EFFECTS OF AFLATOXIN-INHIBITING TECHNOLOGIES ON PRODUCTIVITY OF GROUNDNUTS IN ELGEYO MARAKWET AND BARINGO COUNTIES, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented at this university or any other for the award of a degree.

Signature…… Date: 20/09/2025

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Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

This thesis is dedicated to my lovely parents, wife, children, and friends, who have supported and prayed for me during the course of my studies.

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ABSTRACT

Aflatoxin contamination is a major constraint to Kenya's food safety and market access, causing losses estimated at US$17.28 million annually. Groundnuts are highly susceptible to aflatoxin contamination. Both pre-and post-harvest contaminations are due to favourable conditions for aflatoxin-producing fungi. This leads to low-quality produce, low prices, health risks, and reduced income for smallholder farmers. Although several aflatoxin-inhibiting technologies have been promoted to improve groundnut productivity and quality, existing studies have not adequately documented their use, adoption levels, and impact on productivity, particularly in Elgeyo Marakwet and Baringo counties. The study specifically intended to map pre- and post-harvest aflatoxin-inhibiting technologies, identify factors influencing their adoption, assess the extent of these technologies' adoption, and determine their effects on groundnut productivity and quality. A multistage sampling technique was used to select 384 smallholder farmers across the two counties. Primary data were collected using a validated semi-structured questionnaire. Data analysis was conducted using SPSS and STATA 18. Descriptive statistics were used to examine current practices, while multivariate probit and ordered probit models assessed adoption factors and extent. An ordered probit endogenous switching regression model was applied to estimate the effects on productivity. The results posited that access to education, gender, farming experience, group membership, price of groundnuts, fertiliser use, use of improved varieties, off-farm income, and distance to market significantly influenced the uptake of a majority of aflatoxin-inhibiting technologies. Regarding adoption intensity, the findings revealed a high propensity for adoption among medium adopters as opposed to low and high adopters. Finally, the results denoted increased productivity among the medium (ATT=100kg/acre) and high (ATT=42kg/acre) adopters of aflatoxin-inhibiting technologies. The possible reason may be the selectiveness of the medium adopters when using technologies effectively. Adoption alone is enough, but selecting the most effective and timely application of the technologies is vital. For that reason, medium adopters outperform high adopters, seeing greater yield gains. Prioritise integrated approaches (e.g., resistant seeds + Aflasafe GAPs proper drying) to achieve >95% control, with subsidies for smallholder groundnut farmers. Low adopters were worse off, emphasising the need for optimal uptake to improve outcomes. The study recommends that target extension services delivery, strengthening cooperative groups, reducing the cost of the technologies, and social network programs should be prioritised. This will guide interventions aimed at improving groundnut production and boosting smallholder livelihood in Elgeyo Marakwet and Baringo counties, Kenya.

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LIST OF ABBREVIATIONS AND ACRONYMS

CIDP	County Integrated Development Plan
CGIAR	The Consultative Group on International Agricultural Research
CGA	Cereal Growers Association
CIMMYT	The International Maize and Wheat Improvement Centre
ELISA	Enzyme-Linked Immunosorbent Assay
FT-IR	Fourier Transform Infrared
Ha	Hectare
HIS	Hyperspectral Imaging
HPLC	High-Performance Liquid Chromatography
ICRISAT	The International Crops Research Institute for the Semi-Arid Tropics
IITA	The International Institute of Tropical Agriculture
KALRO	Kenya Agricultural and Livestock Research Organization
LCMS	Liquid Chromatography-Mass Spectroscopy
MT	Metric Tonnes
NGO	Non-Governmental Organization
NIR	Near-infrared
OEC	The Observatory of Economic Complexity
PH	Post-Harvest
PHH	Post-Harvest Handling
PICS	Purdue Improvement Crop Storage
PPB	Parts Per Billion
SDG	Sustainable Development Goals
Ug/Kg	Microgram Per Kilogram
USAID	The United States Agency for International Development

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Groundnut (*Arachis hypogaea* L.) is the 13th most important food crop and 4th oilseed crop in the world (Bhatnagar-Mathur *et al*., 2021). Groundnuts are produced and consumed in several African countries due to their nutritious and hardy nature. Groundnut is cultivated in 28 million hectares of land in over 100 countries in the world, particularly in arid and semi-arid tropics, with 65% produced in Asia and 26% in Africa (Desmae & Sones, 2017). The average groundnut yield in Africa is, however, very low (964 kg/ha) compared to the US (3500 kg/ha) and other developed countries (Ncube & Maphosa, 2020).

It is an annual crop with a production of over 51 million tons on nearly 28 million hectares in 2024, and an average productivity of 1.4 metric tons/ha (Ajeigbe *et al*., 2024). China and India are the world's leading peanut-producing countries, accounting for 37% and 13.9% of the world's output, respectively. Nigeria is the continent's top producer of groundnuts, ranking fourth globally with 2,420,000 MT produced (Variath & Janila, 2017). In Eastern Africa, Sudan is the leading producer of groundnuts (1,641,000 MT), followed by Tanzania (700,000 MT) and Uganda (133,000 MT) (Poopola *et al*., 2024).

In Kenya, locally known as "Njugu karanga", groundnuts are commonly grown by smallholder farmers. The main producing counties are Elgeyo Marakwet, Homa Bay, Kisumu, Kakamega, Baringo, Siaya, Busia and Migori (Farmers Trend, 2024). The annual national production in 2023 was 50,000 MT on an estimated 18,000 hectares (Blair *et al*., 2023) with an average productivity of 1.6 MT/Ha (Virgin *et al*., 2021). Major varieties of groundnuts produced in Kenya include Red Oriata, Manipinta, Makulu Red, Bukene, Homa Bay, Texas peanut, Red Valencia, Atika, Ndovu, and Mwangaza (Okelloh *et al*., 2023).

In Kenya, groundnuts are a source of household food security, employment, and income, which is higher than revenue obtained from a unit area of Maize (Tuei *et al*., 2023). It is a source of edible oil and animal feed for consumption in various forms, such as roasted, blanched, raw, and peanut butter. Aflatoxin can occur in the field or at the post-harvest stage; improper storage of groundnuts is the major cause of fungal growth that produces mycotoxins (Muzoora *et al.,* 2017).

The main fungi that produce aflatoxins are *Aspergillus flavus* and *Aspergillus parasiticus*, which are abundant in warm and humid regions of the world (Muzoora *et al.*, 2017). They are found in agricultural crops such as maize (corn), peanuts, cottonseed, pearl millet, wheat, and tree nuts. Major environmental causes of aflatoxin are plant stress factors like drought, high temperature/heat or insect damage during soil fungus growth, which usually increases aflatoxin levels (ICRISAT, 2014). Physical signs of aflatoxin contamination in groundnuts include discolouration, mould growth, shrivelling and deformation, and insect damage.

Sitienei *et al*. (2022) reported that aflatoxin contamination in groundnuts in Kenya occurs during both the pre-harvest and post-harvest stages of crop production, affecting the quality and safety of groundnuts and groundnut-based products. They tested 40 samples of groundnuts in Elgeyo Marakwet and Baringo; all samples except one were positive for aflatoxin contamination. Aflatoxins can suppress the immune system, cause cancers, retard growth in humans and animals (Muzoora *et al*., 2017). Its contamination of crops causes annual losses of more than $750 million in Africa. In Kenya, it is associated with plausible economic losses estimated to be US $ 17.28 million (Nji *et al.,* 2022).

In 2007, the Kenya Bureau of Standards (KEBS) set a limit for aflatoxins in food products at 10 μg/kg total aflatoxin and 5 μg/kg aflatoxin B1 (AFB1) in peanuts and other food grains. However, the cost of testing for aflatoxins in food products is extremely high, thus discouraging farmers and traders from following the right path (Mutegi *et al*., 2013).

However, interventions intended to control aflatoxins consider all the stages of aflatoxin contamination. Pre-harvest interventions include sourcing clean seeds, using improved seeds, timely planting, on-farm pest and disease control, weeding, Aflasafe KE01 application, and timely and proper harvesting (Atehnkeng *et al*., 2018). Aflatoxin-inhibiting post-harvest technologies that smallholder groundnut farmers have adopted. These include drying on elevated platforms, windrowing, drying on polythene sheets/tarpaulins, sorting, maintaining proper moisture content, roasting, threshing, shelling, and storage in well-ventilated structures, using pic and hermetic bags (CGIAR, 2024; ICRISAT, 2016; Nji *et al.*, 2022; Omara *et al.,* 2024; Sitienei *et al*., 2022).

National and international research organisations have developed pre- and post-harvest technologies, including aflatoxin-tolerant/resistant and drought-stress-tolerant varieties (like Ndovu and Mwangaza) to reduce infection in farmers' fields effectively. These technologies have been deployed by county governments, research organisations (KALRO, Egerton, CIMMYT, IITA, ICRISAT, NGOs, CGA, and World Vision) and farmer exchange (CGIAR, 2024). However, there is insufficient information regarding the linkage between the usage of pre- and post-harvest aflatoxin technologies and the productivity of groundnuts in Kenya.

1.2 Statement of the Problem

Despite their significance to food security and livelihood enhancement in Kenya, groundnuts constitute a significant source of human exposure to aflatoxins. Groundnuts are infested by fungi that produce aflatoxins during pre- and post-harvest stages. The susceptibility of groundnuts to aflatoxins is linked to suitable growth conditions for fungi, such as optimum temperatures and high humidity. In Kenya, the major controllable causes of aflatoxin contamination are production practices, poor post-harvest handling techniques, and poor storage structures. Consequently, the quality of groundnuts is lowered, and productivity is significantly affected. It suppresses the immune system, causing cancer retard growth in humans and livestock. It affects the economic value of groundnuts and the revenue earned by smallholder farmers. Other constraints affecting groundnut productivity and quality are the limited availability of improved tolerant and low-yielding varieties. However, information regarding the effects of these technologies on the productivity and quality of groundnuts in Elgeyo Marakwet and Baringo counties is not well documented. Therefore, this study aims to evaluate the effects of aflatoxin-inhibiting technologies on the productivity and quality of groundnuts in Kenya. The resulting impact will be used to recommend policy interventions for producing safe groundnuts in Kenya.

1.3 General Objective

To contribute to food and nutritional security through mapping and assessing the level of adoption of agricultural technologies for the management of aflatoxin among smallholder groundnut farmers for enhanced food safety in Kenya

1.3.1 Specific Objectives

i. To describe aflatoxin-inhibiting technologies among smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya.

ii. To determine the factors influencing the choice of aflatoxin-inhibiting technologies used by smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya.

iii. To assess the factors that drive the extent of adoption of aflatoxin-inhibiting technologies among smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya.

iv. To estimate the effects of aflatoxin-inhibiting technologies on the yield of groundnut produced in Elgeyo Marakwet and Baringo Counties in Kenya.

1.4 Research Questions

i. What are the aflatoxin-inhibiting technologies used by smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya?

ii. What factors determine the choice of aflatoxin-inhibiting technologies used by smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya?

iii. What factors drive the adoption of aflatoxin-inhibiting technologies among smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya?

iv. What is the effect of aflatoxin-inhibiting technologies on the yield of groundnuts produced in Elgeyo Marakwet and Baringo Counties in Kenya?

1.5 Justification of the Study

Groundnuts are primarily cultivated in Western Kenya but distributed and consumed nationwide (Mutegi *et al*., 2013). Due to its high value of nutritive content, its revenues per unit area are far higher than those of maize (Farm Trends, 2024). As an integral part of the diet, especially in the Nyanza region, groundnuts significantly contribute to food security in Kenya. In 2022, Kenya imported groundnuts worth $47.3 million from Malawi, Argentina, Tanzania, and the United Arab Emirates, making Kenya the 19th largest importer worldwide (OEC, 2024). Like many other African Countries, including Kenya and Gambia, the aflatoxin level in >10 ppb is the minimum requirement for the EU market.

This significant exhaustion of Kenya's foreign exchange results from the huge pre- and post-harvest losses of groundnuts due to several factors, including aflatoxins.

In Kenya, the major controllable causes of aflatoxin contamination are production practices, poor post-harvest handling techniques, and poor storage structures. The resulting impact has been the deterioration of the quality and quantity of groundnuts produced. Consequently, the sales volumes are reduced, the price that infested groundnuts command is low, and the revenue received by smallholder farmers is greatly affected. There is limited empirical evidence regarding the use of such innovations and technologies on the productivity of groundnuts. The study will inform smallholder farmers and other groundnut value chain actors on the potential of aflatoxin-inhibiting technologies in improving the productivity and quality of groundnuts.

The study will contribute to Elgeyo Marakwet and Baringo counties' respective County Integrated Development Plan (CIDP), aiming to achieve food security. Kenya Vision 2030 prioritises food security and manufacturing growth using agriculture as the driver of this growth. The study will contribute to this vision since groundnut is a raw material in several other manufacturing sectors, especially food processors. It also aligns with the key pillars (5) of the African Union Agenda 2063, which advocate for modern agriculture to increase production and productivity. It recognised agriculture as the backbone of many African economies and the potential to contribute significantly to poverty reduction and economic growth. Pillar (7) of Agenda 2063, this goal aims to address climate change through the adoption of appropriate technological practices. The study will contribute to SDGs 1, 2, and 13, which emphasise ending poverty, zero hunger, and climate change.

1.6 The Scope and Limitation of the Study

The study primarily focused on the effects of pre-and post-harvest aflatoxin-inhibiting technologies on the productivity of groundnuts in Elgeyo Marakwet and Baringo counties in Kenya. The two counties have been chosen because they are among the largest groundnut producers in Kenya. Technologies for managing aflatoxin contamination are numerous. However, this study considered the 6 commonly used technologies: drying technologies, mechanical shelling, hermetic storage bags (e.g., PICS bags), GAPs, quality/resistant seed variety, and biological agents. Among the significant limitations was that farmers do not keep records, and most roads are inaccessible. The study only focuses on these technologies because poor production technologies, poor post-harvest handling techniques, and poor storage structures have been cited as the major causes of aflatoxin contamination in groundnuts in Kenya. Additionally, emphasis has been placed on productivity because it is the most visibly affected variable of aflatoxin contamination among smallholder groundnut producers.

1.7 Operational Definition of Terms

Aflatoxins: are a family of toxin compounds produced by certain moulds (fungi), primarily Aspergillus flavus and Aspergillus parasiticus, that can contaminate groundnuts during pre- and post-harvest stages.

Aflatoxin Inhibiting Pre-Harvest Technologies: are practices, tools, and interventions designed to prevent or reduce the production of aflatoxins in crops, particularly before harvest. They are intended to minimise the risk of aflatoxin contamination during production.

Aflatoxin Inhibiting Post-Harvest Technologies: are practices, tools, and interventions designed to prevent or reduce the production of aflatoxins in crops, particularly after harvest. They are intended to minimise the risk of aflatoxin contamination during drying, transportation, and storage.

Agricultural Innovations: Introduction of new ideas (seeds and combinations of organic and inorganic fertilisers), new good agronomic practices, push-pull technologies, harvest and post-harvest practices.

Innovative Technologies: are significantly improved tools, processes, systems, or products that provide advanced solutions to the existing aflatoxin contamination levels in groundnuts.

Productivity: refers to the yield or output of groundnuts per unit of land area. It is a measure of the efficiency and effectiveness of groundnut farming practices. Expressed in terms of the yield of groundnuts produced in kilograms per acre of land, which can be sold.

Quality: Is a detectable attributes like (discolouration, size, insect damaged, moulding and shrivelled) of groundnuts that determine their suitability for selling, which directly influence their demand and market price.

Smallholder Farmer: This study considers a smallholder farmer as one who cultivates groundnuts on less than 5 acres of land.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Groundnut Production in Kenya

Groundnut (*Arachis hypogaea* L) is a legume plant believed to have originated in South America between 2000 and 3000 BC (Desmae & Sones, 2017). It is a tropical plant performing well in warm and extended growing seasons. For maximum performance, it requires well-distributed rainfall of not less than 500mm, warm temperatures (25^0C to 30^0C), and abundant sunshine (Taphee *et al.*, 2015). Fertile, deep, well-drained sandy clay loam or sandy loam soils with a pH range of between 6.5 and 7.0 are suitable for groundnut production (Ajeibe *et al.,* 2015). Currently, its production is widely distributed all over 100 countries (Desmae & Sones, 2017) on nearly 28 million hectares in 2024, with a yield of over 51 million tons and average productivity of 1.4 metric tons/ha (Ajeigbe *et al*., 2024).

The leading groundnut-producing counties are Elgeyo Marakwet, Homa Bay, Kisumu, Baringo, Kakamega, Siaya, Busia and Migori (Farmer Trend, 2024). Smallholder farmers in these counties typically plant groundnuts during the short rains of March and April and harvest between July and September.

In the year 2012, the area under groundnut was 16,387 hectares with a production of 11,639 tonnes (Onyuka *et al*., 2017). The reduction was attributed to farmers diversifying into the production of maize for food security in the western and Nyanza regions due to unattractive prices being offered. In 2023, the annual groundnut yield was approximately 50,000 MT produced on nearly 18,000 Ha of land (Farmer Trend, 2024). This improvement is attributed to the shift from local groundnut varieties such as Red Oriata, Manipinta, Makulu Red, Bukene, Homa Bay, Texas peanut, Red Valencia, and Atika (Okelloh *et al*., 2022) to KEN-GNUT 1, Egerton GN-1 (L), Egerton GN-2 (R), Ndovu, Mwangaza, Gathuku, Lihanga and Kanga (Mwalongo *et al*., 2020).

Nyandiala *et al.* (2023) noted that it is considered the fourth most important cash crop in the Lake Victoria Basin of Kenya, with the heaviest consumption of groundnuts in the Western parts of Kenya. In addition to its natural capacity as a leguminous crop to fix nitrogen in the soil, groundnuts are used in edible oil making, confectionery formulation, making peanut butter, used for making children's food, consumed daily in roasted form, as a protein supplement in human nutrition, it is increasingly being consumed with bread as a healthy and nutritious alternative to margarine (Daba *et al.,* 2023).

2.2 Aflatoxin Contamination in Groundnuts

Aflatoxins are secondary metabolites produced in foods contaminated by *Aspergilus flavus* and *Aspergilus parasiticus* (Muzoora *et al.*, 2017). They contaminate several economically important crops such as maize, sorghum, millet, sugarcane, groundnut, wheat, rice, cotton, fruits, and other oil crops (Pandey *et al*., 2019). The genus Aspergillus produces aflatoxigenic fungi that occur in the soil as conidia, hyphae, and sclerotia (Ncube & Maphosa, 2020). *Aspergillus flavus and Aspergillus parasiticus* are the major producers of aflatoxins (Abdallah *et al*., 2020). AFB1 (the most toxic), AFB2, AFG1, and AFG2 are the most important aflatoxins produced by *A. flavus* and *A. parasiticus,* while AFM1 and AFM2 are secondary products of AFB1 and AFB2, most commonly found in milk products (Ansari *et al*., 2019).

