Impact of agricultural extension services on the technical efficiency of adopters and non-adopters of genetically modified maize in the Eastern Cape Province.

by

Athenkosi Ngqulana (224195341)

Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Agriculture (Agricultural Extension)

in the

Discipline of Agricultural Extension and Rural Resource Management

School of Agriculture and Science

College of Agriculture, Engineering, and Science

University of Kwa-Zulu Natal

Pietermaritzburg

South Africa



Supervisor: Prof O. I. Oladele

Co-supervisor: Dr L. Mdoda

August 2026

DEDICATION

I dedicate this thesis to my late brother, Songezo Ngqulana. Your memory lives in our hearts, and your presence continues to guide and inspire us every day. You will forever be cherished and deeply missed, Dosini. We will always love you, Ngcwina.

DECLARATION 1: PLAGIARISM

Institution: University of KwaZulu-Natal

I, **Athenkosi Ngqulana,** hereby declare that:

I. This thesis is my own original work. It has been prepared in accordance with the institution's requirements and has not been submitted previously to another institution for a degree or otherwise.

II. All sources, data, and references used in this thesis have been duly acknowledged and cited properly.

III. I have obtained the necessary permissions for the inclusion of third-party content where applicable.

I affirm that this declaration is made with full integrity and in compliance with the institution's policies and procedures.

Candidates Signature

Full Names: ATHENKOSI NGQULANA

Signature:- [redacted]

Date: 21 April 2026

As the candidates' supervisors, Prof Oladimeji Idowu Oladele and Dr. Lelethu Mdoda, we agree to the submission of this dissertation:

[redacted]

Prof O.I. Oladele (Supervisor)

Date: 21 April 2026

[redacted]

Dr L. Mdoda (Co-supervisor)

Date: 21 April 2026

DECLARATION 02: PUBLICATION

This section presents manuscripts published and under review.

Manuscript 1- Chapter 2 (Published)

Ngqulana, A., Oladele, O.I., Nontu, Y., Mdiya, L. and Mdoda, L., 2025. A systematic review on enhancing the technical efficiency of genetically modified maize adoption in Sub-Saharan Africa: the role of agricultural extension services and barriers to success. *Frontiers in Sustainable Food Systems*, *9*, p.1609417.

Manuscript 2- Chapter 3 (Under Review)

Ngqulana, A. Oladele, O.I., Mdoda, L., Determinants and Intensity of GM Maize Seed Use among Maize Farmers in the Eastern Cape Province, South Africa.

Manuscript 3- Chapter 4 (Accepted for Publication)

Ngqulana, A., Oladele, O.I., Mdoda, L., Assessing the Productivity Effects of Agricultural Extension on Smallholder Maize Efficiency through a Meta-Frontier and Endogenous Switching Framework in the Eastern Cape Province, South Africa.

Manuscript 4- Chapter 5 (Accepted for Publication)

Ngqulana, A., Oladele, O.I., Mdoda, L., Unpacking Smallholder Maize Farmers' Preferences for Genetically Modified Maize Seeds in the Eastern Cape Province, South Africa.

Manuscript 5- Chapter 6 (Under Review)

Ngqulana, A., Oladele, O.I., Mdoda, L., Productivity-Profitability Trade-offs and the Welfare Effects of GM Maize Adoption: Evidence from Smallholder Systems in the Eastern Cape Province, South Africa.

Manuscript 6- Chapter 7 (Under Review)

Ngqulana, A., Oladele, O.I., Mdoda, L., Sindesi, O.A., Genetically Modified Maize Seed Adoption on Input Elasticities and Productivity among Smallholder Farming Systems: Insights from Eastern Cape Province, South Africa.

ACKNOWLEDGEMENTS

Firstly, I would like to thank our Lord Jesus Christ for the opportunity. I extend my sincere gratitude to my supervisors, Prof. O.I. Oladele and Dr. Mdoda, for their unwavering guidance and support throughout this study. Your dedication, patience, and insightful supervision made this work possible, and I am truly thankful for your invaluable contribution.

To my parents, Makabongwe Phillipson Ngqulana and Nobantu Aurelia Ngqulana, thank you for your love and continued support throughout my studies.

To my family, Amanda Ngqulana, Ntando Ngqulana, Lwando Ngqulana, Nomvuzo Ngqulana, thank you so much for your support you have provided me.

I would like to express my heartfelt appreciation to my friends, Masibulele Bavu, Olwethu Sindesi and Sonwabile Mbuweni for the unwavering support and encouragement you have given me throughout this journey.

I also extend my sincere gratitude to the Department of Agriculture, Eastern Cape, for their support and contribution to the success of this study.

To my friends and everybody who supported me and contributed to the success of this thesis, thank you.

ABSTRACT

Maize (Zea Mays) is one of the most widely grown cereals and is consumed worldwide. In South Africa, maize is grown for various purposes, which include animal feed such as silage and grains, poultry and pig feed, and human consumption, as grains, sweet maize, and grain maize. Despite its importance, maize productivity remains low due to poor seed quality, pest and disease susceptibility, climate variability, limited access to high-quality inputs, inequitable allocation of resources, inadequate extension services, and suboptimal farm management. Genetically modified (GM) maize seeds have been developed to improve production, resilience, and overall farm performance; however, their adoption remains inconsistent. Smallholder farmers often prefer the use of traditional seed varieties, which tend to perform poorly under the harsh conditions of the Eastern Cape. Hence, this study evaluated the impact of agricultural extension services on the technical efficiency of adopters and non-adopters of genetically modified maize across Chris Hani District and OR Tambo District Municipality using a quantitative approach. A multistage sampling method was used to collect data from 306 maize farmers using a semi-structured questionnaire. The descriptive statistics of the overall sample revealed a predominance of female participants (56.9%), with an average age of 61 years, 7 years spent at school, managing about 8 hectares, and an average income of ZAR 6637.52. The average farm size reported in this study reflects the total land that farmers had access to for cultivation rather than land ownership. This includes land that was borrowed or leased from relatives and other landowners, as well as larger landholdings accessed by beneficiaries of the government's land reform programme.

