooling	1.6	0.623547
Sex of the Household head	1.55	0.644666
Marital status	1.49	0.672149
Purpose of growing green grams	1.32	0.756836
Land size	1.24	0.806101
Experience in green grams farming	1.23	0.813256
Occupation of the household head	1.16	0.861394
Household size	1.11	0.897374
Off-farm activities	1.1	0.908629
Plot tenure	1.07	0.938679
Market Distance	1.06	0.941988
Mean VIF	**1.39**	

Source: Survey Data (2019)

Appendix 2: The Pearson Correlation Test Matrix

	Age_HH	Plot_t~e	credit~s	Off-farm~t	Sex_HH	Experience_~l	Househ~e
Age of HH	1.0000						
Plot tenure	-0.2030	1.0000					
Credit access	-0.1254	-0.0335	1.0000				
Off-farm activities	-0.1925	0.1438	0.0136	1.0000			
Sex of HH	0.0205	-0.0366	-0.0240	0.1522	1.0000		
Years of schooling	-0.2550	0.0047	0.3714	0.1502	0.1134	1.0000	
Household size	0.2938	-0.1303	0.0525	-0.0483	0.0761	-0.0739	1.0000
Land size	0.1369	-0.1531	0.1623	0.0003	0.0493	0.3145	0.1017
Market Distance	-0.1374	0.0173	-0.1179	0.0189	0.0656	0.0654	-0.0105
Purpose	-0.0416	-0.0169	0.3275	-0.0246	0.0256	0.1968	-0.0148
Experience in farming	0.2570	-0.0800	0.1934	-0.0890	-0.0310	0.1844	0.1845
Occupation of HH	0.0212	-0.0398	-0.0220	-0.1691	-0.2160	-0.1307	-0.0408
Membership	-0.0841	-0.0295	-0.0768	0.0670	0.3552	0.1429	-0.0491
Farm Income	-0.0966	-0.0794	0.2298	0.2537	0.1819	0.3445	-0.0714

Membership	Lands~e	Market_Di~e	Purpose	Experience_~g	Occup_HH	Member~	Farm Inc~e
Land size	1.0000						
Market Distance	-0.0303	1.0000					
Purpose	0.1008	-0.0100	1.0000				
Experience in farming	0.1807	-0.1223	0.2539	1.0000			
Occupation of HH	0.1389	-0.0606	-0.1001	0.0167	1.0000		
Membership	0.0796	0.1093	0.0605	0.0618	-0.0769	1.0000	
Farm Income	0.3836	0.0258	0.1363	0.1069	-0.1151	0.1766	1.0000

Source: Survey Data (2019)

Appendix 3: Heteroscedasticity Test for Double Hurdle Model

Breusch-pagan/cook-Weisberg test for Heteroscedasticity	
	Ho: Constant Variance
	Variables: Fitted values for X_1
	Chi2(1) = 6.33
	Prob>Chi2=0.0119

Source: Survey Data (2019)

Appendix 4: Household Baseline Questionnaire

ADOPTION OF HERMETIC STORAGE TECHNOLOGIES IN GREEN GRAMS AND ITS IMPACT ON SMALLHOLDER FARMER'S HOUSEHOLD INCOME IN KITUI COUNTY, KENYA 2019

SECTION A: INTRODUCTION

I am a Masters student carrying out a research in partial fulfillment of my studies on the ***Adoption of Hermetic Storage Technologies in Green Grams and its Impact on Smallholder Farmer's Household Income in Kitui county, Kenya.*** Your household has been selected by chance from all households in the area for this interview. Kindly provide appropriate information by ticking or filling where necessary. The survey is voluntary and the information that you give will be confidential, anonymous and will be used for academic purposes only. Thank you for your participation.

SECTION B: DEMOGRAPHIC AND SOCIO-ECONOMIC CHARACTERISTICS

Farmers Questionnaire: Are you a green gram farmer? Yes [ ] No [ ] If NO, terminate the interview.