Aflatoxin contamination in crops occurs during production, during harvest, and after harvest (Ajeigbe *et al*., 2015). Fungal growth and toxin production are favoured by a moisture content above 9%, relative humidity between 65-90%, and temperatures of 10-45^{0}C (Ncube & Maphosa, 2020). To infest groundnut, the fungi access the minute cracks caused by heat stress, abiotic stress, and mechanical injuries on the pod, seed coat, and pod walls (Falade, 2023). According to ICRISAT (2016), crops get contaminated during pre-harvest (through repeated cultivation of host plants, late planting, drought, termite attack, poor field hygiene, low plant population, and poor water management). Poor harvesting techniques were used during harvest, and there was premature harvesting. During post-harvest (through improper drying, improper shelling, poor curing techniques, poor stripping, threshing, windrowing, poor sorting, poor storage conditions, and poor transporting methods).

Consumption of aflatoxin in food results in malnutrition, stunted growth, impaired immune function, disabilities, and death, and adverse effects on reproductive health (Singh *et al*., 2021). Physical signs of aflatoxin contamination in groundnuts include discolouration, mould growth, shrivelling, deformation, and insect damage.

Economically, aflatoxin contamination causes an estimated loss of US$ 750 million (Gbashi *et al*., 2018). Due to strict aflatoxin legal limits, Africa accounted for only 4% of total groundnut exports to Europe between 2004 and 2014 (Edelman & Aberman, 2015). African food-exporting countries, including Kenya, have tried to research the contaminant. In 2007, the Kenya Bureau of Standards set a limit for aflatoxins in food products at 10 µg/kg total aflatoxin and 5 µg/kg aflatoxin B1 (AFB1) in peanuts and other food grains.

Omara *et al.* (2021) reported that over 68% and 54% of grains from Nairobi and Kitui, Makueni, Machakos, and Thika had aflatoxin levels above 20 µg/kg, respectively. Probst *et al.*

(2010) revealed that Aflatoxin contamination in Eastern province (Kitui and Mukueni), Coast (Makueni, Kwale, Kilifi, Tana River, and Taita Taveta), Rift Valley (Marakwet, Kajiado, Baringo, Nakuru, and Laikipia), and Western (Homa Bay and Rongo) ranged from 219.6 to 426.3 μg/kg, 0.1–120.4 μg/kg, 0.1 - 13.4 μg/kg, and 37-54 μg/kg, respectively.

2.3 Technologies for Mitigating Aflatoxin Contamination in Groundnuts

Before delving into technologies used to mitigate aflatoxin contamination, it is worth understanding how it is detected in food products. The most commonly used detection method is Enzyme-Linked Immunosorbent Assay (ELISA) (Kumar *et al*., 2021). Others include High-Performance Liquid Chromatography (HPLC), Liquid Chromatography-Mass Spectroscopy (LC-MS), and Thin Layer Chromatography (Norlia *et al.*, 2019). Quick methods such as spectroscopic techniques, Fourier Transform Infrared (FT-IR), and Near-infrared (NIR), have been introduced (Kaavya *et al.*, 2020). It is unclear which is the most effective, most common, and most suitable in Kenya.

No single control or mitigation mechanism has been successful in managing aflatoxin contamination. As a result, a combination of measures, including biological control, chemical, and physical methods, has been employed (Monda & Alakonya, 2016). Drought-tolerant seed varieties like Ndovu and Mwangaza have been introduced in Kenya by Egerton University to mitigate the impacts of climate change (Kirmuto & Mwangi, 2022). In relation to this, Rahmianna *et al.* (2015) reported the lowest rate of aflatoxin contamination in groundnut varieties that were drought-tolerant in Indonesia. According to Gebre *et al.* (2016), fertiliser and gypsum application, irrigation, weed and pest management, sorting, drying to 8% moisture content, clean cover drying, and using clean storage containers can mitigate aflatoxin contamination in groundnuts.

According to ICRISAT (2016), aflatoxin contamination in groundnuts can be reduced in the field through GAPs. These include early planting, maintaining field hygiene, maintaining water, pest and disease control, and using soil amendments. During harvesting, harvest at the right stage, avoiding injuries to pods, and soil removal from the harvest. At the household level (proper drying, shelling, grading and sorting, and storage). Processing level (through sorting before shelling, grading after shelling, and avoiding using grade-outs).

The application of Aflasafe as a biological control agent to lower aflatoxin levels has been on the rise in Africa (Senghor *et al*., 2021). It was reported in Gambia and Senegal as a helpful tool for reducing groundnut and maize aflatoxin levels, with field tests proving a reduction level of between 70-90% (Mahuku *et al.,* 2023).

According to Mutegi *et al.* (2018), preharvest technologies mitigate aflatoxin by preventing damage to pods and grain and preventing suitable conditions where fungi can flourish. GAPs prevent soils from drying out or being too moist, suppressing the spread of organisms and growth of fungi. Biological agents like Aflasafe produce *Aspergillus flavus,* which does not produce aflatoxin; the non-toxic strain competes with the contaminated areas, thus protecting the crops even during storage. Technologies at the harvest stage prevent damage during harvesting and ensure harvest of mature pods, thereby reducing risks of aflatoxin contamination. Post-harvest technologies inhibit the growth of fungi.

2.4 Adoption of Pre and Post-Harvest Technologies for Mitigating Aflatoxin Contamination in Groundnuts

A multivariate probit model using plot-level data was employed by Kassie *et al.* (2015) to understand the adoption of sustainable agricultural practices in Eastern and Southern Africa. Binswanger and Sawastano (2017) used Boserup and Ruthenberg models in six African countries, and Ainembabazi *et al.* (2016) used stochastic frontier production models in the Great Lakes region. They all reported factors such as farmer education, household size, access to credit, land tenure, access to extension services, and organisational membership that influence the adoption of technologies.

The adoption of improved technologies among groundnut producers has also been studied widely. Mwalongo *et al.* (2020) used a probit regression model to report age, gender, seed availability, seed cost, and group membership as factors influencing improved groundnut varieties' adoption in Tanzania. However, this study was limited to six varieties released by the government of Tanzania. Launio *et al.* (2018) used a binary logit model in the Philippines. Bonabana-Wabbi *et al.* (2016) opted for a multinomial logit model in Uganda, and Mehmood *et al.* (2021) adopted a logit model in Pakistan. In all these studies, results were similar to those of the Tanzanian survey except for the availability of irrigation sources in the Philippines, taste in Pakistan, and seed-saving practices in Uganda.

There’s scant literature regarding the adoption of improved production technologies among smallholder groundnut farmers in Kenya. Thuo *et al.* (2014) studied the adoption of improved groundnut varieties in Uganda and Kenya. They used unrelated bivariate probit and recursive bivariate probit to report external sources, education, and farm size as factors influencing adoption in Kenya. Ombassa *et al.* (2022) focused on Bambara groundnuts in Embu and used logistic regression to expose farm size, experience, education, and group membership as the main factors for adoption.

Meena *et al.* (2009) reported socioeconomic, technological, and farm characteristics as the major determinants of adopting modern post-harvest technologies in India. However, this study considered rural agro-processors as the unit of analysis. A multivariate logistic regression model revealed that training largely influenced the adoption of grain hermetic storage in Uganda (Okori *et al*., 2022) and Kenya (Baributsa & Njoroge, 2020).

Waliyar *et al.* (2014) explored the management practices used by farmers in West Africa to manage aflatoxin contamination. They came across mechanisms such as physical separation, improved storage methods and conditions, disinfestation, detoxification, inactivation, filtration, and use of binding agents. Craggs' two-stage model revealed that the adoption of improved storage structures among groundnut-producing households in Ghana was influenced by household income (Martey *et al*., 2020).

Post-harvest management technologies to mitigate aflatoxins in Kenya are not new; however, they have primarily focused on maize and dairy products. The adoption of tunnel solar dryers, brick coolers, charcoal, and cold storage technologies among mango farmers in Embu County, based on access to training and funding (Mujuka *et al.*, 2019). Price incentives and technology subsidies positively influenced the adoption of food safety technologies among producers in Kenya (Hoffman & Jones, 2021). To a greater extent, the medium through which information is communicated to smallholder farmers influenced the adoption of hermetic bags among grain producers in Kenya (Channa *et al*., 2019).

2.5 Effectiveness of Aflatoxin-Inhibiting Technologies on Groundnuts

An assessment of the relative strength of each technology in controlling aflatoxin contamination in groundnuts (peanuts, Arachis hypogaea L.**) (**Cervini *et al*., 2022). Strengths are expressed as approximate percentage reductions in aflatoxin levels (primarily AFB1 or total aflatoxins) compared to untreated controls, derived from field trials, storage studies, and reviews focused on groundnut production in aflatoxin-prone regions like sub-Saharan Africa (Akale *et al*., 2020). These values represent averages or ranges from peer-reviewed sources, accounting for variations in application, environment, and measurement (e.g., pre-harvest vs. post-harvest). Real-world efficacy depends on proper implementation; combinations of technologies often yield higher reductions (>90%). Percentages are for standalone use (Akale *et al.*, 2020) are as follows:

i. Aflasafe / Biopesticide: 80-95% reduction. This atoxigenic Aspergillus flavus strain biocontrol, applied pre-flowering, outcompetes toxigenic fungi, reducing aflatoxins by 89% at harvest (58-100% range) and 87% post-storage (76-95%) in Senegal groundnut trials. Consistent 80-99% efficacy across Africa (Senghore *et al.,* 2020).
ii. Improved Resistant Groundnut Seeds: 70-90% reduction. Breeding or transgenic resistant varieties (e.g., ICGV-SM 90704, CG7) exhibit lower aflatoxin accumulation due to enhanced seed coat barriers and reduced fungal invasion. Field evaluations show improved varieties averaging 1.82-3.36 µg/kg total aflatoxins vs. 7.11 µg/kg in susceptible locals, equating to ~74% lower levels; transgenic approaches achieve up to 90% reduction (Nunes *et al.,* 2024).
iii. GAP (Good Agricultural Practices): 62-94% reduction. GAP integrates timely planting, crop rotation, insect control, and post-harvest sorting/drying, significantly lowering pre-harvest infections (13-58%) and aflatoxins (62-94%) compared to farmer practices. On-farm trials in India and Africa confirm 63-88% reductions in varying locations (Mdindikasi *et al.*, 2024).
iv. Drying Mats / Tarpaulins: 50-80% reduction. These elevated or covered drying surfaces reduce moisture to 50 ppb in ground drying. Trials show 53-79% lower levels with tarps alone, and up to 69% when combined with sorting (Muitia *et al.*, 2018).
v. Mechanical Shelling:35-80% Practices that can be integrated to improve yield and reduce aflatoxin contamination. Proper shelling by using recommended shelling machines to avoid broken nuts. Using poorly efficient shelling machines can cause cracking of the groundnuts, exposing them to aflatoxin. Soaking groundnuts in water can also expose them to aflatoxin. Low-quality groundnuts will lower prices (Sugri *et al*., 2024).
vi. Hermetic/Polythene Bags: 0-20% reduction: Hermetic /Polypropylene storage bags alternatives, these are triple-layer, airtight bags that create a low-oxygen environment that suffocates moulds and pests, and shows down aflatoxin growth (Daba *et al*., 2023).

2.6 Effects of Technologies for Mitigating Aflatoxin Contamination on Productivity and Quality of Groundnuts

Adejumu *et al*. (2020) employed an average treatment model in Nigeria to explore the fact that using improved post-harvest handling technologies comes with an extra cost. Farmers earned higher revenue, implying that improved technologies were beneficial and profitable. A multiple regression model showed that subjecting tomatoes to anolyte dipping treatment, packaging, and storage conditions of 13^0C increased the probability of productivity in South Africa (Melesse *et al*., 2015). Emerging technologies such as High Hydrostatic pressure vacuum drying, increased the productivity of edible flowers (Fernandes *et al*., 2018).

Using containers to store sweet potatoes was associated with reduced transport costs and improved market presentation in Uganda and Kenya (Abong *et al*., 2016). According to Thakur (2018), the increased productivity of mushrooms in India has been associated with adopting solar dryers, pickling, grading, and steeping preservation. Contrary to most studies, Beharielal *et al.* (2018) report low productivity of fruits and vegetables among smallholder South African farmers due to unhygienic post-harvest practices. This implies that adopting technologies is not enough; it must be accompanied by utmost hygiene. In Turkey, applying treatments such as cleaning, sorting, and packaging has increased the marketability and consumption of fruits and vegetables (Elik *et al.,* 2019).

According to Odoli *et al*. (2019), the adoption of installed cold rooms, dryers, and smoking kilns led to an increase in accessibility of the European Union fish market by Kenyan fish farmers. The adoption of plastic crates in transporting and handling mangoes by fruit farmers in Kenya was associated with increased access to lucrative markets (Chikez *et al*., 2021).

In Niger, the storage of groundnuts in improved storage facilities led to increased profits by 33% and 113% for unshelled and shelled nuts, respectively (Bakoye *et al*., 2019). Threshers have been widely adopted in shelling groundnuts in India; however, the lack of blowers in the locally fabricated threshers has instead lowered the market value of groundnuts due to the presence of foreign material in the marketable produce (Ansari *et al.,* 2014). The low adoption of PH technologies among Malawian groundnut farmers did not significantly affect market access since Lilongwe's unshelled nuts are highly competitive and offer higher prices (Tsusaka *et al.,* 2016).

2.7 Research Gap

There is significant literature regarding groundnut production, pre- and post-harvest management technologies and innovations, and aflatoxin contamination in groundnuts. However, studies about technologies and innovation management to mitigate aflatoxins in Kenya have focused mainly on maize and dairy products. There is limited information regarding the adoption of technologies use among groundnut producers in Kenya. Literature equally shows a variety of technologies used across the world to mitigate aflatoxin levels. However, there is no clear information on whether most technologies have been tried in Kenya and the value chains in which they are commonly used.

This study primarily focused on pre- and post-harvest technologies; therefore, it is imperative to understand what is known regarding the contamination level that occurs in Kenya's groundnuts. The adoption of technologies has generally been linked to productivity improvement, shelf-life enhancement, market access, and price. However, limited studies have explored the adoption of such technologies with the need to mitigate aflatoxin contamination.

Most studies have studied one or two technologies, especially solar dryers and cold chains. This implies that a combined effect of technologies is still lacking. A more comprehensive study of the impacts of technologies and innovations on the management of aflatoxin contamination on groundnut productivity can close the current information gap within the groundnut value chain in Kenya.

2.7 Theoretical Framework

Adoption studies have used numerous theories to expound on the factors for the adoption of agricultural technologies (Rogers, 1962). This study acknowledges the fact that the effects of innovations and technologies for managing aflatoxin contamination on productivity can be explained by theories such as the diffusion of innovation theory.

The diffusion of innovation model was developed by Everett Rogers in 1962 to explain how, why, and at what rate new technologies spread through the population. It consists of five components: innovation, adopters, communication channels, time, and social system. The model acknowledges that a medium transfers innovations or technologies to final users. Therefore, innovations and technologies for managing aflatoxin contamination are assumed to be communicated through a medium to groundnut farmers. Different farmers were at various stages of adoption depending on the benefits perceived, and the adoption rate depends on compatibility, complexity, and observability. Therefore, this study was based on innovation diffusion theory.

2.8 Conceptual Framework

Innovations and technologies for managing aflatoxin contamination are numerous. However, this study considered the six commonly used innovations and technologies: drying technologies, mechanical shelling, hermetic storage bags (e.g., PICS bags), GAPs, quality/resistant seed variety, and biological agents. Figure 2.1 illustrates a conceptual framework that visually explains how the use of innovations and technologies for managing aflatoxin contamination affects the productivity of groundnuts and the resulting impact on household income. The study assumes three categories of adopters, namely the low (1-2 technologies), medium (3-4 technologies), and high adopters (above five technologies). The study assumes that socioeconomic, institutional, and technological characteristics influence the adoption of innovations and technologies for managing aflatoxin contamination. Socioeconomic factors include household size, farming experience, household income, gender, age, level of education, farm size, the variety grown, use of fertiliser, and land ownership; institutional factors include group membership, training received, access to extension services, access to credit, and distance to the market, while technological characteristics include usefulness and technology cost. These factors are assumed not only to influence adoption but also the intensity of adoption of technologies for managing aflatoxin contamination. Adoption of innovations and technologies for managing aflatoxin contamination is assumed to improve the physical qualities and mitigate aflatoxin contamination in groundnuts, thus increasing their productivity. The study focused on productivity as the yield of groundnuts produced in kilograms per acre of land that can be sold. This is expected to improve household income and food security among smallholder groundnut producers.

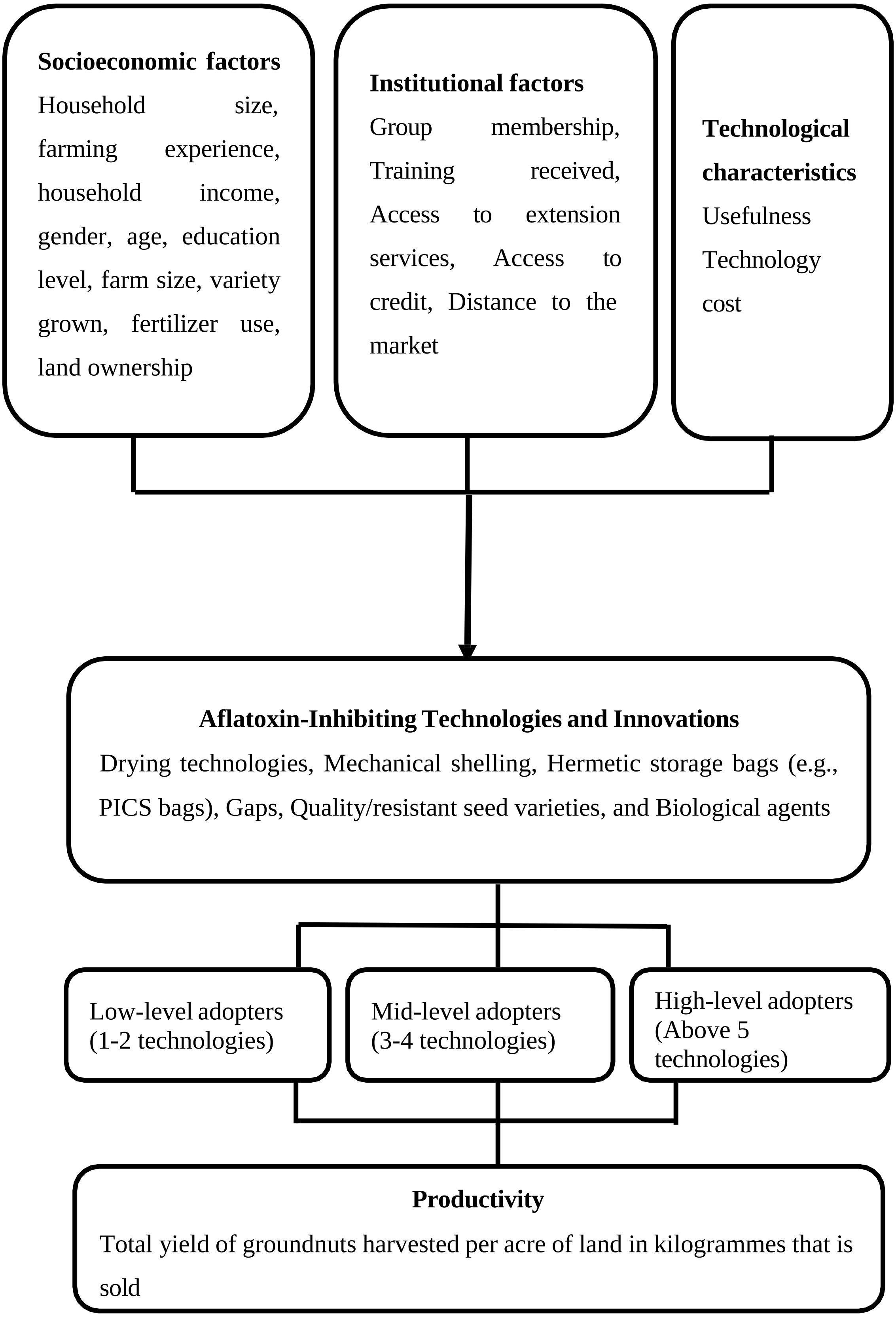

Figure 2.1: Conceptual framework

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presented the process involved in conducting this study. It involved a thorough description of the study areas, sample size determination and sampling procedure, research design to be followed, data collection and analysis process, tools for data analysis, and how results were presented.