Only 6.2% were formerly employed, 19.3% self-employed, 34.0% unemployed, and 40.5% retired, with an average household size of 9.14. The probit model indicated several significant variables that affected GM adoption, such as gender, years spent in school, marital status, household size, household monthly income, land size, access to extension services, and amount of credits, which positively influenced the adoption of GM maize seeds by farmers, while distance to markets was negatively associated with the adoption of GM seeds. The truncated regression model revealed that household size, household income, land size, and amount of credits positively

influenced adoption intensity; distance to markets was negatively associated with the intensity of adoption of GM maize seeds by farmers.

Using the stochastic frontier analysis, Meta-Frontier, and Endogenous Switching, the study further evaluated the productivity effects of agricultural extension on smallholder maize efficiency. The findings revealed that agricultural extension services significantly enhanced maize productivity, with an average yield gain of 0.81 tonnes per hectare. Farmers with access to extension operated closer to the production frontier and exhibited higher technical efficiency than non-participants, with a mean efficiency level of 77%, indicating room for improvement. The study further delved into unpacking Smallholder Maize Farmers' Preferences for Genetically Modified Maize Seeds in the study area. The findings revealed that farmers' seed choices included GM (HT/BT) at 38.6%, GM (BT) at 26.8%, and traditional maize at 35.0%. While Multinomial Regression Logistic results revealed that household age, education, income, years of maize farming, and organizational membership positively influenced both GM (HT/BT) and GM (BT) selection. In contrast, extension services and credit access influenced GM (HT/BT) adoption only, and this might be because it offers combined herbicide tolerance and insect resistance, making it a more comprehensive technology package. Furthermore, the study looked at the productivity-profitability trade-offs and the welfare effects of GM Maize in the study area. The propensity score matching revealed that adopters consistently achieved higher maize yields compared to non-adopters of GM technology, with increases of 2.1 tons/ha (Nearest Neighbor) and 2.25 tons/ha (Kernel). Lastly, the study evaluated the adoption of genetically modified maize seed on input elasticities and productivity among Smallholder Farming Systems. The Cobb-Douglas Stochastic Production Frontier (SPF) model revealed that SPF results indicated that adopters revealed significantly higher input elasticities for seed (0.40, $p < 0.01$) and fertiliser (0.20, $p < 0.01$), while non-adopters showed limited responsiveness to modern inputs.

Technical efficiency was markedly higher among adopters (TE = 0.75) than among non-adopters (TE = 0.60), with adopters operating under constant returns to scale and non-adopters under decreasing returns to scale. These findings demonstrate that GM maize adoption enhances input efficiency, boosts productivity, and provides a pathway for sustainable intensification of smallholder maize systems. Based on these key

findings, the study recommends that strengthening agricultural extension systems through mobile-based platforms, tailored knowledge dissemination, and inclusive targeting of resource-constrained farmers can significantly narrow efficiency gaps and promote sustainable intensification. Furthermore, the study emphasises introducing context- and variety-specific policies, strengthening extension services and farm organizations, engaging experienced farmers as lead farmers, and developing subsidies and microcredit schemes to enhance the choice of GM maize seed selection by farmers. Lastly, the results provide policymakers and agricultural extension personnel with evidence to design effective input support, extension, and technology dissemination programs.

The results provide policymakers and agricultural extension personnel with evidence to design effective input support, improve access to inputs, strengthen extension services, and enhance technology dissemination programs. This should involve the inclusion of public-private partnerships (PPP) models to address the high extension-to-farmer ratios and issue of funding, whereby government collaborates with private seed companies, non-governmental organisations, research institutions, and farmer organisations to co-finance and deliver extension services.

Keywords: Agricultural Extension services, technical efficiency, GM maize seeds, Eastern Cape Province, Input Elasticities, Maize Productivity, and Smallholder Farming.

Contents

DECLARATION 1: PLAGIARISM ..... **ii**

DECLARATION 02: PUBLICATION ..... **iii**

ACKNOWLEDGEMENTS ..... **iv**

ABSTRACT ..... **v**

List of Tables ..... **xiv**

LIST OF ACRONYMS ..... **xvii**

CHAPTER 1 INTRODUCTION: 1.1 Background of the study **1**

1.2 Problem Statement 7

1.3 Main Objective of the Study 13

Specific Objectives 13

1.4 Research Questions 13

1.5 Justification of the Study 14

1.6 Study Assumptions 17

1.7 Organization of the thesis 17

References 19

CHAPTER 2: A Systematic Review on Enhancing the Technical Efficiency of Genetically Modified Maize Adoption in Sub-Saharan Africa: The Role of Agricultural Extension Services and Barriers to Success **28**