Basic Information			
1	Date of survey		
2	Name of the Enumerator		
3	Questionnaire No.		
4	County name		
5	Sub-county name		
6	Ward name		
7	Village		
Socioeconomic and Demographic Characteristics			
8	Who is the Household head?	Female [1]	
		Male [2]	
9	Age of the Household head		
10	Respondents Phone number		
11	sex of the farmer	Male [1]	
		Female [2]	
12	Age of the farmer		
13	Marital Status	Married [1]	
		Single [2]	
		Widowed [3]	
		Separated/ divorced [4]	

14	Level of Education Attained	1= None 2=Primary 3= Secondary 3= Tertiary	
15	Years of Schooling		
16	What is the household size		
17	Number of working people within the household	1=At least one 2=Two working members 3=three and above	
18	Do you belong to any farmers group?	Yes [1] No [0]	
19	If yes, which one?		
20	Main occupation	Formal employment [1] Casual employment [2] Farmer [3] Business person [4] others(specify)---------------------------	

SECTION C: FARM ATTRIBUTES/CHARACTERISTICS

21. How many years have you been practicing green grams farming?

22. How many seasons do you plant green grams in a year? One [1], Two [2]

23. Size of land owned by the household in acres?..........................

24. What is the size of land rented in or leased by the household in acres?.........

Provide the details below about the land owned by the household

Plot ID	**Season**	**Total plot *cultivated* in Acres**	**Plot tenure** (CODE D: below)	**Who owns this plot:** (1=Male 0=Female 2=Joint)	**Proportion of owned land under Green grams production (In Acres)**	**Proportion of land leased/rented in under green grams production (In Acres)**	**Green grams yield Quantity:**	**Unit** 1=90kg bag 2=70kg bag 3=50kg bag
	Long rains							
	Short rains							
	Long rains							
	Short rains							

1.Holds a formal title or allotment letter
2.Owns but has no formal title/document (e.g. inherited)
3. Lease/ Rented in
4. communal Rights

SECTION D: Questions on the factors influencing the utilization of Hermetic Storage Technology

25. Are you aware of the HST bag?

Yes [1] No [0]

26. (a) Do you use the HST bag?

Yes [1] No [0]

(b)If yes, how many bags do you have? ---------

27.How many 50kg and 100kg do you have? 50kg [ ] 100kg [ ]

28. Is the HST bags sold in the nearest market?

Yes [1] No [0]

29. (a) How much do 50kg and 100kg of HST bag cost in the market? 50kg…...100kg…….

(b) Is the bag affordable? Yes [1] No [0]

30. Is the technology easy to use?

Yes [1] No [0]

31.Where do you store your Hermetic bagged green grams?

(a) Farm store [ ]

(b)Living room [ ]

(c) Others Specify---

32. How did you know about HST?

Extension Officers [1] NGO [2] Project [5] Farmers [6]

SECTION E: INSTITUTIONAL FACTORS

33. In the last one year, have you received any form of extension service/training on green gram production? Yes [1]; No [0]

If yes, complete the table below.

Source of extension/training	Frequency of visits/training	Had you requested for the service (1= Yes; 0= No)	Level of satisfaction	Distance to extension office (Kms)
Government [1]	Never [1]		Very Dissatisfied [1]	

Private [2]	Fortnightly [2]		Dissatisfied [2]	
NGO [3]	Monthly [3]		Neutral [3]	
CBO [4]	Quarterly [4]		Satisfied [4]	
Other farmers [5]	Annually [5]		Very satisfied [5]	
6=Others(specify)				

34. Comment on the access to credit for green-gram and other cash crop farming.

(a)Do you have access to credit……….? *no [0] yes [1]*

(b) If yes, fill in the details below if no, skip the table and answer question 35

Major source of credit (Code H)	**Major form of credit (Code I)**	**Amount (Kshs)**	**Purpose of the loan**	**Interest rate (%)**

<u>Code H</u> 1= Government fund 2= Buyers 3= Commercial bank 4= Shylocks 5= MFI's	6= Donor/NGO 7= Groups (farmer groups) 8= Relative/friends 9= Input dealers 10= Others (Specify)_____	**<u>Code I</u>** 1= Money 2= Material(s) and/or inputs 3= Others (specify)_______	**<u>Purpose of loan</u>** 1=purchase of storage facilities 2=school fees 3=food 4=land 5=livestock 6=offset a problem one had 7=other, specify_________

(c) To what extent are you satisfied with credit facilities accessed?

Very dissatisfied [1]
Dissatisfied [2]
Neutral [3]
Satisfied [4]
Very Satisfied [5]

35. What is the main reason for not applying for credit?

High interests rate[1], Lack of collateral[2], Too much paper work [3], Too risky [4], Not a member of the Microfinance Institution (MFI)[5], High cost of obtaining credit [6], I don't need it [7], Other Specify[8]………………………………………………………………………

<u>SECTION F: SOURCES OF HOUSEHOLD INCOME (OFF-FARM AND FARM ACIVIIES)</u>

36.Did you receive any cash through any of the following means?