3.1.1 Study Area

The study was conducted in Keiyo South Sub-County in Elgeyo Marakwet and Baringo Central Sub-County in Baringo County, as depicted in Figure 3.1. According to Farmer Trends (2024), these two counties are among the leading groundnut producers in Kenya. This informed the decision to consider them for the study. Elgeyo Marakwet County is located in the Rift Valley region of Kenya and covers a total area of 3029.6 km^2. It extends from latitude 0 20′ to 1^o 30′ to the North and longitude 35^o 0′ to 35^o 45′ to the East. It borders West Pokot County to the North, Baringo County to the East, Trans Nzoia County to the Northwest, and Uasin Gishu County to the West (CIDP, 2018-2022). According to the 2019 National Housing and Population Census, the county has an approximate population of 454,840. It comprises four sub-counties: Keiyo North, Keiyo South, Marakwet East, and Marakwet West.

The Elgeyo Marakwet County meteorological department reports annual mean temperatures on the highland range from 18^{o}C– 22^{o}C while down in the valley, it ranges from 25^{o}C – 28^{o}C as of December 2022. The average annual rainfall in the county ranges from 700 mm in the semi-arid Kerio Valley to 1700 mm in the Keiyo and Marakwet highlands (Cherangany Hills). Mixed farming is the main economic activity in the area, with major crops grown including maize, beans, groundnuts, wheat, and millet by over 80% of the population (Kirui, 2022). About 40% of the county is covered by the Kerio Valley, which is suitable for livestock production and annual crops such as groundnuts (Elgeyo Marakwet County, 2020). The largest groundnuts cooperative in Elgeyo Marakwet is headquartered near the Kapkayo market in the Soy South sub-county (USAID, 2018). Another reason was due to the intervention of the Food Safety for Africa Project. Against this background, the Soy South and North wards in Keiyo South Sub-County were selected for consideration.

On the other hand, Baringo County is located in the Northern part of the Rift Valley region, covering a total area of 11,075.3 km^2. It neighbours Turkana County in the North, Samburu and Laikipia in the East, Nakuru in the South, Kericho and Uasin Gishu in the South West, West Pokot in the North West, and Elgeyo Marakwet in the West. The county is positioned at a latitude of 0.8555° north and a longitude of 36.0893° east. According to the 2019 National Housing and Population Census, the county has an approximate population of 666,763. It comprises six sub-counties: East Pokot, Marigat, Baringo North, Baringo Central, Koibatek, and Mogotio.

Baringo County receives annual mean temperatures ranging from a minimum of 10 ˚C to a maximum of 35ºC. The average yearly rainfall in the county ranges between 300 mm and 500 mm, decreasing from South to North. Agriculture is a significant economic activity practised in the County. Primary farming activities include dairy farming and growing crops like maize, groundnuts, coffee, and cotton. Baringo County CIDP (2023-2027) states that Baringo Central receives the utmost priority when considering oil seeds and groundnut value chains (CIDP, 2023). Interventions of a processing company like Delis, Nutri, and Green Forest project intervention in Baringo. Against this background, Tenges and Sacho wards in Baringo Central were selected for consideration.

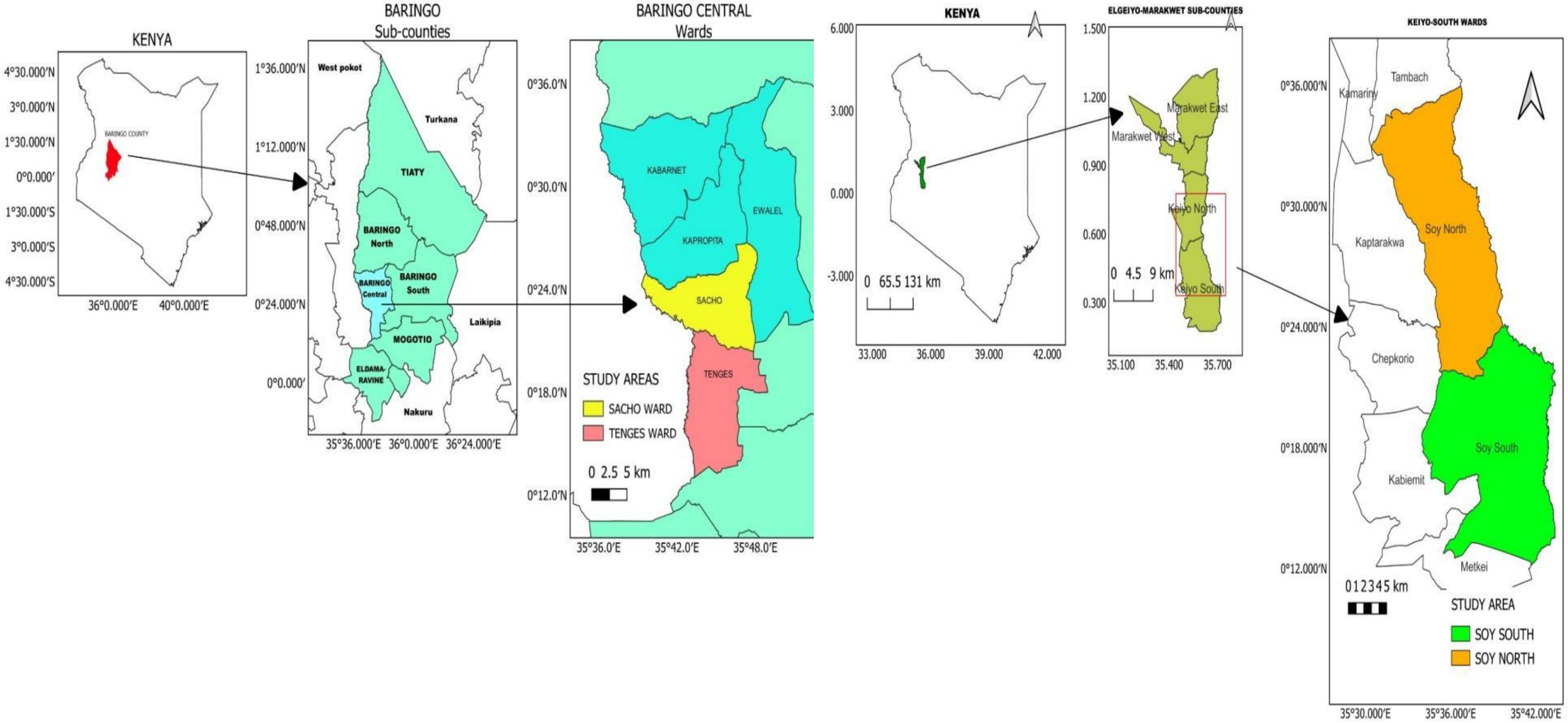

Figure 3.1: Map of the study area

Source: IEBC (2022)

3.2 Research Design

This research adopted a survey research design, which was considered an appropriate method for this study since the data were collected from a cross-section of respondents. Therefore, the researcher interacted with the participants through interviews during data collection to get the necessary information on how innovations and technologies for managing aflatoxin contamination influence the yield of groundnuts produced among smallholder farmers in Elgeyo Marakwet and Baringo counties. A list of smallholder groundnut producers was obtained from the respective sub-county agricultural officers and was used as a sampling frame. The sample unit of analysis was smallholder groundnut producers.

3.3 Study Population and Sampling

3.3.1 Sample Size

The determination of the sample size followed the proportionate sampling methodology specified by Cochran (1963) as follows:

$$n = \frac{z^2\, pq}{e^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where: n = sample size, p= implies maximum possible variance q = 1-p, z = the standard value at a given confidence level (α = 0.05), e = the acceptable error (precision). The study desired a 95% confidence level and a 5% precision level with a z score 1.96. In addition, the study assumed that p=0.5, since the number of smallholder groundnut farmers in the study area is unknown.

The sample was determined as:

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

The derived sample size for the study will be 384 respondents.

3.3.2 Sampling Procedure

A multistage sampling technique was employed in the study. Smallholder groundnut producers are using innovations and technologies for managing aflatoxin contamination, which is widespread, thus making constructing a sampling frame costly. In the first stage, Keiyo South in Elgeyo Marakwet and Baringo Central in Baringo counties were purposively selected because they are among Kenya's leading producers of groundnuts. In the second stage, two wards from each sub-county were purposively selected because they had the largest groundnut cooperative in Elgeyo Marakwet and were targeted by Baringo CIDP for groundnut projects, respectively. The third stage involved systematically sampling smallholder groundnut producers within the chosen wards. A list obtained from the agricultural officers of the respective sub-counties was used to identify the respondents in the two wards that were considered. The respondents were selected using systematic sampling using the Kth interval to give a total of 384 respondents as per Table 3.1.

K th = N/n, where N is the total population and n is the desired sample size.

Table 3.1: Sample size per selected ward

Sub-county/Ward	**Number of Households**	**Proportion to size (%)**	**Sample**
	Elgeyo Marakwet		
Keiyo South Sub-County			
Soy South ward	8,140	47	180
Soy North ward	2,791	16	61
Total	10,931	63	241
	Baringo County		
Baringo Central			
Tenges ward	3,058	18	69
Sacho ward	3,340	19	73
Total	6,398	37	143
Overall Total	**17,329**	**100**	**384**

Source: KNBS (2019)

3.4 Data Collection

A pilot study was carried out before the actual data collection involving 10% of the study area's total sample size to test the research instrument's validity and reliability. Primary data collection was conducted through interviews using a semi-structured questionnaire administered to smallholder groundnut producers. Questionnaires contained open-ended and closed-ended questions that allowed the researcher to collect data on the use of innovations and technologies for managing aflatoxin contamination and their effect on the productivity of groundnuts in Elgeyo Marakwet and Baringo Counties in Kenya.

3.5 Data Analysis

The statistical package for social sciences (SPSS) program was used for data entry, while STATA 18 was used to run the models in objectives 2, 3, and 4. Descriptive statistics, including mean, frequencies, percentages, and standard deviation, were used to analyse the first objective. For the second objective, to determine the factors influencing the intensity of adoption of innovations and technologies for managing aflatoxin contamination among smallholder groundnut farmers, a multivariate probit model and an ordered probit model was used for the third objective, an ordered endogenous switching regression was used to determine the effect of innovations and technologies on the managing aflatoxin contamination on the yield of groundnuts produced. STATA was used to generate econometric results.

3.6 Analytical Framework

3.6.1 To Describe the Aflatoxin-Inhibiting Technologies Used by Smallholder Groundnut Farmers in Elgeyo Marakwet and Baringo Counties in Kenya

Descriptive statistics were used to analyse this objective to identify and characterise innovations and technologies for managing aflatoxin contamination. Frequencies, percentages, and standard deviations of various variables were also obtained. This helped to determine the most common innovations and technologies, and sources of the technologies were used to assess the significance of innovations and technologies between the two counties, i.e., Elgeyo Marakwet and Baringo.

3.6.2 Factors Influencing the Choice of Aflatoxin-Inhibiting Technologies among Smallholder Groundnut Farmers in Elgeyo Marakwet and Baringo Counties in Kenya

This study considered the eight commonly used innovations and technologies: drying techniques, mechanical shelling, hermetic storage bags (e.g., PICS bags), GAPs, quality/resistant seed variety, and biological agents. The study used a Multivariate Probit (MVP) model to analyse the factors influencing the choice of different aflatoxin-inhibiting technologies among smallholder farmers in Elgeyo Marakwet and Baringo counties, Kenya. The multinomial logit (MNL) and logit models are also appropriate for this research, as the dependent variables have more than two outcomes or categories. The MNL model is suitable when the decision maker chooses one alternative from a set of choices (Arumugam *et al*., 2022). It is also employed when farmers can select an outcome from a set of mutually exclusive alternatives. However, in this study, aflatoxin-inhibiting technologies are not mutually exclusive, and smallholder farmers can choose more than two technologies.

In this study, the choice of aflatoxin-inhibiting technologies used by smallholder groundnut farmers represents a multiple response that is not mutually exclusive. This implies that the MVP model was applied in this research, as smallholder farmers can use aflatoxin-inhibiting technologies simultaneously. The econometric model of this study is characterised by a set of dependent variables Y_{it}. The functional form of the MVP model is specified as follows:

$Y_{it}^{*}= \beta_{it}X_{it}+ \varepsilon_{it}$ with (t=1, 2,…8)... (3)

Where (t=1,2,…8) represents the choice of aflatoxin-inhibiting technologies including drying techniques, mechanical shelling, hermetic storage bags (e.g., PICS bags), GAPs, quality/resistant seed variety, and biological agents, X_{it} is a $1\times$ k vector of all factors that affect the choice of aflatoxin-inhibiting technologies, β_{it} represents k $\times$ 1 vector of the parameter to be estimated, the i^th farmer is given I (1,2,....,n) to choose aflatoxin-inhibiting technologies and ε_{it} (t= 1,….,m) represents error terms. The observed outcome for choosing the different aflatoxin-inhibiting technologies was modelled as follows,

Y_{it} $[1\ if\ Y_{it}^{*} > 0\ \ 0\ otherwise$ t= 1, 2 8; 0 = otherwise

In this study, smallholder groundnut farmers choose aflatoxin-inhibiting technologies based on expected utility maximization. Since the choice of aflatoxin-inhibiting technologies is not mutually exclusive, the choice of the technologies can include the simultaneous use of 8 different technologies. Consequently, the system of equations for each technology becomes:

$Y_{i}^{*}= \beta_{i}X_{i}+ \varepsilon_{i}$……………………………………………………………… (4)

where, Y_{i}^{*} = aflatoxin-inhibiting technology.

The unknown parameters of equation (4) are estimated by simulated maximum likelihood. Consequently, the implicit functional form was assessed to determine the factors that influence the decision to choose aflatoxin-inhibiting technologies by smallholder groundnut farmers, as shown as follows:

Y_{i}= β_0 + β_1Age + β_2Gend + β_3Educ + β_4Exp + β_5HHsize + β_6Train + β_7Group + β_8Credit + β_9Mktdst + β_{10}Exten + β_{11}Price + β_{12}Usefullness + β_{13}Fmize + β_{14}Variety + β_{15}Ownland + β_{16}Fertlza +e_i..(5)

where, Y_i represents the choice of the aflatoxin-inhibiting technologies used by smallholder groundnut farmers. β_0 is a constant, β_1 to β_{15} are coefficients and e_i is the error term.

3.6.3 To Assess the Factors That Drive the Extent of Adoption of Aflatoxin-Inhibiting Technologies among smallholder Groundnut farmers in Elgeyo Marakwet and Baringo Counties in Kenya

The extent of adoption in this study was used to refer to the level (number) to which a smallholder groundnut farmer embraced and utilised aflatoxin-inhibiting technologies. Aflatoxin-inhibiting technologies are numerous. However, this study considered the 8 commonly used innovations and technologies: drying techniques, threshing, mechanical shelling, hermetic storage bags (e.g., PICS bags), GAPs, irrigation technologies, quality/resistant seed variety, and biological agents. In this objective, the study employed an ordered probit model to determine the intensity of adoption of aflatoxin-inhibiting practices among groundnut producers.

Kiconco *et al.* (2022) categorised technology adoption intensity into three sub-categories, namely low-level adopters (1-3) technologies, mid-level adopters (4-6) technologies, and high-level adopters (above 7 technologies). This study adopted the same categorisation. Based on the number of aflatoxin-inhibiting technologies used by farmers, the study assumes three categories of adopters, namely the low (1-2 technologies), medium (3-4 technologies), and high adopters (above 5 technologies). Thus, there are multiple choices, and particular interest lies in the individual effect of explanatory variables on each option. The ordered probit model recognises unequal differences between ordinal categories in a dependent variable. This means that for any change in the explanatory variable, the model captures the qualitative difference between the categories, thus accounting for the ordinal nature of the dependent variable.

Literature recognises that linear regression is inappropriate, especially when the dependent variable is categorical and qualitative (Tisdell & Svizzero, 2001). In such an instance, Green (2003) suggests using an ordered probit model as appropriate because intensity can be naturally ordered, in this case, low, mid, and high-level adopters, depending on the number of technologies adopted. The link between the observed categories and the latent outcome index is assumed to be of an ordered probit type and is a nonlinear model; thus, the effect of the explanatory variables can be measured in terms of marginal effects. The ordered

The probit model is conceptualised as;

$$Ordered\ Probit^{(HLA,MLA,LLA)} = \beta_0 + \beta_i X_i + e_i \text{ .... } (5)$$

where, High-level adopters (HLA)=3, Mid-level adopters (MLA)=2, and Low-level adopters (LLA)=1

Explicitly, the intensity of the adoption equation will be modelled as

$Y = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \cdots + \beta_n X_{ni} + e_i$………………………………. (6)

Since these adoption categories are logically ordered, it is possible to distinguish them rather than lump them together as adopters of technology users. In that case, an ordered probit adoption decision will be estimated. This approach allows for non-zero censoring points at the first stage, thresholds below or above which a smallholder groundnut producer found it worthwhile to be a high, mid, or low-level adopter of aflatoxin-inhibiting technologies. The decision to be a high, mid, or low-level adopter is trichotomous. Thus, smallholder groundnut farmers are assumed to adopt at a given intensity depending on their expected utility. The latent model m^*_{ji} describe the i^{th} smallholder groundnut producer's decision to adopt a regime *j* (*j*=1, 2, and 3);

$m^*_{ji} = \beta_j X_{ji} + e_{ji}$……………………………………………………………………… (7)

Where m denotes the latent variable, which can be represented by the level of expected benefit/utility derived from using an adoption regime *j*, Xs are vectors of covariates influencing the *j*th technology adoption regime, βs are an associated vector of parameters, and ε are the unobserved factors influencing the adoption intensity. The utility to adopt a given regime is not observable, but the decision to adopt is observable. A smallholder groundnut producer adopted a given regime *j* if;

$\{1\ if\ \ m^*_{ji} >$

$0\ 0\ otherwise$..(10)

The parameters j were estimated using coefficients of the ordered probit that allow for multiple ordered values (high, mid, and low-level adopters). The description of variables for ordered probit and priori expectation is shown in Table 3.2.