Abstract 28

2.1 Introduction 29

2.2 Methodology 31

2.3 Results and Discussion 33

2.3.3 Overview of maize production in sub-Saharan Africa 37

2.3.4 Overview of extension services in sub-Saharan Africa 38

2.3.5 Genetically Modified Maize in Sub-Saharan Africa 40

Resistance to insect pests 42

Improved productivity 43

Reduced pesticide use 43
Ecosystem impacts and reduced herbicide usage 44
Reducing postharvest losses 44
2.3.6 Challenges of GM maize adoption in sub-Saharan Africa 44
Stringent national regulations 45
Accessibility of GM crops 45
Biosafety concerns 46
Regulations and policies 46
Human health concerns 46
Public perception and acceptance 47
High seed and labour costs 47
Limited knowledge of GM maize 47
Limited availability, poor labelling, and knowledge gaps 48
Stakeholder perspectives on GM maize adoption 48
Cultural, Spiritual, and Environmental Concerns Regarding GM Crops 49
GM Maize: Food Security versus Potential Risks 49
Environmental and medical benefits of GM maize 50
GM maize and simplified farm management 50
2.3.7 Technical efficiency in agriculture 50
Production factors influencing the technical efficiency of maize farmers 50
Technical inefficiency variables affecting maize production 52
Role of extension services in enhancing efficiency 55
Impact of extension services on adopters of GM maize in sub-Saharan Africa 56
2.3.8 Barriers to adoption and efficiency gains from the adoption of GM maize 58
2.4 Limitations of the review 60
2.5 Summary of key findings 60
2.6 Recommendations for future research 61

2.7 Authors Contributions 61
2.8 Funding 61
2.9 Conflict of Interest 61
2.10 Generative AI statement 62
2.11 Publisher's note 62
References 62
CHAPTER 3: Determinants and Intensity of GM Maize Seed Use among Maize Farmers in the Eastern Cape Province, South Africa 74
Abstract 74
3.1 Introduction 75
3.2 Theoretical Framework 80
3.3 Research Methodology 84
3.3.1 Description of the Study Area 84
3.3.2 Sampling Procedure, Size, and Frame 86
3.3.2 Data Collection 88
3.3.3 Data analysis 89
Model Specification 89
3.3.4 Data 92
3.4 Results and Discussion 94
3.4.1 The Demographic Characteristics of adopters and non-adopters of GM maize seeds in Eastern Cape Province. 94
3.4.2 The Distribution of Maize Seed Types Among Sampled Farmers in the Study Area 98
3.4.3 Reasons for Adopting GM Maize Seeds by Farmers in the Eastern Cape Province 99
3.4.4 Sources of Information for GM maize of smallholder Farmers in the Eastern Cape Province 100
3.4.5 Challenges to the adoption of GM maize seeds by Smallholder farmers in the study area 101

3.4.6 Factors influencing the adoption decision of GM maize seeds by smallholder maize farmers in the Eastern Cape Province 102

3.4.6 Factors influencing the intensity of GM maize seeds by smallholder farmers in the Eastern Cape Province. 106

3.5 Conclusion and Recommendations 108

References..... 111

CHAPTER 4: Assessing the Productivity Effects of Agricultural Extension on Smallholder Maize Efficiency through a Meta-Frontier and Endogenous Switching Framework in the Eastern Cape Province, South Africa..... 120

Abstract 120

Access to agricultural extension services 132

Stage 2: Stochastic Frontier Analysis for agricultural extension participants and non-participants. 133

4.4.1 The Demographic characteristics of maize farmers in the Eastern Cape Province..... 139

4.4.2 Types of Agricultural Extension Services Provided in the Study Area 143

4.4.3 Methods of Communication Used by Agricultural Extension Services.... 144

4.4.4 Practices adopted by Maize Farmers due to Agricultural Extension Services in the Eastern Cape Province. 145

4.4.5 Agricultural extension services Providers in the Study Area..... 146

4.4.6 Perceived Quality of Agricultural Extension Services Received by Farmers 147

4.4.7 Diagnostic Tests and Model Validation..... 148

4.4.8 Stage 1: Factors Influencing Access to Agricultural Extension Services by Maize Farmers in the Eastern Cape Province. 149

4.4.9 Analysing the technical efficiency of maize farmers in the Study Area ... 153

4.4.10 Analysis of Technical Inefficiency Model Parameters..... 155

4.4.11 The Technical Inefficiency Scores of Maize Farmers 158

4.4.12 Impact of Agricultural Extension Services on Maize Productivity of Maize Farmers in Eastern Cape Province 159
4.4.13 Test of mean technical efficiency 162
4.5 Conclusion and Recommendations 165
Ethical Considerations 167
Study Limitations 168
Future Research 168
Acknowledgement 168
Author contributions 168
Funding 169
Data Availability 169
Conflict of interest 169
Reference 169
CHAPTER 5: Unpacking Smallholder Maize Farmers' Preferences for Genetically Modified Maize Seeds in the Eastern Cape Province, South Africa 181
Abstract 181
Model Specification 193
5.2.6 Data 194
5.3 Results and Discussion 196
5.4 Conclusion and Recommendations 202
References 203
CHAPTER 6: Productivity-Profitability Trade-offs and the Welfare Effects of GM Maize Adoption: Evidence from Smallholder Systems in the Eastern Cape Province, South Africa 209
Abstract 209
6.2 Conceptual Framework 213
6.3 Methodology 215
6.3.5 Data 221

6.4 Results and discussion 223

6.4.1 Demographic Characteristics of the farmers in the study area 223

References 229

CHAPTER 7: Genetically Modified Maize Seed Adoption on Input Elasticities and 235

Productivity among Smallholder Farming Systems: Insights from Eastern Cape Province, South Africa 235