(a) Off-farm activities

Off-farm income activity	**Did someone in your household receive income from that activity? (1=yes, 0=no)**	**Amount received in the last 12 months (Kshs)**
Salaried employment		
Pension income		
Social protection		
Farm labor wages (household head and spouse)		
Non-farm labor wages (household head and spouse)		
Net income received from business (e.g. posho milling, trading, boda boda, crafts, charcoal,shops		
Amount received from children within the household (employment or off-farm income)		
Remittances (from relatives outside the household		
Renting out land		
Renting out equipment or machinery		

(b) Farm activities

Farm income activity	**Did someone in your household receive income from that activity? (1=yes, 0=no)**	**Amount received in the last 12 months (Kshs)**
Income from crop activities (include agroforestry)		
Income from livestock activities		
Income from woodlot activities (farm forest)		
Income from fishing activities (pond and natural)		
Income from renting out/selling pastures and forages		
Any other farm income		

Section F: Questions on the Market Information and Access

37.(a). What is the distance to the nearest main market Centre from the farm? (Kms)___________

(b). What is the distance from the farm to the road (Kms) ___________

(c). What is the type of road from the farm to that main market?

1=Tarmac, 2=All-weather marram road, 3=Seasonal marram road, 4=other (specify)

(d)What is the price of green grams in the market during harvest seasons?.............(kshs)

(e) What is the price of green grams during off seasons?............(kshs)

SECTION G: Questions on the impact of HST utilization on household income

38. What is the extent to which using HST has positively impacted on your household income?
1=Very Dissatisfied [ ] 2=Dissatisfied [ ] 3=Neutral [ ] 4=Satisfied [ ] 5=Very satisfied []

39. (a) Did you lose some green grams after harvest during storage? Yes[ ] No[ ]

(b)If yes, fill in the table below

Point in the value chain	**Causes of loss**	**Quantity lost last**

39. a. Do you experience increase in market price of green grams stored in HST bags/kg after months of storage? 1=Yes [ ] 0=No [ ]

b. If yes, indicate in the table below

Quantity of green grams stored (kg)	Before the use of HST			After the use of HST		
	2 months (ksh)	4 months (ksh)	6 months and above(ksh)	2 months (ksh)	4 months (ksh)	6 months and above (ksh)

40. (a)What is the main use of the green grams stored in HST bags? (List them starting from the most important)

a) Sale
b) Household consumption
c) Donation
d) Seed

Others (Specify)---

(b) If its for sale, how much is a kg of green grams?...............(kshs)

41. a. With the use of HST, are You able to store your grains as long as you want to?

1=Yes [ ] 0=No [ ]

b. Have your grains ever been infested with weevils while stored in the HST bag?

Yes [ ] No [ ]

42. a. What is the quantity of green grams you have for storage? ……… bags

b. What is the main use of the money from green grams sales?

a. Family expenses [ ]
b. Agricultural inputs [ ]
c. Savings [ ]
d. Others (Specify) --

43. a. Which of the following possessions did you have before and after the use of HST? (Tick)

Property	**Before adopting HST**	**After adopting HST**
a) Bicycle		
b) Motorcycle		

c) Car		
d) TV		
e) Radio		
f) Video player		
g) Fan		
h) Stove		
i) Gas cooker		

b. List any other item/property you bought after growing and selling green grams stored on HST
……

44. What are some of the problems and constraints for not adopting the use of HST?

Constraints associated with HST	Reasons for abandonment	Reasons for not using HST
1=Expensive	1=Expensive	1=Expensive
2=Not reliable	2=Not reliable	2=Not reliable
3=Insect damage	3=Insect damage	3=Insect damage
4=Not available	4=Not available	4=Not available
5=Others(specify)-------------------------------	5=Others(specify)------------------------------	5=Lack of information
		6=Others (Specify)---------------------------------

45. To what extent are you satisfied with the HST bag efficiency in storing green grams?
1=Very Dissatisfied [ ] 2=Dissatisfied [ ] 3=Neutral [ ] 4=Satisfied [ ] 5=Very satisfied [ ]

46. Any other comment about HST storage and impact on household income?
………………………………………………………………………………………………………...

END

THANK YOU FOR YOUR TIME