Table 3.2: Variables used in the MVP and ordered probit models

Variable	Description of variables	Priori Assumptions
Dependent		

Aflatoxin-Inhibiting Technologies	Drying techniques (1- Yes, 0 – No)	
	Threshing (1- Yes, 0 – No)	
	Mechanical shelling (1- Yes, 0 – No)	
	Hermetic storage bags (e.g., PICS bags) (1- Yes, 0 – No)	
	GAPs (1- Yes, 0 – No)	
	Irrigation technologies (1- Yes, 0 – No)	
	Quality/resistant seed variety (1- Yes, 0 – No)	
	Biological agents (1- Yes, 0 – No)	
Adoption Intensity	High-level adopter = above 5 technologies	
	Mid-level adopters = 3-4 technologies	
	Low-level adopters = 0-2 technologies	
Independent		
Age	Age of the farmer in years	+/-
Gender	Gender of the farmer (1 - Male, 0 - Female)	+/-
Education	Level of education of the farmer (Number of years in school)	+
Household income	Income per year in KES	+/-
Experience	Level of experience of the farmer (In years)	+
Household size	Number of members in a household	+/-
Training	Access to training by the farmer (1-Yes, 0-No)	+
Group membership	Membership to group (1- Yes, 0 – No)	+
Credit	Access to credit by the farmer (1-Yes, 0-No)	+
Market distance	Distance in kilometres to the market	+/-
Extension	Access to extension services (1-Yes, 0-No)	+/-
Buying price	Cost of technology in KES	+/-
Usefulness	Time-saving and quality improvement ability of the technology (1 – Yes, 0 – No)	+/-
Farm size	Size of the farm in acres	+/-
Variety grown	Use of improved or traditional seeds (1 – Yes, 0 – No)	+/-
Land ownership	Land tenure system (Owned – Yes, Rented– No)	+/-
Fertilizer use	Use of fertiliser in growing groundnuts (1 – Yes, 0 – No)	+/-

3.6.4 To Estimate the Effects of Aflatoxin-Inhibiting Technologies on the yield of Groundnuts Produced in Elgeyo Marakwet and Baringo Counties in Kenya

At this stage, the model considered three categories of adopters, namely the low adopters (1-2 technologies), medium adopters (3-4 technologies), and high adopters (above 5 technologies), as shown in Table 3. The effect of innovative agricultural technologies on productivity as the outcome variable was measured in terms of groundnuts harvested in kilograms per acre of land yield. Determining the impact of aflatoxin-inhibiting agricultural innovative technologies on the yield of groundnuts produced can be achieved using Propensity Score Matching (PSM) and Endogenous Switching Regression models (ESR). Both models can predict observed and counterfactual effects if farmers decide to adopt aflatoxin-inhibiting agricultural innovative technologies. However, some unobservable characteristics, such as the innovativeness of the technology, can influence the decision to adopt technologies, thus giving rise to endogeneity and self-selection problems (Di Falco & Veronesi, 2011).

The categorical choices of adoption levels are ordered, while at the same time, the farmer's decision to adopt a given level/category of technology use is not random; rather, it is influenced by observable and unobservable characteristics. The Ordered Probit Endogenous Switching Regression Model (OPESRM) accounts for this selection bias by modelling the adoption decision from outcome equations. This helps to isolate the actual effect of technology adoption on productivity (yield of groundnuts produced per acre of land in kilograms), by controlling for factors that may influence adoption and outcomes. Additionally, allowing different outcome equations for various categories of adopters using OPESRM provides flexibility to capture varying effects of technology adoption on productivity. This is attributed to the fact that adopting different levels of technology indirectly explains resource differences, experience, and differences in market access.

OPESRM followed two steps, namely the selection model and the regime equation. The selection model involved determining the decision to use agricultural innovative technologies. In contrast, the regime equation determines the effect of using the technologies at the three levels (low, mid, and high) on the productivity of groundnuts. Productivity as the dependent variable was measured in two different metrics, namely the yield of groundnuts produced ($Y_{kilograms}$) and an Acre of groundnuts (Y_{acres}). In the first stage, it is assumed that the ith groundnut producer decided to adopt innovative agricultural technologies if the outcome increases the kilogram volume. As earlier conceptualised, technology adoption levels were defined as low-level adopters ($D_i = 1$), Mid-level adopters ($D_i = 2$), and High-level adopters ($D_i = 3$). This can be given as:

$D_i^{*} = \beta_0 + \beta_1 X_i + e_i$ ....(8)

Where the observable decision level D_i will be defined as

$D_i = \{1 \; if \; D_i^{*} \leq C_1 \;\; 2 \; if \; C_1 < D_i^{*} \leq C_2 \;\; 3 \; if \; D_i^{*} > C_2$

Where D_i^{*} latent variable captured expected outcomes of using agricultural innovative technologies by the ith groundnut producer, vector D_i are variables that determine usage of the technologies, β represents a vector of parameters to be estimated, e_i is the random error term and $C_1 \; and \; C_2$ Cut-off points define the threshold between low, mid, and high-level adopters.

In the second stage, the two outcome equations are conditional on D_i where two regimes are faced, that is, (1) low-level adopters, (2) mid-level adopters, and (3) high-level adopters, will be specified using the following estimations:

Low adopters 1 $Y_{1i} = \beta_1 X_{1i} + e_{1i}$ if $D_i = 1$ ....(9)

Mid adopters 2 $Y_{2i} = \beta_2 X_{2i} + e_{2i}$ if $D_i = 2$...(10)

High adopters 3 $Y_{3i} = \beta_3 X_{3i} + e_{3i}$ if $D_i = 3$... ....(11)

where Y_{1i} , Y_{2i} and Y_{3i} are effects on the productivity of groundnuts observed for each group, depending on the selection equation, χ_i represents a vector of exogenous variables that influence the outcome variables for equations (7), (8), and (9), β is a vector of parameters to be estimated, ε_{1i} and ε_{2i} are the error terms associated with the outcome equation. The error terms μ_i , ε_{1i} and ε_{2i} are the error terms of selection and regime equations, respectively, and are assumed to have a trivariate normal distribution with zero mean vector and the covariate matrix shown below:

$$Cov(\mu, \varepsilon_1, \varepsilon_2) = \begin{pmatrix} \sigma_{\mu}^{2} & \sigma_{\mu\varepsilon_1} & \sigma_{\mu\varepsilon_2} \\ \sigma_{\mu\varepsilon_1} & \sigma_{\varepsilon_1}^{2} & . \\ \sigma_{\mu\varepsilon_2} & . & \sigma_{\varepsilon_2}^{2} \end{pmatrix} \text{.. (12)}$$

A maximum likelihood function combines probabilities from the selection equation with conditional expectations from the outcome equations to simultaneously estimate the parameters of both the selection equation and the outcome equations while accounting for potential endogeneity and selection bias. The likelihood function that finds parameter estimates that maximise this likelihood function will be expressed as:

$L(\beta, \text{ɒ}; \Upsilon, D) = \prod_{i=1}^{N} P(D_i|X_i;\ \beta)\, P(Y_i, D_i|\ X_i;\ \text{ɒ})$..(13)

Where $P(D_i|X_i;\ \beta)$ is the probability of being in a particular adopter category given observable characteristic, $P(Y_i, D_i|\ X_i;\ \text{ɒ})$ is the probability distribution of productivity outcomes conditional on being in that category. The coefficients from the selection equation β indicate how various factors influence the likelihood of adopting different levels of aflatoxin-inhibiting technologies. The coefficient from each outcome equation ɒ reveals how technology adoption impacts productivity metrics (yield of groundnuts produced per acre of land), allowing for the assessment of economic significance.

The OPESR model addresses the selection bias problem as a missing variable for the Average Treatment Effect on the Treated (ATT) and Average Treatment Effect on the Untreated (ATU).

This study aimed to explore the effects of aflatoxin-inhibiting technologies and innovations on the productivity of groundnuts, which was measured in terms of the yield of groundnuts produced in kilograms per acre of land. The expected outcomes for groundnut producers using agricultural innovative technologies under observed conditions and counterfactual conditions will be computed using the equations below:

Where $E(\Upsilon|D=j)$ and $E(\Upsilon|D=0)$ represent the expected outcome for the adoption of a given level of aflatoxin-inhibiting technologies and the expected outcome for non-adoption of a given level of aflatoxin-inhibiting technologies respectively. This was repeated for all three levels.

The difference in the expected outcome from the above equations is referred to as the average treatment effect on treated (ATT) and constitutes the effect of using agricultural technologies and innovations on the productivity of groundnuts by different levels of adopters.

$ATT_{low} = E(\Upsilon|D=1) - E(\Upsilon|D=0)$ ....(20)

$ATT_{mid} = E(\Upsilon|D=2) - E(\Upsilon|D=0)$ .... (21)

$ATT_{high} = E(\Upsilon|D=3) - E(\Upsilon|D=0)$ .... (22)

In the same way, the expected outcomes for different levels of adopters under counterfactual conditions will be computed using the equations below:

$ATU_{low} = E(\Upsilon|D=0) - E(\Upsilon|D=1)$ ....(23)

$ATU_{mid} = E(\Upsilon|D=0) - E(\Upsilon|D=2)$ ....(24)

$ATU_{high} = E(\Upsilon|D=0) - E(\Upsilon|D=3)$..(25)

The difference in the expected outcomes from the above equations is referred to as the average treatment effect on the untreated (ATU). Table 3.3 presents the variables used in the model.

Table 3.3: Description of variables used in the model and the a priori assumptions

Variable	Description of variables	Priori Assumptions
Dependent Variable		
Productivity	Yield of groundnuts produced per acre of land in kilograms	
Treatment variables		
High-level adopter	Groundnut producers using above 5 technologies	+/-
Mid-level adopter	Groundnut producers using between 3-4 technologies	+/-
Low-level adopter	Groundnut producers using between 0-2 technologies	+/-
Independent Variables		
Age	Age of the farmer in years	+/-
Gender	Gender of the farmer (1-Male, 0- Female)	+/-
Education	Level of education of the farmer (Number of years in school)	+
Experience	Level of experience of the farmer (In years)	+
Household income	Income per year in KES	+/-
Household size	Number of members in a household	+/-
Training	Access to training by the farmer (1-Yes, 0-No)	+
Group membership	Membership to group (1- Yes, 0 – No)	+
Credit	Access to credit by the farmer (1-Yes, 0-No,)	+
Market distance	Distance in Kilometers to the market	+/-
Extension	Access to extension services (1-Yes, 0-No,)	+/-
Buying price	Cost of technology in KES	+/-
Usefulness	Time-saving and quality improvement ability of the technology (1 – Yes, 0 – No)	+/-
Farm size	Size of the farm in acres	
Variety grown	Use of improved or traditional seeds (1 – Yes, 0 – No)	
Land ownership	Land tenure system (Owned – Yes, Rented– No)	

Fertilizer use	Use of fertilizer in growing groundnuts (1 – Yes, or No)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter presents the results and discussion of the study findings. The socioeconomic characteristics of the sampled households were described using descriptive analysis. Econometric models were used to determine factors influencing the choice of the adoption levels and the effects of adoption on productivity.

4.1 To Describe the Aflatoxin-Inhibiting Technologies Used Among Smallholder Farmers in Elgeyo Marakwet and Baringo Counties in Kenya

The results in Table 4.1.1 summarise the relationship between adoption levels of inhibiting technologies and various socio-economic and farm-related variables, with the F-values indicating whether differences in the mean across adoption levels are significantly different. Age was fairly consistent across all the adoption levels. Most farmers who adopted these technologies were on average 40 years old. The adoption process takes place when most farmers are agile and within their productive age. Young and old farmers are crowded out from adopting these technologies. A plausible explanation is that young farmers are crowded out due to a lack of productive resources. Older farmers are risk-averse; most tend to maintain the status quo rather than adopt a new technology. The findings align with Miine *et al.* (2023) in a study done in Ghana on drivers for technology adoption, asserting that older farmers shy away from integrating new technologies on their farms due to the risks accompanying the adoption and applicability of new technologies.

High differences were denoted by the years an individual spends in school and experiential knowledge among groundnut farmers on adopting aflatoxin-inhibiting technologies as posited by high F-values (3.33, 9.38). As the level of education and experience increases, more and more farmers adopt these technologies. A plausible explanation is that education and experience are key to knowledge diffusion. Risk aversion and enhanced awareness concerning the relative importance of integrating aflatoxin-inhibiting technologies on farms to realise high outputs. The findings align with a study by Bisheko *et al.* (2023), who highlighted that experience and education improve one’s ability to obtain and understand the information required to efficiently use innovative technologies.

Additionally, adoption of technologies is positively associated with high yields and high market prices. High yields and high premium prices were obtained by high-level adopters as opposed to low-level adopters. Presumably, these technologies are essential in reducing pre-and post-harvest losses, enabling most farmers to have high-quality produce commanding high premium prices in the market. These are high among the high adopters as opposed to the low-level adopters.

Distance to markets among the different levels of adopters posited significant differences. Overall, farmers cover a distance of approximately 15 kilometres in search of a market. High adopters cover relatively longer distances to markets than medium and low adopters of the technologies. A plausible explanation will be that high-level adopters tend to adopt more of these technologies to compensate for the cost of travelling the distance, as opposed to low-level adopters. The findings corroborated with a study by Abdulai *et al.* (2021), asserting that distance to the market is critical in accelerating technology adoption among farmers in Ghana.

Table 4.1.1: Summary statistics for continuous variables and adoption levels of technologies

Variable	Low (N= 249)	Medium (98)	High (N=37)	All (N=384)	f-value
Age	39.92(11.72)	40.11(11.14)	38.97(12.42)	39.88(11.62)	6.13***
Education	9.65(3.69)	10(3.41)	10.62(3.34)	9.83(3.59)	3.33**
Land size for crops	2.84(2.25)	3.04(2.21)	3.23(2.62)	2.93(2.27)	0.62
Land under groundnuts	1.70(1.10)	1.77(1.00)	1.78(1.08)	1.72(1.08)	0.23
Experience	12.24(10.37)	16.09(10.09)	18.57(9.52)	13.83(10.44)	9.38***
Distance	6.85(3.85)	8.06(5.53)	8.70(6.35)	7.33(4.65)	4.25 **
Yield of shelled groundnuts (kgs)	456.55(329.88)	569.31(393.30)	598.57(395.83)	499.01(357.44)	5.20***
Price/kg of shelled groundnuts	149.89(33.96)	156.83(22.46)	162.43(21.40)	152.87(30.59)	3.87**

***, **, * denotes significance at 1%, 5%, and 10% respectively, figures in parentheses are standard deviations associated with the variables indicated.

The results in Table 4.1.2 represent categorical variables and the relationship with adoption levels of aflatoxin-inhibiting technologies. Chi-square (X^2) denotes significance levels of association between the categorical variables and the level of adoption among ground-nut farmers. The results posit a high association between gender and the adoption of technologies. Adoption is high among male farmers as opposed to their female counterparts across all levels of adoption. This is because male farmers have high access to agricultural resources and hold a significant sway in decision-making, crowding out their female counterparts. The findings corroborate a study done by Abate *et al.* (2024), which denoted that male farmers hold prerogative rights on decision-making and have access to productive agricultural resources, making it easy for most of them to adopt new technologies as opposed to their female counterparts.

Table 4.1.2: Summary statistics for categorical variables and adoption levels of technologies

Variable		Low (25.52)	Medium (25.5)	High (9.64)	Share of farmers (%)	$\chi 2$
Gender	Male	55.02	61.22	78.38	58.85	7.563**
	Female	44.98	38.78	21.62	41.15	
Age	18 - 35	38.55	36.73	37.84	38.02	1.136
	36 - 59	47.79	53.06	48.65	49.22	
	Above 59	13.65	10.20	13.51	12.76	
Income from salary	Yes	5.22	6.12	16.22	6.51	6.431**
	No	94.78	93.88	83.78	93.49	
Income from wages	Yes	0.40	5.10	0.00	1.56	10.752 ***
	No	99.60	94.90	100.00	98.44	
Income from remittance	Yes	0.00	0.00	2.70	0.26	9.403 ***
	No	100.00	100.00	97.30	99.74	
Income from farming	Yes	98.80	98.98	97.30	98.70	0.644

	No	1.20	1.02	2.70	1.30	
Income from business	Yes	13.25	22.45	32.43	17.45	10.512***
	No	86.75	77.55	67.57	82.55	
Education levels	No formal education	8.84	6.12	5.41	7.81	7.4871
	Primary	30.52	27.55	18.92	28.65	
	Secondary	44.58	47.96	43.24	45.31	
	Tertiary	16.06	18.37	32.43	18.23	
Group membership	Yes	16.87	28.57	64.86	24.48	41.335***
	No	83.13	71.43	35.14	75.52	
Credit access	Yes	17.67	22.45	16.22	18.75	1.227
	No	82.33	77.55	83.78	81.25	
Fertilizer use	Yes	16.06	11.22	18.92	15.10	1.749
	No	83.94	88.78	81.08	84.90	
Extension access	Yes	39.76	35.71	43.24	39.06	0.7840
	No	60.24	64.29	56.76	60.94	
	Land owned	71.89	77.55	75.68	73.70	1.246
	Communal/rented	28.11	22.45	24.32	26.30	
Ndovu variety	Yes	72.69	75.51	67.57	72.92	0.876
	No	27.31	24.49	32.43	27.08	
Mwangaza	Yes	22.49	18.37	10.81	20.31	3.022
	No	77.51	81.63	89.19	79.69	
Cheplambus	Yes	34.94	31.63	45.95	35.16	2.428
	No	65.06	68.37	54.05	64.84	
Improved variety	Ndovu and Mwangaza	56.22	88.78	94.59	68.23	47.503***
	Cheplambus	43.78	11.22	5.41	31.77	5.106*
County	Baringo	43.78	33.67	37.84	40.62	
	Elgeyo Marakwet	56.22	66.33	62.16	59.38	

Training on Aflatoxins	Yes	41.77	50.00	40.54	43.75	2.108
	No	58.23	50.00	59.46	56.25	

***, **, * denotes significant at 1%, 5% and 10% respectively

Household income had a mixed effect among high and low adopters of aflatoxin-inhibiting technologies. Meanwhile, income from salaries, remittances, and business was highest among high adopters as opposed to low adopters. Interestingly, income from wages was high among the medium-level adopters. A plausible explanation is that income is vital in encouraging farmers to adopt new technologies. As farmers earn more, they are more likely to try to use improved technologies. This is because income helps cover the costs of buying and maintaining new technologies. It also gives farmers better access to credit, training, and information, which reduces the risks and challenges of trying new technologies. The findings align with a study done in Tanzania by Mutungi *et al.* (2023) on the adoption of post-harvest technologies to realise food security, positing that income is critical to facilitate the uptake of different technologies among maize farmers.