References 261

CHAPTER 8: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS 270

Constituents of the Philosophy of the PhD 274

Appendix I: Questionnaire 279

Appendix II: Ethical Clearance 287

List of Tables

Table 2.1: Smallholder Farm Typologies in sub-Saharan Africa 36
Table 2.2: Impact of agricultural extension services by country. 39
Table 2. 3: Adoption trends of genetically modified maize in sub-Saharan Africa 40
Table 2.4: Benefits of adoption of GM maize in sub-Saharan Africa 42
Table 2.5: Challenges to GM maize adoption reported in reviewed studies..... 45
Table 2.6: Stakeholders' perspectives on GM maize adoption..... 48
Table 2.7: Production factors utilized by smallholder farmers 51
Table 2.8: Showing factors affecting the technical inefficiency of maize farmers 52
Table 2.9: Role of extension services in enhancing the technical efficiency of farmers 55
Table 2.10: Illustrating the Impact of Extension Services on GM Maize Adopters ... 57
Table 2.11: Constraints to the adoption of GM maize and efficiency gains 58

Table 3.1: Showing maize production from 2014/15 to 2022/23 production seasons in South Africa..... 77
Table 3.2: Description of Study Variables and Expected Outcomes of Explanatory variables used in the Double Hurdle Model to analyze the adoption intensity of GM maize by smallholder farmers in the Eastern Cape Province 93
Table 3.3: Demographic characteristics of GM maize seed adopters and nonadopters. 96
Table 3.4: Distribution of maize seed types among sampled farmers (n = 306)..... 98
Table 3.5: Sources of Information for GM maize seed by maize farmers..... 101
Table 3.6: Factors influencing the adoption decision of GM maize seeds by smallholder maize farmers 103
Table 3.7: Factors affecting the intensity of GM maize seed use by smallholder farmers in the Eastern Cape Province..... 106

Table 4.1: Description of Study Variables and Expected Outcomes of Explanatory variables used in the logit regression, Stochastic Frontier Analysis, and Endogeneity Switching Regression [ESR] model..... 137
Table 4.2: Descriptive statistics of continuous socio-economic characteristics of maize farmers 142

Table 4.3: The Types of Services Provided in the Study Area 143
Table 4.4: Practices Adopted by Maize farmers because of Agricultural Extension Services 146
Table 4.5: Diagnostic Evaluation of the Logit Model..... 148
Table 4.6: Factors Influencing Access to Agricultural Extension Services in the Study Area..... 149
Table 4.7: Technical efficiency of maize farmers in the Study Area 153
Table 4.8: Maximum likelihood estimation results of the technical inefficiency model variables. 156
Table 4.9**:** Analysis of Technical Efficiency Distribution 159
Table 4.1 10: Average treatment effects using an endogenous switching regression model. 160
Table 4.11: Test of the significant difference in mean technical efficiencies between access to agricultural extension services and non-access to AES for maize farmers. 162
Table 4.12: Technology Gap Ratio (TGR) and Meta-Frontier Technical Efficiency (MFTE) by Farmer Group 164

Table 5.1: Summary of variables used in the Multinomial Regression Model 195
Table 5.2: The factors influencing the GM maize seed selection choices in the study area 199

Table 6.1: Illustrating the distribution of Maize production by provinces from 2014/15 to 2019/20 production season (Tons)..... 211
Table 6.2: Data collected from maize farmers in the study area 221
Table 6.3: Demographic characteristics of maize farmers in the study area 224
Table 6.4: Effect of GM Maize Seed Adoption by Smallholder Maize Farmers 226

Table 7.1: Demographic characteristics of maize farmers in the study area. 251
Table 7.2: Descriptive Statistics of Production Variables by Adoption Status 252
Table 7.3**:** Input Elasticities of Maize Production by Adoption Status (Cobb– Douglas Estimates) 254

LIST OF FIGURES

Figure 2.1: A systematic step-by-step data search and collection process was followed. 32
Figure 2.2: Showing countries on publication based on the current review 34
Figure 2.3: Shows annual research production from the current review for 2011-2024. 34

Figure 3.1: The Technology Acceptance Model [TAM] 83
Figure 3.2: Map showing the Eastern Cape Province 86
Figure 3.3: Reasons for adopting GM maize seeds 100
Figure 3.4: Challenges to the adoption of GM maize seeds 102

Figure 4.1: Conceptual Framework Showing factors affecting technical efficiency of maize farmers 128
Figure 4.2: Showing the Eastern Cape Province 129
Figure 4.3: Showing the demographic characteristics of maize farmers in Eastern Cape Province 141
Figure 4.4: Showing agricultural extension sources of Information 145
Figure 4.5: Agricultural Extension Services Providers in the Study 147
Figure 4.6: Quality of Agricultural Extension Services Received by Farmers 148

Figure 5.1: Theory of Planned Behaviour and Diffusion Theory 188
Figure 5.2: Maize varieties grown in the study area 198

Figure 6.1: Conceptual Framework on GM Adoption Effects on Farm Income and Input Costs. 215
Figure 6.2: Showing the OR Tambo and Chris Hani District Municipalities, Eastern Province 217

Figure 7.1: Map indicating the local municipalities of the ORTDM. 241
Figure 7.2: Map indicating the local municipalities of the CHDM. 243

LIST OF ACRONYMS

AES	Agricultural Extension Services
ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
ATU	Average Treatment Effect on the Untreated
BT	Bacillus thuringiensis
C-B	Cobb-Douglas
CHDM	Chris Hani District Municipality
DARD	Department of Agriculture and Rural Development
DCTA	Department of Cooperative and Traditional Affairs
DRC	Democratic Republic of Congo
DTMA	Drought Tolerant Maize for Africa
ESR	Endogeneity Switching Regression
FFS	Farmer Field School
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
HT	Herbicide-Tolerant
MLE	Maximum Likelihood Estimates
MNL	Multinomial
NAADS	National Agricultural Advisory Services
NAB	Namibia Agronomic Board
NCP	National Council of Provinces
NAMC	National Agricultural Marketing Council
NGO	Non-Governmental Organization
ORTDM	Oliver Regional Tambo District Municipality
PSM	Propensity Score Matching
SA	South Africa
SADC	Southern African Development Community
SDG	Sustainable Development Goals
SSA	Sub-Saharan Africa