Group membership is highly significant (X^2=41.335), increasing the adoption of post-harvest technologies. There were more high-level adopters in groups as opposed to low-level adopters of the technologies. A plausible explanation is that group membership enhances information diffusion and awareness of these technologies' relative importance and applicability, significantly influencing the adoption of post-harvest technologies. The findings are in line with Magesi *et al.* (2024) in a study done in Kenya, highlighting the importance of group membership in escalating the adoption of climate-smart technologies. That is facilitated through collating and pooling resources and knowledge on the applicability of different strategies to realise high output.

A strong association exists between groundnut variety use and the adoption of aflatoxin-inhibiting technologies, as posited by a high Chi-square (X^2=47.503). High adopters predominantly use improved varieties more than their middle and low-level adopters. The use of improved varieties is strongly correlated with high technology adoption. Integrating improved groundnut variety technologies is critical to realize high output, as evidenced among high adopters.

4.1.1 Pre-estimation Tests

4.1.2 Multicollinearity Test

A Variance Inflation factor (VIF) was used to determine multicollinearity among the explanatory variables. The VIF mean value is 1.3, which is below the acceptable threshold value of 5 (Table 4.1.3). This implies that multicollinearity is not a problem. Multicollinearity is not a problem; all values are below the recommended threshold of 5.

Table 4.1.3: Test for multicollinearity among explanatory variables

	VIF	1/VIF
Age	1.803	.555
Farming Experience	1.755	.57
Education	1.518	.659
Income	1.225	.816
House size	1.182	.846
Fertilizer use	1.153	.867
Group Membership	1.14	.877
Land Size	1.136	.88
Income farming	1.127	.888
Improved variety	1.112	.899
Sales Price	1.104	.906
Cost of Technologies	1.09	.918
Gender	1.084	.923
Distance to Market	1.076	.93
Extension access	1.065	.939
Usefulness of the Technologies	1.042	.96
Mean VIF	1.226	.

4.1.3 Pairwise Correlation for Categorical Variables

A pairwise correlation was used to test for correlation among the categorical variables. All values were below the threshold of 0.5, indicating that the variables are not correlated (Table 4.1.4).

Table 4.1.4: Pairwise correlation for categorical variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)
(1) Gender	1.000					
(2) Credit access	0.039	1.000				
(3) Fertiliser use	-0.049	0.077	1.000			
(4) Extension access	0.069	0.067	-0.054	1.000		
(5) Training	0.067	0.168	0.170	0.305	1.000	
(6) Group membership	0.039	1.000	0.077	0.067	0.168	1.000

4.1.4 Heteroscedasticity test

The Breusch-Pagan test was used to test for heteroscedasticity. The test indicated the presence of heteroscedasticity due to a significant p-value. Heteroscedasticity was addressed using robust standard errors in the models.

4.1.5 Test for a valid Instrument

A simple falsification test was used for instrument validity. A valid instrument should influence the decision and not the outcome variable. Group membership was the valid instrument for this study, as shown in Table 4.1.5. Insignificant p-values for productivity under different adoption levels indicate that group membership affects the decision (low, medium, and high adoption levels) and not the outcome variable (productivity).

Table 4.1.5: Simple falsification test for a valid instrument (Group membership)

Outcome (Productivity)	f-value	p-value
Levels of adoption		
Low	0.71	0.3992
Medium	1.86	0.1768
High	3.67	0.6720

4.2 Factors Influencing the Adoption of Different Aflatoxin-Inhibiting Technologies

A multivariate probit model was used to achieve this objective. Table 4.2.1 presents the socioeconomic factors influencing the adoption of different Aflatoxin-inhibiting technologies. These technologies include drying, shelling, hermetic storage, resistance seeds, Afla safe, and good agricultural practices. The model is highly significant (Prob > chi2 =0.0000), indicating that the variables used in the model explain the variation in the dependent variable.

The age of the respondents emerged as a significant factor that negatively influenced the adoption of resistant seeds, achieving a significant level of 5%. The findings posit a decrease in the likelihood of adopting resistant seeds with an increase in the age of farmers. Plausibly, because older farmers prefer to maintain the status quo, they adopt mainly due to continuous appraisal and the risks associated with the new technologies. On the contrary, young farmers are better placed to adopt new technologies due to a broad knowledge diffusion and increased ease of integrating new technology. The finding corroborated the findings by Udimal *et al.* (2017), positing a negative correlation between age and the adoption of improved rice varieties in Ghana, asserting it to be a risk-averse nature of older farmers compared to their young counterparts.

Table 4.2.1: MVP estimates for determinants of uptake of technologies

	Drying		Shelling		Hermetic storage		Resistant seeds		Aflasafe		GAP	
	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.
Age	-0.252	0.162	-0.257	0.340	-0.247	0.205	-0.588**	0.251	0.156	0.175	-0.308	0.190
Gender	-0.083	0.150	-0.561*	0.320	-0.063	0.183	-0.165	0.205	0.674***	0.188	0.013	0.172
Household size	0.042	0.037	-0.060	0.062	0.071	0.044	-0.121***	0.046	0.069***	0.041	-0.065	0.044
Income	-0.236	0.276	0.917**	0.439	-0.033	0.394	0.640*	0.358	0.252	0.312	0.849***	0.312
Education	-0.008	0.107	-0.176	0.174	0.156	0.145	-0.116	0.144	-0.003	0.122	0.015	0.131
Experience	0.014	0.010	-0.003	0.024	0.008	0.015	0.023	0.014	-0.017	0.012	0.009	0.012
income	-0.072	0.081	0.215	0.202	0.041	0.105	-0.344**	0.099	-0.250***	0.088	-0.193**	0.090
Group	-0.013	0.189	1.364***	0.406	0.846***	0.230	0.787***	0.209	0.037	0.219	0.722***	0.213
Fertilizer	0.126	0.216	-1.052*	0.562	-1.092***	0.402	-0.616**	0.261	0.140	0.255	-0.566**	0.286
Extension	0.598**	0.152	0.137	0.273	0.143	0.199	-0.153	0.196	0.811***	0.168	-0.085	0.177
Land size	-0.010	0.035	0.134***	0.043	0.025	0.054	0.110**	0.045	-0.105**	0.048	0.124***	0.043
Variety	0.041**	0.019	0.287	0.369	0.029	0.024	-0.029	0.023	0.037	0.024	-0.024	0.020
Distance	0.024*	0.014	-3.778**	1.519	0.079***	0.019	-0.033	0.022	-0.035*	0.021	0.002	0.018
_cons	0.237	0.650	-0.257**	0.340	-3.902***	0.846	0.591	0.759	-1.317*	0.713	-0.764	0.781

Number of observations

Prob > chi2 = 0.0000

Wald chi2(77) = 332.75

Log pseudolikelihood = -703.97686

***, **, * denotes significant at 1%, 5% and 10% respectively

Group membership exhibited a positive correlation with the adoption of shelling, hermetic storage, resistant seeds, and GAP at the 1% significance level. As a farmer becomes a group member, individual participation significantly accelerates the uptake of these technologies. This effect is likely attributable to the role of group membership in facilitating information dissemination among farmers, thereby enhancing the ease of adoption and implementation. Githumbi *et al*. (2024) emphasised that group membership serves as a conduit for knowledge diffusion and awareness creation, fostering a greater propensity among farmers to adopt new agricultural technologies as a strategy for mitigating post-harvest losses in Kenya.

Fertiliser use exhibited a negative relationship with the adoption of Good Agricultural Practices (GAP) and hermetic storage at a 1% significance level, resistant seed varieties at a 5% significance level, and improved shelling techniques at a 10% significance level. The study found that an increase in fertiliser usage reduced the likelihood of adopting these technologies, likely because resource constraints force farmers to prioritise inputs perceived as more immediately beneficial. The increased expenditure on agricultural inputs can create financial trade-offs, limiting the adoption of alternative technologies. These findings align with Zegeye *et al.* (2019), who emphasised the importance of agricultural input subsidies in enhancing the adoption of improved technologies. Agricultural inputs are vital, as they influence farm productivity and profitability, affecting farmers' capacity and willingness to invest in complementary innovations.

The study established a positive and significant relationship between income generated from the sale of agricultural produce and the adoption of Good Agricultural Practices (GAP), improved shelling techniques, and resistant seed varieties, with significance levels of 1%, 5%, and 10%, respectively. Higher income levels increased the likelihood of adopting these technologies among groundnut farmers, likely because income serves as a financial buffer, mitigating potential risks associated with adopting new agricultural innovations. These findings are in line with the study by Kattel *et al.* (2020) in Nepal on the adoption of post-harvest techniques. The study posits that income from agricultural produce plays a vital role in the adoption of new technology among farmers.

Household size exhibited a dual effect on technology adoption, showing a negative correlation with the adoption of resistant seed varieties and a positive correlation with the adoption of Aflasafe, both at the 1% significance level. Specifically, larger households were less likely to adopt resistant seed varieties but more inclined to adopt Aflasafe. This dynamic may be attributed to household decision-making processes and the availability of disposable income, which influence the prioritisation of agricultural technologies. Contrary to these findings, Melesse *et al.* (2023) observed that households with a larger number of active members tend to adopt agricultural technologies more readily, as increased family participation enhances information sharing and collective decision-making.

The study established a significant relationship between gender and technology adoption. Gender was positively correlated with the adoption of Aflasafe at a 1% significance level but negatively correlated with the adoption of shelling. The findings indicate that male farmers were more likely to adopt Aflasafe, whereas female farmers exhibited a higher propensity to adopt shelling as a strategy for reducing post-harvest losses. This trend is likely driven by differences in resource access and household labour responsibilities. Male farmers generally have greater access to financial and technical resources, facilitating the adoption of Aflasafe. Meanwhile, cultural factors may influence female farmers to prioritise shelling as a practical and cost-effective method for minimising post-harvest losses. The findings are in line with Mwalongo *et al.* (2020), on the adoption of improved technology in Tanzania, who found that male farmers have access to productive resources and that decision-making is mandated by male farmers while crowding out their female counterparts.

The study revealed that extension services had a significant positive impact on the adoption of Aflasafe and drying technologies among groundnut farmers, at the 1% and 5% significance levels, respectively. Farmers with access to extension services demonstrated greater efficiency in adopting aflatoxin-inhibiting technologies compared to those with limited or no access. This underscores the critical role of extension services in raising awareness and disseminating information on the applicability and benefits of agricultural innovative technologies. These findings are consistent with Abady *et al.* (2019), who emphasised the pivotal role of extension services in facilitating the adoption of improved technologies among groundnut farmers in Eastern Ethiopia.

The study revealed a positive correlation between land sizes owned by groundnut farmers and the choice of shelling and GAP at a 1 % level of significance, the use of resistant seeds at 5 % significance level, while Aflasafe had a negative effect at 5 % level of significance. An increase in the size of land under groundnut production by 1 unit increased the probability of adopting shelling, GAP, and the use of resistant seeds, while decreasing the likelihood of using Aflasafe technology. Large tracts of land enhance farmers' economies of scale and risk aversion, thus positively reducing the costs associated with agricultural inputs, making it easy for farmers to integrate other technologies. The findings corroborated those of Obiero (2019), who posited that land size positively influenced the incorporation of agricultural technologies in farming.

The study found a significant positive relationship between the variety of groundnuts used and the adoption of drying technologies as a strategy to reduce post-harvest losses at the 5% significance level. Access to improved groundnut varieties serves as a catalyst for adopting new technologies, as farmers seek to enhance productivity. This is because improved varieties often offer higher yields, better resistance to pests and diseases, and shorter maturation periods, making them more attractive to farmers who are willing to invest in complementary technologies such as drying to maximise their benefits. These findings align with Vabi *et al.* (2019), who reported that improved groundnut varieties played a key role in influencing the adoption of groundnut technologies in Nigeria.

4.3 To Assess the Factors that Drive the Extent of Adoption Levels of Aflatoxin-Inhibiting Technologies

This objective was achieved using an ordered probit model. Tables 4.3.1 and 4.3.2 present the results on factors influencing the adoption level of aflatoxin-inhibiting technologies and their marginal effects. The table lists the variables that influence how widely aflatoxin-inhibiting technologies are adopted.

Table 4.3.1: Determinants of adoption levels using ordered probit

	Coefficient	Standard errors
Age_	-0.681***	.147
Gender	0.778***	.161
Household size	0.052	.034
Farm income	0.375	.326
Off-farm income	0.415	.643
Education	0.218***	.109
Experience	0.056***	.009
Group Membership	0.826***	.161
Fertilizer use	-0.382*	.231
Extension access	-0.124	.152
Cost of Technologies	0.051**	.024
Land size	0.171	.17
Usefulness of Technologies	0.42**	.214
Improved varieties	1.276***	.215
Sales Price	0.007*	.004

Distance to Market	0.028**	.014
cut1	6.343	1.028
cut2	7.73	1.039

Number of observations=384

Prob > chi2=000

Wald chi2(16) = 151.29

Log Pseudo R^2=0285

Log pseudo likelihood=-234.58024

***, **, * denotes significant at 1%, 5% and 10% respectively. The high adopter category was used as the base category.

The marginal effects of the ordered probit model is presented in Table 4.3.2. The Table shows the impact of a change in independent variables on the predicted probability of the dependent variable on average, given other variables constant. Thus, the effects of explanatory variables can be measured in terms of marginal effects.

Table 4.3.2: Marginal effects of the adoption levels

	dy/dx	std.	dy/dx	std.	dy/dx	std.
	Low Adopters		Medium Adopters		High Adopters	
Age of H.H. head	0.167***	0.034	-0.087***	0.020	-0.08***	0.017
Gender of H.H	-0.190***	0.036	0.099***	0.020	0.091***	0.020
Household size	-0.013	0.008	0.007	0.004	0.006	0.004
Farm income	-0.092	0.079	0.048	0.041	0.044	0.039
Off-farm income	-0.101	0.158	0.053	0.082	0.048	0.076
Education	-0.053**	0.027	0.028**	0.015	0.026**	0.013
Farming Experience	-0.014***	0.002	0.007**	0.001	0.007***	0.001

Group Membership	-0.202**	0.037	0.106***	0.021	0.097***	0.021
Fertilizer use	0.094*	0.056	-0.049	0.030	-0.045*	0.027
Extension access	0.030	0.037	-0.016	0.020	-0.015	0.018
Cost of technology	-0.012**	0.006	0.006**	0.003	0.006**	0.003
Land size	-0.042	0.042	0.022	0.022	0.020	0.020
Usefulness	-0.103**	0.052	0.054**	0.027	0.049**	0.026
Improved groundnut variety	-0.312***	0.045	0.163***	0.026	0.149***	0.027
Sales price	-0.002*	0.001	0.001**	0.000	0.001*	0.000
Distance to market	-0.007**	0.003	0.004**	0.002	0.003**	0.002

***, **, * denotes significant at 1%, 5% and 10% respectively. The high adopter category was used as the base category.

Age was negative and statistically significant for medium and high adopters, while it was positively correlated with low adopters. As age increases by 1, the propensity of being in the medium and high adoption categories decreases, while it increases for low adopters. A possible explanation for this scenario is that older age is correlated with reduced physical energy and risk aversion. This reduces their willingness to adopt more technologies. However, there is a debate on the direction of the effect of age on adoption. For instance, Sennuga *et al*. (2020) found that younger farmers were more likely to adopt improved technologies in Nigeria. On the other hand, Dissayanake *et al*. (2020) argued that older farmers have experienced and accumulated resources enabling them to adopt agricultural technologies.

Gender was negatively correlated with low adoption at 5% significance level, while positively associated with medium and high adoption levels at 1% significance level. This implies that male-headed households were more likely to adopt aflatoxin-inhibiting technologies compared to female-headed households. A possible explanation for this is that the majority of males have access to production resources and, thus, have the discretion to adopt new technologies. Consequently, female-headed households are mostly widowed and lack property rights. In such situations, their likelihood of adopting aflatoxin-inhibiting technologies is negligible, alongside the cultural factors. Studies (Ainembabazi *et al*., 2016; Melesse *et al*., 2016) have found similar results. The respondents' education level had a negative effect on low adopters at a 5% significance level, while it positively influenced medium and high adopters at a 1% significance level. This suggests that households with a high level of formal education were more equipped with knowledge to understand the importance of aflatoxin-inhibiting technologies, which influenced their adoption. Previous literature has established this relationship (Binswanga & Sawastano, 2017; Sennuga *et al*., 2020).

Farming experience in groundnuts was negatively associated with low adoption and positively associated with medium and high adopters at 1% significance level. An increase in the number of years of groundnut farming by one positively influenced the adoption of aflatoxin-inhibiting technologies. Longer farming experience is associated with knowledge accumulation and established social networks, which enhance information sharing. This finding aligns with those of Sennuga *et al.* (2020), who found that farming experience significantly influenced the adoption of improved agricultural technologies.

Membership in agricultural groups had a negative influence on low adoption at 5% while it had a positive impact on medium and high adoption levels at 1% significance level. Social networks provide a platform for sharing information and enable farmers to pool resources. Similarly, Dan *et al.* (2021) highlighted that membership in an agricultural cooperative group membership positively influenced the adoption of agricultural technology. However, studies (Ahmed *et al*., 2019; Awotide *et al*., 2019) found that group membership was negatively correlated with the adoption of improved agricultural technologies.

The study finds that fertiliser use is positively associated with low and medium adoption levels but negatively associated with high adoption levels at the 10% significance level. This suggests that farmers using fertiliser may prioritise increased productivity over the adoption of additional technologies. As a result, they may focus more on enhancing production rather than integrating new aflatoxin-inhibiting technologies.

The cost of the technologies had a negative influence on low adoption and a positive influence on medium and high adopters at 5% significance level. This implies despite the increased cost of the technologies that farmers were more likely to adopt them due to the benefits that come with the adoption of aflatoxin-inhibiting technologies. The use of these technologies reduces losses and increases production, market access, and profit (Adejumu *et al*., 2020; Bakuye *et al*., 2019; Odol *et al*., 2019).

Perceived usefulness of the aflatoxin-inhibiting technologies was negatively correlated with low adoption, while positively correlated with medium and high adoption at 5% significance level. The farmers' perception of the benefits of adoption, including improved quality, colour, size, ease of use technologies, increasing production, and market access, increased their likelihood of adopting aflatoxin-inhibiting technologies. Farmers are more likely to adopt technologies that offer tangible benefits. This finding is consistent with existing literature that found increased technology adoption due to access to incentives (Odol *et al.*, 2019; Thakur, 2018).

The use of improved groundnut seeds was negative and statistically significant for low adopters, while it had a positive influence on medium and high adopters at 5% significance level. Groundnut farmers who use improved seeds might experience increased production, thus be more likely to adopt aflatoxin-inhibiting technologies to reduce losses and to increase market access. Beharielal *et al.* (2018) and Chickez *et al*. (2021) found that post-harvest management practices increased market access among the farmers.

The sales prices of groundnuts per kilogram had a negative influence on low adoption at 10% and a positive influence on medium and high adoption at 5% and 10% significance levels, correlates with higher yields and better prices. High quality groundnuts with good colour, big size with minimum defects are preferred by consumers and processors. Driving up demand and increase in price, this implies that farmers get more income from quality groundnuts, enabling them to meet the cost of adopting the aflatoxin-inhibiting technologies. Increased income reduces cash constraints among farmers, thus enhancing the adoption of the technologies. Equally, Awotide *et al.* (2016) noted that an increase in income among rice farmers reduced the need for credit and thus increased the adoption of improved rice varieties in Nigeria.

Distance to the market was negatively correlated with low adoption, while positively correlated with medium and high adoption at 5% significance level. An increase in the distance by a kilometre was associated with increased adoption. A longer distance to the market implies an increase in transport cost. A possible explanation for this scenario is that as distance increases, farmers are likely to adopt the technologies for increased production and income to cater for the increased transport cost. This finding is consistent with those of Kinyangi (2014). On the contrary, Ayenew et al. (2020) found that high transport costs and poor roads to the market reduced the likelihood of adopting wheat technologies in Ethiopia.

4.4 To estimate the Effects of Aflatoxin-inhibiting Technologies on the Yield of Groundnuts Produced in Elgeyo Marakwet and Baringo Counties

Table 4.4.1 shows the findings on the effects of aflatoxin-inhibiting technologies on the yield of groundnuts produced. Productivity was measured as the number of shelled groundnuts produced in kilograms per acre. According to Table 4.41, farmers should be viewed from two scenarios: one, where farmers are adopters of low, medium, and high adopters; secondly, where farmers are non-adopters of each of the categories. The ATT and ATU were positive and negative, suggesting that some farmers realised increased productivity while others experienced losses depending on the adoption level adopted. Groundnut farmers were worse off by being in the low adoption category. For example, farmers reduced their production by (ATT) 78 Kgs by being at a low adoption level.

On the other hand, farmers increased their production by being in the medium and high adoption categories. Farmers reported maximum productivity for being in the medium adoption category (ATT 100 kgs). Similarly, high adopters increased their productivity by 41 kgs compared to the non-adopting households. The possible reason may be the selectiveness of the medium adopters when using technologies effectively. Adoption alone is enough, but selecting the most effective and timely application of the technologies is vital. For that reason, medium adopters outperform high adopters, seeing greater yield gains. Low adopters were worse off, emphasising the need for optimal uptake to improve outcomes This finding is supported by studies showing increased production due to the adoption of groundnut technologies (Konja, 2021; Vabi *et al.*, 2019). For counterfactual cases, households that adopted the aflatoxin-inhibiting technologies would have had both losses and higher productivity (ATU) had they not adopted them. For instance, the ATU of non-adopting households would have decreased by 140 kgs per acre if they were in the low adoption category. On the other hand, their productivity would have increased by 17 and 40 kgs per acre, respectively, had they not been in the medium and high adoption categories.

Table 4.4.1: ATT and ATU estimates of the OPESR model (Productivity*)*

Technologies Adoption	Scenario	Productivity of the actual scenario (a)	Productivity of counterfactual scenario (b)	Treatment effects ATT/ATU (a-b)	SE

Low	Adopter	456.55kg	534.77kg	ATT=-78.22kg***	10.84kg
	Non-adopter	436.63kg	577.33kg	ATU=140.70kgkg***	14.60kg
	Heterogeneity effect	19.92kg	-40.56kg	HE= 62.48kg	
Medium	Adopter	569.31kg	469.46kg	ATT= 99.85kg ***	18.72kg
	Non-adopter	414.65kg	474.92kg	ATU= -60.27kg***	17.11kg
	Heterogeneity effect	154.66kg		HE= 160.12kg	
High	Adopter	609.38kg	568.29kg	ATT= 41.09kg	36.280kg
	Non-adopter	528.59kg	488.40	ATU= 40.19***	10.2721
	Heterogeneity effect	80.79kg	119.89	HE=0.9	

***, ** denotes statistical significance at 1%, and 5% level, respectively

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides a summary, conclusions, and recommendations based on the specific objectives of the study. The study`s policy implications are for the adoption of multiple aflatoxin-inhibiting technologies in a country like Kenya. There is limited access to agricultural support services such as extension, labour, and inputs. To fill the gap and bring service closer to members, farmers' groups can play a very important role by providing greater knowledge and increasing awareness about technology, labour availability, and credit availability through farmers' cooperatives. The likelihood of adopting a full package of technologies leading to improved productivity. Expanding the credit delivery system when promoting the use of multiple agricultural technologies.

5.1 Summary of Technologies to Support Policy Making

For policy advice, prioritise integrated approaches (e.g., resistant seeds + Aflasafe GAPs proper drying) to achieve >95% control, with subsidies for smallholder groundnut farmers in Elgeyo Marakwet and Baringo Counties, Kenya. Ensure compliance with limits (e.g., 10-20 ppb per Codex/ regional standards).

These estimates support policy prioritisation of high-impact options to be selective and effective usage of these aflatoxin-inhibiting technologies like Aflasafe and resistant seeds and GAP, for >95% control, from aflatoxin-related issues in Elgeyo and Baringo Counties, Kenya.

Table 5.1: Technologies and their production relevance stages

Technology	Stage	Reference
Improved Resistant 70-90	Pre-harvest Seeds	Nunes *et al*. (2024), in Kenya.
GAP 62-94%	Pre-& Postharvest	Mdindikasi *et.al* (2024) in Kenya.
Aflasafe / Biopesticide 80-95%	Pre-harvest	Senghor (2020) in Senegal.
Drying Mats / Tarpaulins 50-80%	Post-harvest	Muitia *et al.* (2018) in Mozambique.
Polythene Bags 0-20%	Storage	Daba *et al.* (2023). Ghana and Uganda.
Mechanical Shelling 35-80%	Post-harvest	Sugri *et al*. (2024) in Ghana.

5.2 Conclusions

i. The findings revealed a mixed effect on the choice and adoption of different aflatoxin-inhibiting technologies. Access to extension and group membership showed a positive and significant impact across various aflatoxin-inhibiting technologies such as Drying, Mechanical shelling, hermetic storage, quality-resistant seeds, Aflasafe, and GAP. This indicates that extension and group membership enhance awareness and accelerate the decisions on the adoption of these technologies. Highlighting the importance of extension programs and social networks in promoting the adoption of aflatoxin-inhibiting technologies.

ii. The marginal effects analysis reveals that several socioeconomic, institutional, and technological factors significantly influence the likelihood of farmers being in low, medium, or high.

iii. Adoption categories of aflatoxin-inhibiting technologies. Older household heads and female-headed households are more likely to be low adopters. At the same time, education, farming experience, group membership, and use of improved groundnut varieties significantly increase the probability of being in medium and high adoption categories. Cost of technology, perceived usefulness, and market access (price and distance) also play essential roles in determining adoption levels.

iv. The adoption of aflatoxin-inhibiting technologies has a varied impact on groundnut productivity depending on the level of adoption. While low adoption levels result in reduced productivity, medium and high levels of adoption significantly enhance yield, with medium adopters benefiting the most. These findings underscore the importance of optimal adoption intensity to achieve maximum productivity gains.

5.3 Recommendations

i. Agricultural development programs should strengthen extension services and actively promote farmer group formation and participation to boost the adoption of aflatoxin-inhibiting technologies. By leveraging extension platforms and social networks, farmers can access timely information, share experiences, and build confidence in adopting a range of aflatoxin-inhibiting technologies such as drying, mechanical shelling, hermetic storage, quality-resistant seeds, Aflasafe, and Good agricultural practices.

ii. Policies should target key enablers such as farmer education, access to improved seed varieties, and group-based extension services to enhance the adoption of aflatoxin-inhibiting technologies.

iii. Interventions should also aim to reduce technology costs and improve market accessibility, to boost the technology adoption intensity, particularly for younger and female-headed households, who are more inclined toward higher adoption levels.

iv. Programs promoting aflatoxin-inhibiting technologies should focus on supporting groundnut farmers with technical support to be selective in choosing technologies that are more effective in reducing aflatoxin. Adoption alone is enough, but selecting the most effective and timely application of the technologies is vital. It requires proper training on effectively using the technologies to amplify their productivity. Addressing barriers such as cost, awareness, and access to inputs. Extension services should prioritise tailored interventions encouraging and facilitating adoption levels to maximise productivity, quality, and safeguard farmers' livelihoods.

5.4 Areas of Further Research

This study will contribute to the existing literature by identifying the key variables that affect the choice and extent of adopting technological packages involving aflatoxin-inhibiting technologies and their effects on groundnut productivity in Kenya. However, more research should be conducted to establish the factors that determine the choice and intensity of groundnut productivity to ascertain the effective and efficient use of aflatoxin-inhibiting technologies.

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APPENDICES

APPENDIX 1: QUESTIONNAIRE

My name is Buba Daffeh, a student at Egerton University pursuing a Master of Science Degree in Agribusiness Management. This survey aims to determine the **Effects of Aflatoxin-Inhibiting Technologies on the Marketability of Groundnuts in Elgeyo Marakwet and Bringo Counties.** You have been selected to participate in the study. Your participation in this survey is entirely voluntary and will be treated with the highest level of confidentiality, only to be used for research purposes. No right or wrong answer exists, and your responses are completely anonymous.

Questionnaire identification

Questionnaire Number …………………………………………………………………….
Sub-county …………………………………………..… Ward…………….……………….
Name of the respondent………………………….…. Tel contact……. …..…………….
Name of enumerator…………………………...…. Tel contact ....……………….
Date……………..… Start time………..……………… End time…………………………

Section A: Profile of the respondent

Kindly tick (✓) the appropriate box and write where necessary.

A1. Age in years……………………………………………………..

A2. Gender

Male [ ]   Female [ ]

A3. Household size (number of members in a household)............................. members

A4. How many years did you spend in school? ……….

No formal education (0 years in school) [ ]   Primary level education (1-8years) [ ]
Secondary level (9-12 years) [ ]   Tertiary level education (13-15years) [ ]

A5. Farming experience .... years

A6. What is your total household income per year .... KES.

A7. Farm size .... acres

A8. Land ownership system

Owned [ ]   Rented [ ]

A8. Are you a member in agricultural groups or cooperatives?

Yes [ ]   No [ ]

A9. Do you access credit for agricultural purposes?

Yes [ ]   No [ ]

A10. Do you apply fertilizer during groundnut production?

Yes [ ] No [ ]

A11. Do you have access to extension services?

Yes [ ] No [ ]

A12. What is the distance to nearest market in your community? .... Kilometres.

A13. What is the total land size for agriculture that you own? .... acres

A14. What proportion is allocated to groundnut production? .... acres.

A15. What varieties of groundnuts do you grow?

1…………………… 2……………………….. 3……………………………..

A16. Are they improved or traditional?

Improved [ ] Traditional [ ]

A17. What other crops do you grow? (list according to order of importance)

1……………………….. 2……………………………… 3…………………………

Section B: Characterization of aflatoxin-inhibiting technologies

B1. Have you ever heard of aflatoxins before?

Yes [ ] No [ ]

B2. From who or where did you hear about aflatoxin?

……………………………………………………………………………………………..

B3. Do you know any practices used to manage aflatoxins before?

Yes [ ] No [ ]

B4. If yes, list the practices/technologies used to manage aflatoxins before?

……………………………………………………………………………………………

……………………………………………………………………………………………

B5. Which aflatoxin-inhibiting technologies and innovations do you use? (you can tick more than one)

Drying technologies [ ] Irrigation technologies [ ]

Threshing [ ] Mechanical shelling [ ]

Hermetic storage bags (e.g., PICS bags) [ ] GAPs [ ]

Quality/resistant Seed Variety [ ] Biological agents [ ]

Other (please specify): ___________________________

B6. Have you ever been trained on the use of aflatoxin-inhibiting technologies?

Yes [ ] No [ ]

B7. For the technologies and innovations that you use, what is the buying price and maintenance cost?

Technology	Buying price/Cost of establishment (KES) per unit
Drying technologies	
Threshing	
Hermetic storage bags	
Mechanical shelling	
Quality seed/resistant variety	
Irrigation technologies	
Biological agents	
GAPs	
Others	

B8. Are these technologies and innovations easy to use, compatible with local conditions, useful in saving time and quality of groundnuts?

Technology	Easy to use (Indicate Yes or No)	Compatible with local conditions/whether (Indicate Yes or No)	Saves time (Indicate Yes or No)
Drying technologies			
Threshing			
Hermetic storage bags			
Mechanical shelling			
Quality seed/resistant variety			
Irrigation technologies			
Biological agents			
GAPs			
Others			

B9. Where do you get information about these technologies and innovations?

Technology	Source of information (Radio, TV, extension workers, Friends, government, NGOs, Agro-shops, others)
Drying technologies	
Threshing	
Hermetic storage bags	
Mechanical shelling	
Quality seed/resistant variety	
Irrigation technologies	

Biological agents (aflasafe)	
GAPs	
Others	

B10. Where do you source these technologies and innovations?

Technology	Source of technologies (Government, NGOs, Agro-shops/local market, others)
Drying technologies	
Threshing	
Hermetic storage bags	
Mechanical shelling	
Quality seed/resistant variety	
Irrigation technologies	
Biological agents	
GAPs	
Others	

Section C: Adoption Intensity.

C1. How many aflatoxin-inhibiting technologies and innovations do you use?

1-3 [ ] 4-6 [ ] above 6 [ ]

C2. What is the total volume of groundnut sold or marketed, processed using aflatoxin-inhibiting technologies and innovations?

………………………………………………………………………………………………

C3. Are there factors limiting the use of some of these technologies?

Technology	Factors (high cost, lack of awareness, lack of training, limited availability, others-specify)
Drying technologies	
Threshing	
Hermetic storage bags	
Mechanical shelling	
Quality seed/resistant variety	
Irrigation technologies	
Biological agents (Aflasafe)	
GAPs	
Others	

C4. Have you noticed any change in groundnut quality since you started using these technologies and innovations?

Yes [ ] No [ ]

Section D: Effects on marketability

D1. Do these technologies and innovations affect the physical qualities of your groundnuts?

Physical Quality	**0-No improvement 1-Moderate improvement 2-Significant improvement**
Shape	
Colour	
Insect damage	
Shrivelled	
Size	
Mold growth	

D2. Changes in volumes of groundnuts sold and not sold (as a result of poor physical qualities).

Period :- 2024 Last production Season	Yield per acre (Kg)	Volumes sold (Kg)	Volume retained (Kg) – poor quality	Price per Kg
Before adopting technologies				
After adopting technologies				

D4. Based on D1 and D2, has the physical qualities of your groundnuts improved?

Yes [ ] No [ ]

D5. Have these technologies and innovations affected your ability to access groundnuts markets.

Yes [ ] No [ ]

D6. Which markets do you access now that you were not accessing before adoption these technologies? (Tick)

Local markets [ ] Regional markets [ ] National markets [ ] Aggregators [ ]

No change [ ] Others…………….

D7. What improvements would you suggest about the existing technologies and innovations to enhance marketability of groundnuts?

………………………………………………………………………………………………

………………………………………………………………………………………………

…………………………………………………………………………………………

D8. Have buyers ever rejected your groundnuts before? If yes, was it before or during the adoption of these technologies?

……………………………………………………………………………………………….

D9. What were the reasons for the rejection of your groundnuts?

1……………………………………….. 2……………………………………………….

3……………………………………….. 4……………………………………………….

D10. Share any experiences regarding the use of agricultural technologies and innovations on management of aflatoxin contamination on marketability of groundnut?

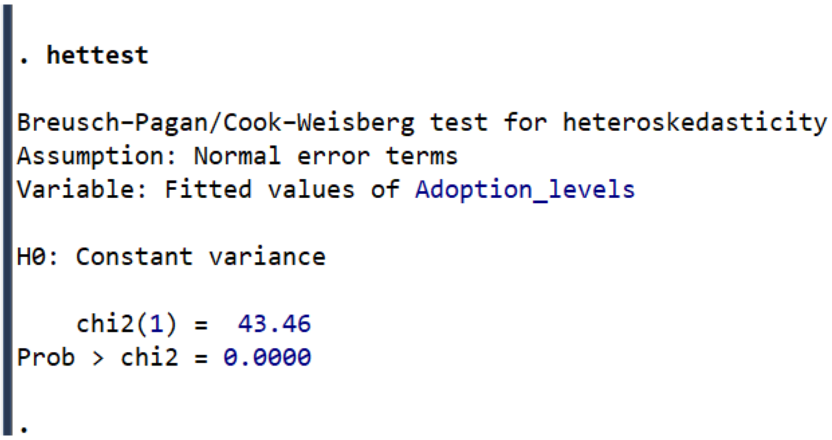
………………………………………………………………………………………………

………………………………………………………………………………………………

APPENDIX 2: DATA ANALYSIS OUTPUTS

Heteroscedasticity test

Presence of heteroscedasticity due to a significant p-value



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. hettest

Breusch-Pagan/Cook-Weisberg test for heteroskedasticity
Assumption: Normal error terms
Variable: Fitted values of Adoption_levels

H0: Constant variance

    chi2(1) =  43.46
Prob > chi2 = 0.0000

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Table 1: Simple falsification test for a valid instrument (Group membership)

Outcome (Productivity)	f-value	p-value
Levels of adoption		
Low	0.71	0.3992
Medium	1.86	0.1768
High	3.67	0.6720

Insignificant p values for productivity under different adoption levels indicate that group membership affects decision (low, medium and high adoption levels) and not the outcome variable (productivity).