SFA	Stochastic Frontier Analysis
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour
TE	Technical Efficiency
T&V	Training and Visit
UN	United Nations
UKZN	University of KwaZulu-Natal
UCLG	United Cities and Local Governments
USAID	United States Agency for International Development

CHAPTER 1 INTRODUCTION

1.1 Background of the study

Hunger persists as the biggest challenge of our lifetime throughout the world. Around 800 million people remained undernourished in the year 2017, with 1/3 reported to be from sub-Saharan Africa (Herrera et al., 2021). Women and children are the most affected by food security and malnutrition, making them a very high-risk population. This may increase the risk of infection by diseases throughout the world (Herrera et al., 2021). For instance, Degefa (2021) conducted a study in Ethiopia on malnutrition, which discovered that malnutrition was among the causes of stillbirths and child deaths, with 53 of 59 cases reported to be caused by malnutrition. In South Africa, over 683,000 households with children aged five years or younger were reported to have experienced hunger in 2021(Statistics South Africa [Stats SA] (2021).

The government is now left with anxious concern about how to address the issue of poverty and hunger. Hence, it is important to take necessary steps by introducing and implementing both temporary and long-term initiatives that focus on ending the poverty problem and subsequently ending hunger (Mbajiorgu and Odeku, 2022). Agriculture can be used as the best tool in achieving these goals, particularly in developing countries like South Africa (Mpundu and Bopape, 2022). The industry plays a significant role in promoting economic growth, alleviating poverty, and enhancing food security across the Southern African region (United States Agency for International Development [USAID], 2023). More than 70% of rural communities depend on agriculture as a livelihood strategy, although regional economic growth has been constrained by the relatively poor performance of the agricultural sector (USAID, 2023). About 42.5% of the total employment in Africa was in the sector in 2021 (STATS SA, 2023).

In Africa, the sector contributed about 35% of the continent's Gross Domestic Product [GDP], though it differed by region (Nachum, 2023). For instance, the sector accounts for about 5% of South Africa’s GDP while contributing a staggering 57.45% for Sierra Leone (Department of Agriculture and Rural

Development, 2021; Stats SA, 2022). A recent study by Nyiwul and Koirale (2023) revealed that the agricultural sector in Africa employs around 224 million people. While over 60% of Africa's population relies on smallholder agriculture for both food and income (Food and Agriculture Organization, 2021). In South Africa, the agriculture sector created job opportunities, especially for low to semi-skilled households in rural communities, while employing around 843 177 people per year between 2018 and 2022. This is around 5.4% of the total employment around the country (Mosoma et al., 2023). Noko (2023) noted that given the rise in prominence of food security concerns, the agricultural sector's role as a food provider is particularly relevant now. There is a growing need for innovative strategies to boost agricultural productivity to meet food demand and enhance overall well-being.

As is well known, agriculture in South Africa remains dualistic, comprising both commercial farmers, who are predominantly white and occupy about 87% of the land, whilst smallholder farmers are mainly black and occupy the remaining 13% of the land (Sihlobo and Qobo, 2021; Mpundu and Bopape, 2023). The discrepancy in fortunes results from the long history of segregation policies and apartheid (Sihlobo and Qobo, 2021). Therefore, this study will mainly focus on smallholder farmers. Carelsen et al. (2021) define smallholder farmers as those who produce mostly for home consumption and sometimes sell surplus to earn income. These farmers have the potential to expand their operations and transition into commercial agriculture; however, they require comprehensive government support, including technical assistance, financial resources, and managerial capacity building. According to Wale, Chipfupa et al. (2021), the efficiency of smallholder farmers is inhibited by land tenure insecurity, having access to land without significant complementary resources, a lack of agronomic techniques, credits, and residing far away from irrigation schemes.

Smallholder farmers in South Africa engage in a range of agricultural activities, with maize farming being one of the key enterprises. According to Myeni (2021), maize is the main source of food security and livelihood strategy for many South Africans. Maize is dominantly practiced by smallholder farmers who are often located in remote areas, particularly in their former homelands, with around 2.3

million smallholder maize farmers across the country (Zantsi et al., 2021). In the 2021/22 season, SA became the ninth largest producer of maize across the world, and the largest maize producer in Africa (Adam Makhteshim Agan [ADAMA], 2023). A staggering 14 million tonnes was produced per year, with 12 million tonnes as white maize and the rest as yellow maize (ADAMA, 2023). According to the Department of Agriculture, Land Reform and Rural Development (2021), yellow maize is frequently utilized in producing animal feed, whereas white maize is used for human consumption. Apart from providing nutrients to both humans and animals, maize can also be a basic raw material used in the production of fuel, starch, oil, and alcoholic beverages, as well as other economic benefits such as income (Phetoe, 2023). Therefore, the study focuses in the Eastern Cape specifically on the smallholder maize farmers at Chris Hani District Muncipality. The distribution of farmers based on the registered farmers across the two districts under study is as follows: around 511 maize farmers in the OR Tambo District and around 410 maize farmers in the Chris Hani District Municipality, respectively (Department of Rural Development and Agrarian Reform, 2023).