Table 2: MVP estimates

Drying			Shelling		Hermetic storage		Resistant seeds		Alfla safe		GAP	
	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.	Coeff.	Std.
Age	-0.252	0.162	-0.257	0.340	-0.247	0.205	-0.588**	0.251	0.156	0.175	-0.308	0.190
Gender	-0.083	0.150	-0.561*	0.320	-0.063	0.183	-0.165	0.205	0.674***	0.188	0.013	0.172
Household size	0.042	0.037	-0.060	0.062	0.071	0.044	-0.121***	0.046	0.069***	0.041	-0.065	0.044
Income-Sal	-0.236	0.276	0.917**	0.439	-0.033	0.394	0.640*	0.358	0.252	0.312	0.849***	0.312
Education	-0.008	0.107	-0.176	0.174	0.156	0.145	-0.116	0.144	-0.003	0.122	0.015	0.131
Experience	0.014	0.010	-0.003	0.024	0.008	0.015	0.023	0.014	-0.017	0.012	0.009	0.012
income	-0.072	0.081	0.215	0.202	0.041	0.105	-0.344**	0.099	-0.250***	0.088	-0.193**	0.090
Group	-0.013	0.189	1.364***	0.406	0.846***	0.230	0.787***	0.209	0.037	0.219	0.722***	0.213
Fertilizer	0.126	0.216	-1.052*	0.562	-1.092***	0.402	-0.616**	0.261	0.140	0.255	-0.566**	0.286
Extension	0.598**	0.152	0.137	0.273	0.143	0.199	-0.153	0.196	0.811***	0.168	-0.085	0.177
Land size	-0.010	0.035	0.134***	0.043	0.025	0.054	0.110**	0.045	-0.105**	0.048	0.124***	0.043
Variety	0.041**	0.019	0.287	0.369	0.029	0.024	-0.029	0.023	0.037	0.024	-0.024	0.020
Distance	0.024*	0.014	-3.778**	1.519	0.079***	0.019	-0.033	0.022	-0.035*	0.021	0.002	0.018
_cons	0.237	0.650	-0.257**	0.340	-3.902***	0.846	0.591	0.759	-1.317*	0.713	-0.764	0.781

Number of observations

Prob > chi2 = 0.0000

Wald chi2(77) = 332.75

Log pseudolikelihood = -703.97686

***, **, * denotes significant at 1%, 2% and 10% respectively

Table 3: Determinants of adoption levels using ordered probit

	Coefficient	Standard errors
Age_	-0.681***	.147
Gender	0.778***	.161
Household size	0.052	.034
Farm income	0.375	.326
Off-farm income	0.415	.643
Education	0.218***	.109
Experience	0.056***	.009
Group	0.826***	.161
Fertilizer use	-0.382*	.231
Extension access	-0.124	.152
Cost	0.051**	.024
Land size	0.171	.17
Usefulness	0.42**	.214
Improved varieties	1.276***	.215
Price	0.007*	.004
Distance	0.028**	.014
cut1	6.343	1.028
cut2	7.73	1.039

Number of observations=384

Prob > chi2=000

Wald chi2(16) = 151.29

Log Pseudo R^2=0285

Log pseudo likelihood=-234.58024

***, **, * denotes significant at 1%, 2% and 10% respectively

Table 4: Marginal effects of the ordered probit model

	dy/dx	std.	dy/dx	std.	dy/dx	std.
	low		Medium		High	
Age	0.167***	0.034	-0.087***	0.020	-0.080***	0.017
Gender	-0.190***	0.036	0.099***	0.020	0.091***	0.020
Household size	-0.013	0.008	0.007	0.004	0.006	0.004

Farm income	-0.092	0.079	0.048	0.041	0.044	0.039
Off-farm income	-0.101	0.158	0.053	0.082	0.048	0.076
Education	-0.053**	0.027	0.028**	0.015	0.026**	0.013
Experience	-0.014***	0.002	0.007**	0.001	0.007***	0.001
Group	-0.202**	0.037	0.106***	0.021	0.097***	0.021
Fertilizer use	0.094*	0.056	-0.049	0.030	-0.045*	0.027
Extension access	0.030	0.037	-0.016	0.020	-0.015	0.018
Cost of technology	-0.012**	0.006	0.006**	0.003	0.006**	0.003
Land size	-0.042	0.042	0.022	0.022	0.020	0.020
usefulness	-0.103**	0.052	0.054**	0.027	0.049**	0.026
Improved variety	-0.312***	0.045	0.163***	0.026	0.149***	0.027
prices	-0.002*	0.001	0.001**	0.000	0.001*	0.000
Distance	-0.007**	0.003	0.004**	0.002	0.003**	0.002

***, **, * denotes significant at 1%, 2% and 10% respectively

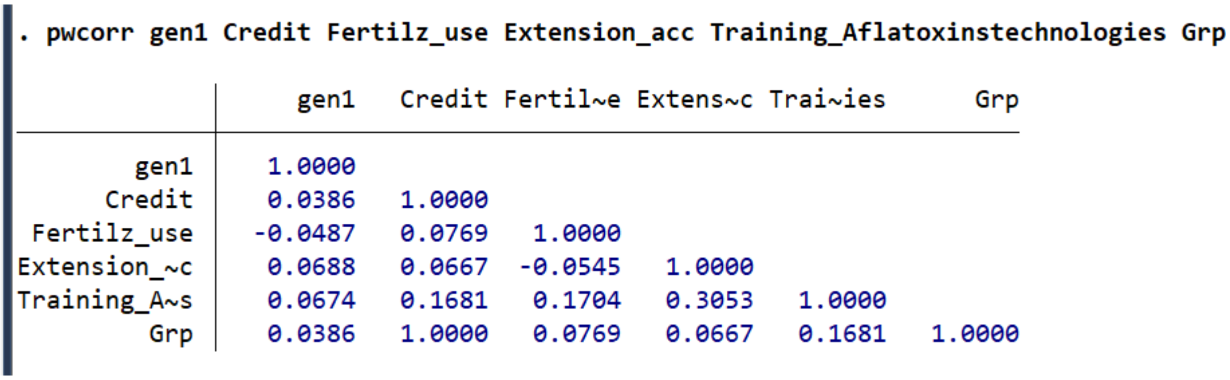
Table 5: ATT and ATU estimates of the OPESR model (Productivity)

Technologies Adoption	Scenario	Productivity of actual scenario (a)	Productivity of counterfactual scenario (b)	Treatment effects ATT/ATU a-b	SE
Low	Adopter	456.55	534.77	ATT=-78.22***	10.84
	Non-adopter	436.63	577.33	ATU= -140.70***	14.60
	Heterogeneity effect	19.92	-40.56	HE= 62.48	
Medium	Adopter	569.31	469.46	ATT= 99.85 ***	18.72
	Non-adopter	414.65	474.92	ATU= -60.27***	17.11
	Heterogeneity effect	154.66		HE= 160.12	
High	Adopter	609.38	568.29	ATT= 41.09	36.280
	Non-adopter	528.59	488.40	ATU= 40.19***	10.2721

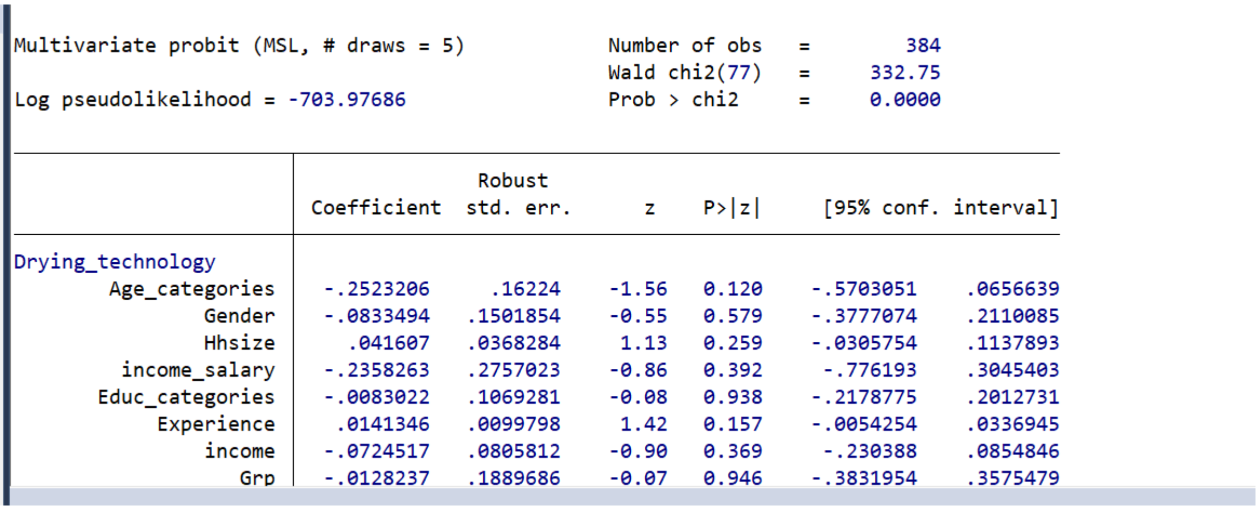
Heterogeneity effect	80.79	119.89	HE=0.9

***, ** denotes statistical significance at 1%, and 5% level

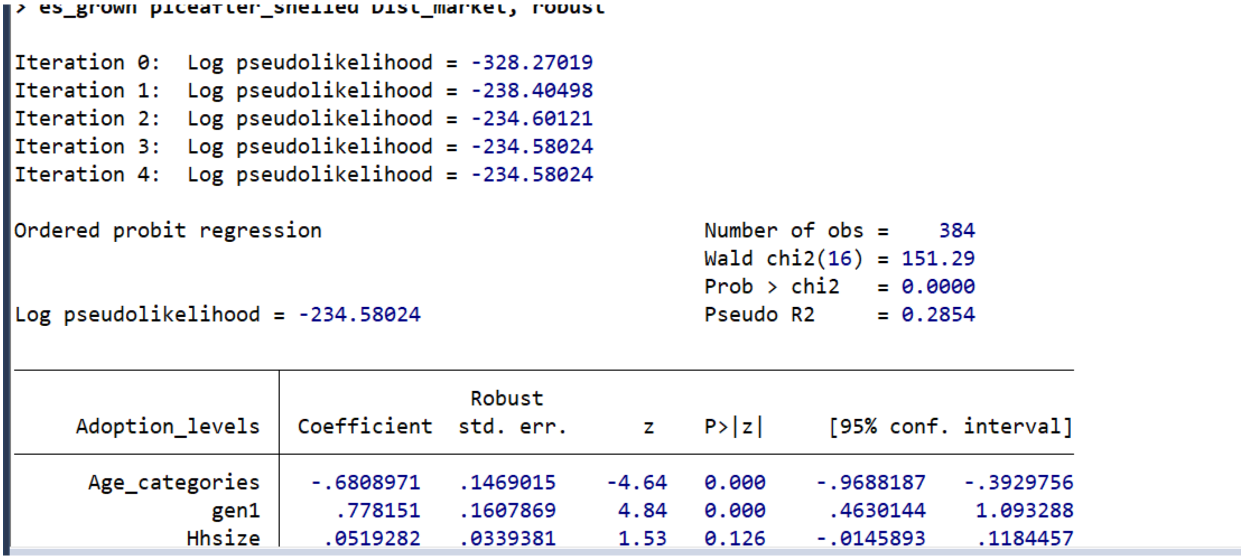
Pairwise correlation for categorical variables



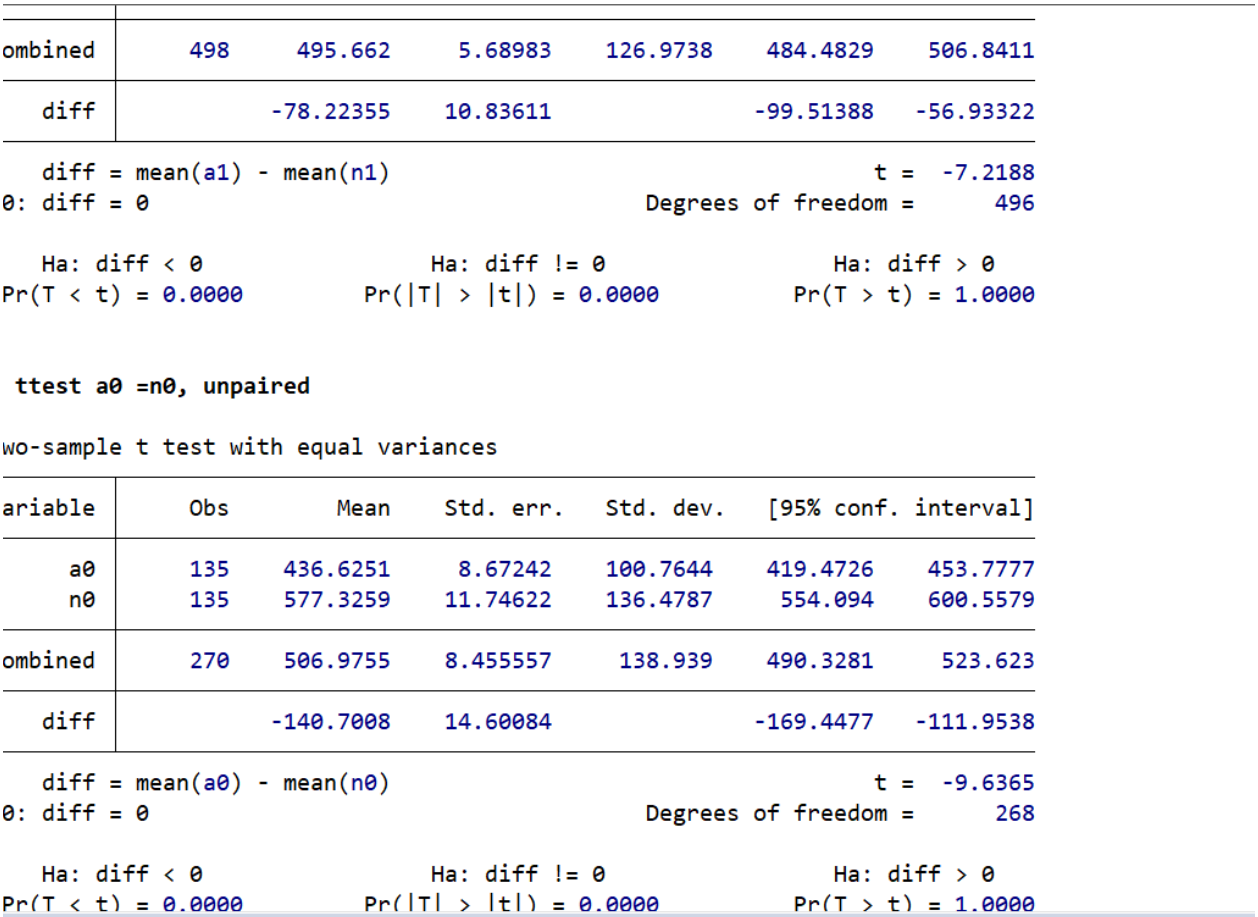
```
. pwcorr gen1 Credit Fertilz_use Extension_acc Training_Aflatoxinstechnologies Grp

             |     gen1   Credit Fertil~e Extens~c Trai~ies      Grp
-------------+------------------------------------------------------
        gen1 |   1.0000 
      Credit |   0.0386   1.0000 
 Fertilz_use |  -0.0487   0.0769   1.0000 
Extension_~c |   0.0688   0.0667  -0.0545   1.0000 
Training_A~s |   0.0674   0.1681   0.1704   0.3053   1.0000 
         Grp |   0.0386   1.0000   0.0769   0.0667   0.1681   1.0000 
```



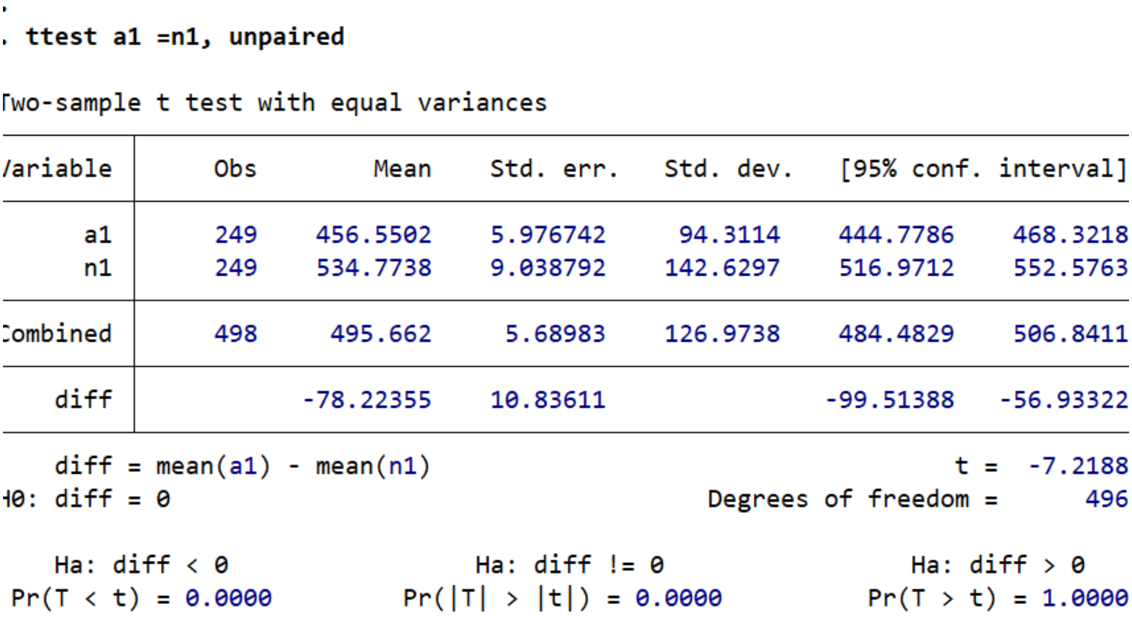
```
Multivariate probit (MSL, # draws = 5)           Number of obs    =        384
                                                 Wald chi2(77)    =     332.75
Log pseudolikelihood = -703.97686                Prob > chi2      =     0.0000

------------------------------------------------------------------------------
             |               Robust
             | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
Drying_technology |
Age_categories |  -.2523206     .16224    -1.56   0.120    -.5703051    .0656639
      Gender |  -.0833494   .1501854    -0.55   0.579    -.3777074    .2110085
      Hhsize |    .041607   .0368284     1.13   0.259    -.0305754    .1137893
income_salary |  -.2358263   .2757023    -0.86   0.392     -.776193    .3045403
Educ_categories |  -.0083022   .1069281    -0.08   0.938    -.2178775    .2012731
  Experience |   .0141346   .0099798     1.42   0.157    -.0054254    .0336945
      income |  -.0724517   .0805812    -0.90   0.369     -.230388    .0854846
         Grp |  -.0128237   .1889686    -0.07   0.946    -.3831954    .3575479
```



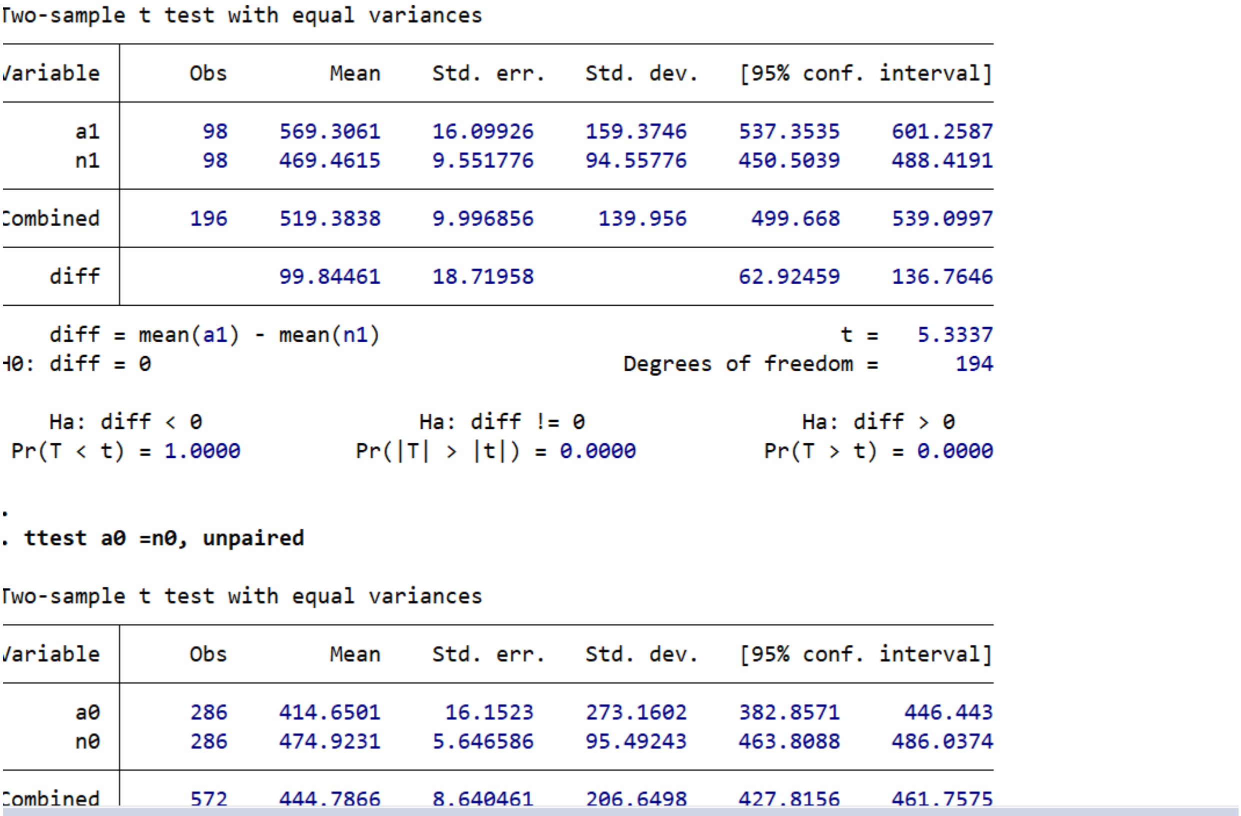
```
> es_grown pickafter_shelled Dist_market, robust

Iteration 0:  Log pseudolikelihood = -328.27019
Iteration 1:  Log pseudolikelihood = -238.40498
Iteration 2:  Log pseudolikelihood = -234.60121
Iteration 3:  Log pseudolikelihood = -234.58024
Iteration 4:  Log pseudolikelihood = -234.58024

Ordered probit regression                               Number of obs =    384
                                                        Wald chi2(16) = 151.29
                                                        Prob > chi2   = 0.0000
Log pseudolikelihood = -234.58024                       Pseudo R2     = 0.2854

------------------------------------------------------------------------------
             |               Robust
Adoption_levels | Coefficient  std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
Age_categories |  -.6808971   .1469015    -4.64   0.000    -.9688187   -.3929756
        gen1 |    .778151   .1607869     4.84   0.000     .4630144    1.093288
      Hhsize |   .0519282   .0339381     1.53   0.126    -.0145893    .1184457
```



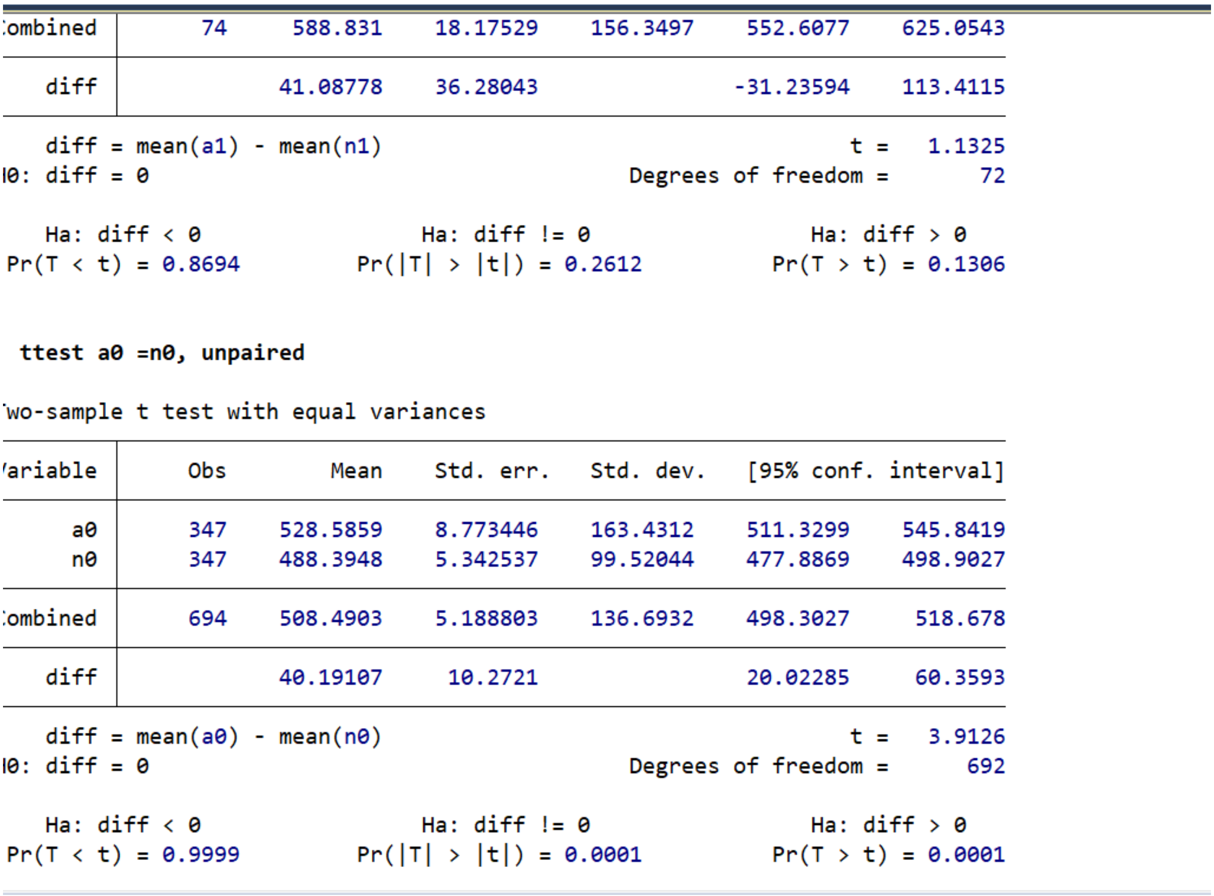
```
ombined │       498     495.662     5.68983    126.9738    484.4829    506.8411
────────┼────────────────────────────────────────────────────────────────────
   diff │             -78.22355    10.83611               -99.51388   -56.93322
────────┴────────────────────────────────────────────────────────────────────
   diff = mean(a1) - mean(n1)                                      t =  -7.2188
0: diff = 0                                       Degrees of freedom =      496

   Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000


 ttest a0 =n0, unpaired

wo-sample t test with equal variances
────────┬────────────────────────────────────────────────────────────────────
ariable │     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
────────┼────────────────────────────────────────────────────────────────────
     a0 │     135    436.6251     8.67242    100.7644    419.4726    453.7777
     n0 │     135    577.3259    11.74622    136.4787     554.094    600.5579
────────┼────────────────────────────────────────────────────────────────────
ombined │     270    506.9755    8.455557     138.939    490.3281     523.623
────────┼────────────────────────────────────────────────────────────────────
   diff │             -140.7008    14.60084               -169.4477   -111.9538
────────┴────────────────────────────────────────────────────────────────────
   diff = mean(a0) - mean(n0)                                      t =  -9.6365
0: diff = 0                                       Degrees of freedom =      268

   Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



```
.
. ttest a1 =n1, unpaired

Two-sample t test with equal variances
────────┬────────────────────────────────────────────────────────────────────
/ariable │     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
────────┼────────────────────────────────────────────────────────────────────
     a1 │     249    456.5502    5.976742     94.3114    444.7786    468.3218
     n1 │     249    534.7738    9.038792    142.6297    516.9712    552.5763
────────┼────────────────────────────────────────────────────────────────────
Combined │     498     495.662     5.68983    126.9738    484.4829    506.8411
────────┼────────────────────────────────────────────────────────────────────
   diff │             -78.22355    10.83611               -99.51388   -56.93322
────────┴────────────────────────────────────────────────────────────────────
   diff = mean(a1) - mean(n1)                                      t =  -7.2188
H0: diff = 0                                      Degrees of freedom =      496

   Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 1.0000
```



```
Two-sample t test with equal variances
------------------------------------------------------------------------------
 ariable |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
      a1 |      98    569.3061    16.09926    159.3746    537.3535    601.2587
      n1 |      98    469.4615    9.551776    94.55776    450.5039    488.4191
---------+--------------------------------------------------------------------
 ombined |     196    519.3838    9.996856     139.956     499.668    539.0997
---------+--------------------------------------------------------------------
    diff |            99.84461    18.71958                62.92459    136.7646
------------------------------------------------------------------------------
    diff = mean(a1) - mean(n1)                                    t =   5.3337
0: diff = 0                                      Degrees of freedom =      194

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000

.
. ttest a0 =n0, unpaired

Two-sample t test with equal variances
------------------------------------------------------------------------------
 ariable |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
      a0 |     286    414.6501     16.1523    273.1602    382.8571     446.443
      n0 |     286    474.9231    5.646586    95.49243    463.8088    486.0374
---------+--------------------------------------------------------------------
 ombined |     572    444.7866    8.640461    206.6498    427.8156    461.7575
```



```
ombined |        74     588.831    18.17529    156.3497    552.6077    625.0543
---------+--------------------------------------------------------------------
    diff |             41.08778    36.28043               -31.23594    113.4115
------------------------------------------------------------------------------
    diff = mean(a1) - mean(n1)                                    t =   1.1325
0: diff = 0                                      Degrees of freedom =       72

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.8694         Pr(|T| > |t|) = 0.2612          Pr(T > t) = 0.1306


 ttest a0 =n0, unpaired

wo-sample t test with equal variances
------------------------------------------------------------------------------
ariable |     Obs        Mean    Std. err.   Std. dev.   [95% conf. interval]
---------+--------------------------------------------------------------------
      a0 |     347    528.5859    8.773446    163.4312    511.3299    545.8419
      n0 |     347    488.3948    5.342537    99.52044    477.8869    498.9027
---------+--------------------------------------------------------------------
ombined |     694    508.4903    5.188803    136.6932    498.3027     518.678
---------+--------------------------------------------------------------------
    diff |             40.19107     10.2721                20.02285     60.3593
------------------------------------------------------------------------------
    diff = mean(a0) - mean(n0)                                    t =   3.9126
0: diff = 0                                      Degrees of freedom =      692

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9999         Pr(|T| > |t|) = 0.0001          Pr(T > t) = 0.0001
```

APPENDIX 3: PUBLICATION ABSTRACT

Factors Influencing the Choice of Aflatoxin-inhibiting Technologies Among Smallholder Groundnut Farmers in Elgeyo Marakwet and Baringo Counties in Kenya

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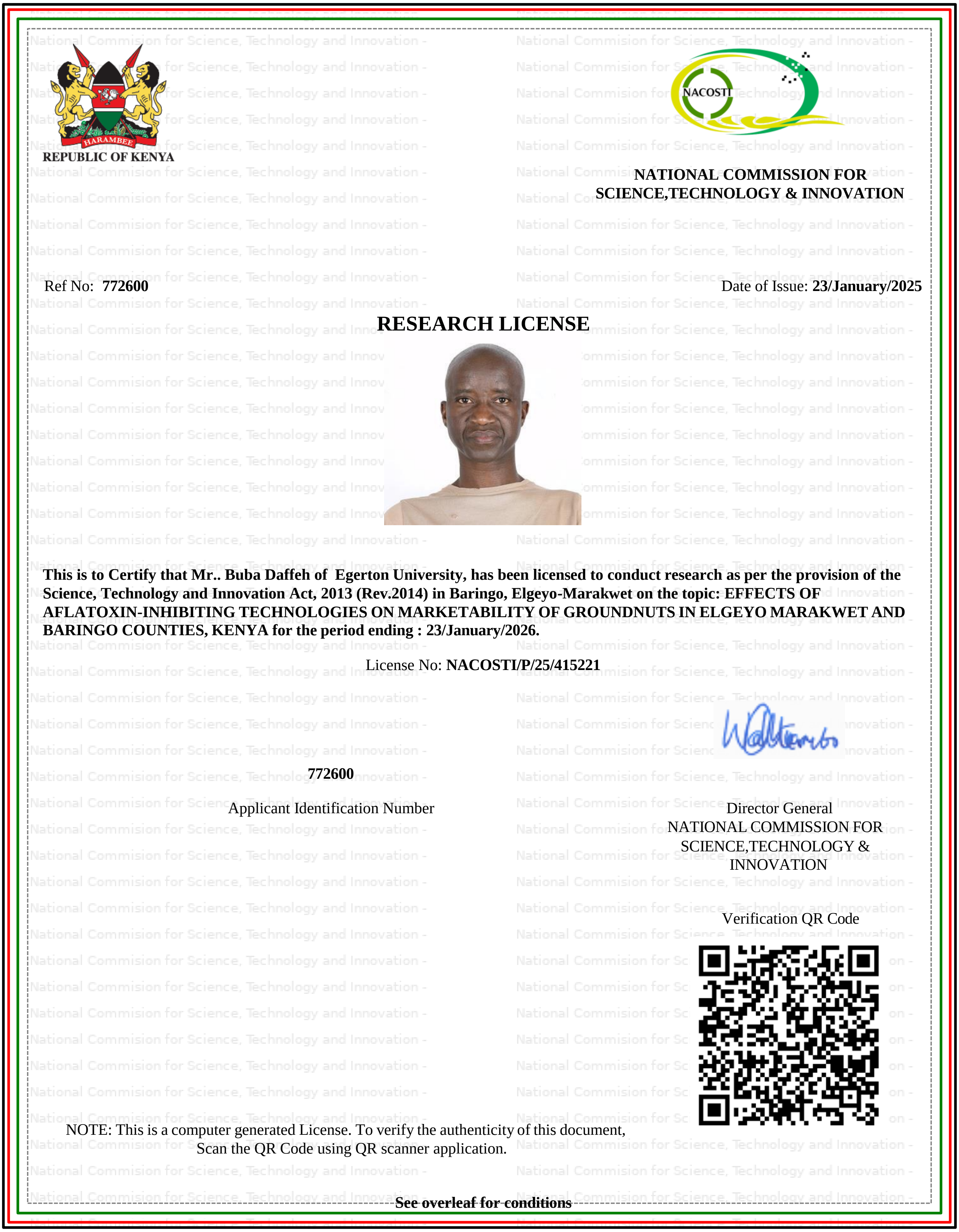
[2]Department of Agricultural Economics and Agribusiness Management, and Department of Crops, Horticulture and Soils, Faculty of Agriculture, Egerton University, Egerton - Njoro, Kenya

Abstract

Access and use of Aflatoxin-inhibiting technologies among smallholder farmers can improve their livelihoods and reduce post-harvest losses due to Aflatoxin contamination. However, the use of technologies including drying technologies, shelling, hermetic storage, resistant seeds, Aflasafe, and Good Agricultural Practices (GAP) remains low among smallholder groundnut farmers. This study assesses the factors influencing the choice of Aflatoxin-inhibiting technologies for increased production and marketability of groundnuts in farming households. Data analysis was conducted using SPSS and STATA 18. Descriptive statistics were used to examined current practices, while a multi-stage sampling approach was used to select 384 smallholder farmers from Elgeyo Marakwet and Baringo Counties in Kenya. A multivariate probit model was used to determine the factors influencing the choice of Aflatoxin inhibiting technologies. The study highlights that farmers' decision to adopt Aflatoxin-inhibiting technologies was significantly influenced by gender, sales price, group membership, fertiliser use, household size, land size, household income, extension access, use of improved groundnut varieties and distance to market. The study provides insights into the dynamics of adoption of Aflatoxin-inhibiting technology. It underscores the need for strengthening group membership, extension service delivery and social network programs for farmer information dissemination to promote adoption and enhance agricultural productivity to improve the livelihoods of smallholder farmers in Kenya.



REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **772600**

Date of Issue: **23/January/2025**

RESEARCH LICENSE

This is to Certify that Mr.. Buba Daffeh of Egerton University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Baringo, Elgeyo-Marakwet on the topic: EFFECTS OF AFLATOXIN-INHIBITING TECHNOLOGIES ON MARKETABILITY OF GROUNDNUTS IN ELGEYO MARAKWET AND BARINGO COUNTIES, KENYA for the period ending : 23/January/2026.

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EU/RE/DIR/009

***Approval No. EUISERC/APP/393/2025 20th February* 2025**

Buba Daffeh
P.O.Box 536-20115,
Egerton- Njoro, Kenya
Telephone +254745947914/ +2203014199
Email: daffehb3@gmail.com

Dear Buba,

RE: ETHICAL APPROVAL: EFFECTS OF AFLATOXIN-INHIBITING TECHNOLOGIES ON MARKETABILITY OF GROUNDNUTS IN ELGEYO MARAKWET AND BARINGO COUNTIES, KENYA

This is to inform you that the ***Egerton University Institutional Scientific and Ethics Review Committee*** has reviewed and approved your above research proposal. Your application approval number is ***EUISERC/APP/393/2025.*** The approval period is ***20th February 2025 – 21st February 2026***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***Egerton University Institutional Scientific and Ethics Review Committee***.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affect safety or welfare of study participants and others or affect the integrity of the research must be reported to ***Egerton University Institutional Scientific and Ethics Review Committee*** within 72 hours.

v. Clearance for Material Transfer of biological specimens must be obtained from relevant institutions.

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vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal. vii. Submission of an executive summary report within 90 days upon completion of the study to ***Egerton University Institutional Scientific and Ethics Review Committee***.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely.

20/02/2025

Prof. Kennedy N. Ondimu PhD
CHAIRMAN, EUISERC
KNO/BK/