Despite this significance, smallholder maize farmers in South Africa still face numerous challenges. These challenges include climate change, lack of innovative technology adoption, and poor access to production credit (Mujuru et al., 2022a). These challenges stem from the inefficient allocation of farm inputs and other resources, which ultimately results in low productivity and poor efficiency. For ‘technical efficiency’

the study adopts the definition by Mdoda et al. (2021), who define it as the capability of a farm to get the maximum possible production using the available set of resources at the lowest possible cost. Reduced efficiency leads to lower maize production, thereby jeopardizing livelihoods as well as food and nutritional security (Mujuru et al., 2022a). Persistently low productivity makes pursuing livelihoods in arable agriculture an increasingly vulnerable economic activity. For instance, in South Africa, the average maize yield is less than three metric tonnes for smallholder farmers, which is far less compared to the one

commercial farmer who gets yields ranging from four to fifteen tonnes per hectare (Mamashila and Antwi, 2025).

Improving the technical efficiency of farmers will result in an increase in production, which is required to achieve the two critical objectives of Sustainable Development
Goals [SDGs], which are ‘no poverty’ and ‘zero hunger’ by 2030 (Mahlatsi, 2021). Several authors have acknowledged that the adoption of improved technologies such as Genetically Modified [GM] Maize could improve smallholder farmers' efficiency levels significantly (Zamisa and Taruvinga, 2022; Brookes, 2022; Phetoe, 2023). Hypothetically, the adoption of GM maize seeds can increase farm income through an increase in production and marketable produce, which will positively improve employment and income (Mujuru et al., 2022a).

The use of improved maize varieties can lead to improved productivity due to characteristics such as high-yielding, resistant to diseases, and can withstand harsh conditions such as drought and respond well to inorganic fertilizers (Tovihoudji et al., 2022). Transferring genes from one plant to another can help to overcome the efficiency challenges of conventional plant breeding, as the new transgenic plants lower the utilization of pesticides and improve food security in less developed nations (Kavhiza et al., 2022). Additionally, using improved maize varieties will help farmers to grow maize even during periods of drought, especially when drought periods strike during the most crucial crop stages of development, which include both the flowering and grain filling stages (Tovihoudji et al., 2022). On the other hand, traditional or local seeds tend to have lower yields but are sometimes more adaptable to the local environment (Dokyi et al., 2021). A recent study conducted by Zamisa and Taruvinga (2022) noted that smallholder farmers' productivity is mostly affected by pests such as the stem borer on maize, which results in a reduction in productivity. Genetically modified maize is resistant to stem borer damage, which can have a significant positive impact on farmers and their households. However, GM maize seeds are often not widely adopted by smallholder farmers, partly because they have diverse needs and perceptions (Makwela, 2021).

Hence, an intellectual debate has arisen as to whether GM technology is acceptable or not (Makwela, 2021). According to Nowamukama (2022), the controversy surrounding GM maize largely stems from differing perceptions of its risks and benefits among various social groups, driven by fear of the unknown and uncertainty about the potential risks associated with the technology. As a result, certain countries in the Southern African Development Community [SADC have decided to take a precautionary approach, which is a risk-oriented approach, considering the perceived risks and the unknown health consequences that might result from the use of GMOs (Muzhinji and Ntuli, 2021). Conversely, GM crops have been adopted in several countries, despite growing concerns about their potential impacts on human health and the environment. Some of the possible risks to human health include food allergies, antibiotic resistance, an increase in toxic substances, an increase in pesticides in food consumed, and limited information on packaging labels (Ghimire, 2022). Hence, there is a dire need for the government to disseminate more information to smallholder farmers about the use of Genetically Modified seeds (Makwela, 2021).

Therefore, the introduction of agricultural extension programs through agricultural extension advisory services can be one of the main conduits of addressing the issue of low adoption of GM seeds by smallholder farmers. Agricultural extension is regarded as a rural development approach that depends on non-formal education and a traditional curriculum, working in close collaboration with both applied and academic agricultural research. (Harder et al., 2021) According to Agwu et al. (2023), agricultural extension refers to a body that facilitates farmers' access to innovations through promoting interaction with researchers and other relevant stakeholders to assist them in enhancing technical, organizational, and management skills. A review study conducted by Hamasalih and Layeeq (2023) defined ‘agricultural extension’ as an informal adult education process that deals with the dissemination of new information to farmers to improve their agricultural production and subsequently improve the standard of living. Although there are several definitions of agricultural extension, all emphasize the development of new information and technologies, capacity development, and improved standards of living.

Agricultural extension advisory services are equipped to disseminate technical information and technologies, facilitate adult learning in rural areas, support farmers in problem-solving, and promote their participation in agricultural knowledge and information systems. Various methods and approaches are used to disseminate these agricultural advisory services to farmers, such as farmer field school, participatory approaches, and training & visit (Ngqulana and Obi, 2019). Therefore, access to these services by smallholder farmers can improve their efficiency as farmers will receive diverse information about cultivation practices such as fertilization, plant protection (pests, weeds, and disease control), marketing, and crop management (Maake and Antwi, 2022).

Previous research in South Africa and globally has questioned the relevance of agricultural extension services; the results have been diverse, from significantly positive to disappointing (Maltitz and Van Niekerk, 2023; Maake and Antwi, 2022; Antwi-Agyei and Stringer, 2021). As a result, the revitalization of the agricultural sector remains constrained by several factors, including limited availability and access to extension services, which in turn affect the adoption and use of GM cultivars, as well as restricted access to markets and production inputs (Jolex, 2022). Hence, these constraints tend to impede maize production and result in low yields despite the introduction of these strategies, resulting in poor efficiency by smallholder farmers (Jolex, 2022). According to Somanje et al. (2021), constraints to the delivery of excellent agricultural advisory services are owed to the historical setup of the public advisory services, including the poor political and financial resource support. Nevertheless, agricultural extension impact is positively related or linked to the technical efficiency of the beneficiaries; this implies that the productivity of the farmers can be boosted if they can be taught how to utilize their resources efficiently (Biswas et al., 2021). Hence, the current study investigates the role of agricultural extension services in improving the technical efficiency of maize farmers in the Eastern Cape Province.

1.2 Problem Statement

Maize is a major staple food crop in Southern Africa, accounting for more than 36% of the region's total caloric intake (Kotey, 2017). A study by Gbadegesin et al. (2022) reported that adult maize consumption in Southern Africa, measured in grams per person per day, is the highest at an average of 267, followed by Eastern Africa at 157. These figures exceed both the African average of 120 and the global average of 48. In addition to being consumed by humans, maize is also a major component of animal feed and serves as an intermediate input in industrial processes, where it is used in the production of other food products and oils (Kotey, 2017). This was supported by Erenstein et al. (2022), who noted that maize, like wheat and rice, is a much more versatile multi-purpose crop; it can sometimes be used as animal feed and as an industrial and energy crop, especially in well-developed nations. For instance, of the total 15,7 290.96 tonnes of maize in Namibia (both locally produced and imported) during 2019/20, 79.8% (125, 529 tonnes) was processed as maizemeal while 15.8% (24.885 tonnes) was processed into animal feed (chop), while 4.4% (6,874 tonnes) was used as both maize grain products (instant porridge and cereal and other byproduct of samp (Namibia Agronomic Board [NAB], 2023).

According to Jena (2021) and Makgoba et al. (2021), 90% of the farmers across the region are involved in maize production, even though productivity differs widely among these farmers, with more than 200 million people dependent on maize as a source of living. Therefore, maize is the major driver of the systems in support of agriculture, as it supplies the volume to make services required for competent grain trade (Kotey, 2017). An average of 18-24 million tons per annum is produced by Southern Africa, with 55% of that produced in South Africa (Kotey, 2017). Of the maize produced in South Africa, approximately 60% is white maize, while the remaining 40% is yellow maize (Department of Agriculture, Land Reform and Rural Development [DALRD], 2021). Yellow maize is mainly used in the production of animal feed, whereas white maize is predominantly grown for human consumption. Therefore, maize remains a significant contributor to the economy of South Africa as it serves as an employer and earner of foreign currency (DALRD, 2021).

According to Agbugba et al. (2020), South Africa has more than 9,000 commercial maize producers who contribute the majority of the country's maize output, while the rest is produced by thousands of smallholder farmers. Despite this, maize produced by smallholder farmers in South Africa continues to be very low, largely due to limited access to quality inputs, insufficient extension services, and poor farm management practices, reliance on old indigenous knowledge for farming, and poor adoption of improved technologies (Agbugba et al., 2020; Zamisa and Taruvinga, 2022). Assessing technical efficiency is therefore critical to determine the extent to which farmers maximize output from available resources and to identify productivity gaps that can be addressed through targeted interventions. Evidence shows that smallholder maize outputs remain well below potential levels, reflecting significant inefficiencies in the use of available production resources. Understanding these efficiency levels within the South African context is essential for informing policies and support strategies that enhance smallholder maize productivity, strengthen food security, and promote sustainable rural development.

According to Chimonyo et al. (2020), the maize production levels by smallholder farmers are also affected by abiotic and biotic stresses, changing environmental conditions, the utilization of unsuitable maize cultivars and restricted resources. In addition, provision of services to farmers in South Africa has been hindered by challenges such as low extension contact with farmers, the utilization of outdated extension methods, and to ration of extension to farmers (Chimonyo et al., 2020). Hence, the study seeks to investigate the role of extension on the efficiency of the farmers and thus examine the exact factors that may affect the efficiency of farmers in the study area. A study conducted by Simanjuntak et al. (2023) noted that persistent high temperatures, which are above the temperature threshold, could prevent maize development and result in reduced yields by farmers.

A study by Muzhinji and Ntuli (2021) found that most smallholder farmers expend considerable effort on low-productivity farming practices, despite the availability of modern and improved agricultural technologies that could enhance their productivity. In countries such as South Africa, China, India, and Colombia, the

adoption of genetically modified organisms (GMOs) enables farmers to produce more food for a growing population while using fewer resources and lowering costs, as well as reducing the impact of pests and diseases (Muzhinji and Ntuli, 2021; Pardo, 2023; Liao, 2022). Therefore, the use of GM maize seeds could enhance maize yield and make it robust to both biotic and abiotic stresses (Sigigaba et al., 2021). For instance, Merga et al. (2023) conducted a study in Ethiopia and discovered that the use of improved maize seeds resulted in a huge increase in coverage, with around 54.9% of the national maize field in 2018. Another study conducted in South Africa by Ala-kokko et al. (2021) revealed that, on average, the use of GM maize has improved yield production by 21%, while at the same time reducing the quantities of the pesticides used by 37% and the costs of the pesticides by 39%.

South Africa is a signatory to the Cartagena Protocol on Biosafety, an international agreement that governs the transboundary movement of living modified organisms (LMOs) derived from modern biotechnology, including genetically modified organisms (GMOs) (Beeckman and Rüdelsheim, 2020). The Protocol is designed to ensure the safe transfer, handling, and use of GMOs, with particular emphasis on reducing potential risks to both the environment and human health (Muzhinji and Ntuli, 2021). South Africa, as a signatory to the Cartagena Protocol, is committed to implementing measures to regulate the transboundary movement of GMOs and to make informed decisions regarding the import and export of such organisms. The country's adherence to this protocol reflects its dedication to responsible and sustainable practices in the field of biotechnology and genetic engineering (Department of Agriculture, Land Reform & Rural Development [DALRRD], 2022). It also underscores the importance of international cooperation in addressing the challenges and opportunities presented by GMOs on a global scale (DALRRD, 2022).

Though South Africa is signatory to the Cartagena Protocol on Biosafety on the use of GMOs and the potential benefits, the adoption of these crops remains very slow. Smallholder farmers tend to be more risk-averse and opt for high discount rates, tend to avoid engaging in innovations, and are hesitant to invest in GM maize (Sarwosri, 2021). These farmers tend to continue utilising

traditional maize varieties with relatively low productivity when compared to the GM maize varieties (Sigigaba et al., 2021). Evanega et al. (2023) added that, although scientific consensus on the safety of GM technology by the World Health Organization, the adoption remains a huge controversy and public debate. Opinions from the public and the government stances on GM crops differ dramatically across the world, including South Africa (Evanega et al., 2023). According to Mmbando (2023), even though several countries have put in place legislative and institutional frameworks that guard and control the use of GM technologies in agriculture, the anticipated results will not be achieved unless farmers' knowledge and perceptions about the GM crops are well known and adequately addressed. There is little to no knowledge known about how farmers perceived the use of GM seeds in their farming practices. There is limited knowledge and information available to farmers regarding the GM seeds used.

The yield gap between traditional crop varieties and genetically modified organisms
(GMOs) has been a focal point in contemporary agricultural debates. Advocates for GMOs often highlight studies that showcase enhanced yields and increased resistance to pests and diseases (Ala-kokko et al., 2021; Abdul Aziz et al., 2022; Kovak et al., 2022). For instance, a study by Kovak et al. (2022) on genetically modified crops and climate change mitigation conveyed an average yield increase of 22% for GM crops compared to their non-GM counterparts. A similar study conducted in Vietnam by Brookes and Dinh (2021) found that GM yield was 30% higher when compared to normal maize. Furthermore, a study conducted by Brookes and Barfoot (2018) analysed global economic and environmental impacts of GM crop adoption, suggesting increased yields and reduced pesticide use by farmers in Vietnam.

On the contrary, critics argue that the yield advantages of GMOs are not universally applicable and are influenced by various factors such as local agroecology and farming practices. A study conducted in South Africa by Ashton (2021) raised concerns about the exaggerated claims of yield benefits from GM crops, emphasizing the need for further evaluation of these crops. Ashton (2021) further argues that, though South Africa managed to improve production

of most staple crops, including maize, these increases are not closely linked to the adoption of GM technology, but rather to improved germplasm, economies of scale, increased irrigation in recent years, and favourable weather conditions. Additionally, Kovak et al. (2022) published a report underscoring that the actual performance of GM crops in terms of yields varies and can be unpredictable.

Limited dissemination of information on GM maize seeds is seen as the key obstacle for successful adoption and diverse perceptions by smallholder farmers (Loki and Mdoda, 2023). This limited information constrains farmers from knowing the benefits of GM maize seeds and ultimately reduces their adoption level. Whereas a study by Sigigaba et al. (2021) specified that the low adoption by smallholder farmers is due to their high prices and limited accessibility. Smallholder farmers find it financially challenging to invest in these seeds, especially when the perceived benefits are not clear or immediate. Smallholder maize farmers are not fully informed about the benefits of GM seeds (Sigigaba et al., 2021). Limited awareness about the advantages, such as increased yield, pest resistance, and tolerance to adverse weather conditions, contributes to low adoption rates. Additionally, smallholder farmers have concerns about the safety of GM crops for human consumption and the environment (Muzhinji and Ntuli, 2021). Fears related to the potential long-term health effects and ecological impacts of genetically modified organisms (GMOs) deter adoption and use by farmers (Muzhinji and Ntuli, 2021).

Smallholder farmers are unwilling to adopt GM seeds due to their perceived high level of dependence on seed companies for their agricultural inputs. This dependency can be a concern for farmers who value traditional seed-saving practices (Mudigere et al., 2022). The severe regulations and approval processes for GM crops can deter smallholder farmers' adoption. Smallholder farmers become reluctant to adopt GM seeds if they perceive the approval process for the use of GM seeds as complex (Catherine et al., 2024). Additionally, there are increasing concerns about market acceptance of GM crops, thus influencing farmers' decisions. If there is limited demand or market access for GM produce, farmers may opt for traditional seeds to ensure a market for their harvest, given that farming is their only source of livelihood. Limited

market opportunities for GM crops can reduce the incentive for farmers to adopt these technologies (Kedisso et al., 2022). Furthermore, sociocultural beliefs and practices also play a role. There is high resistance within communities or cultural beliefs against the use of GM technology, which forces farmers to be less inclined to adopt and use GM seeds (Gbadegesin, 2022).

The limited adoption of improved seeds among smallholder farmers is a significant worry for the government and development organizations. Hence, inadequate infrastructure, such as irrigation, transportation, and storage facilities, reduces the efficiency of GM seed adoption (Myeni and Moeletsi, 2023). Additionally, a lack of extension services and support for farmers in terms of training and technical assistance can hinder successful implementation (Myeni and Moeletsi, 2023). This is particularly concerning in the context of climate change, which is currently affecting and is expected to further impact vulnerable communities. The consequences of low seed adoption include increased exposure to food and nutrient insecurities, heightened poverty levels, economic crises, environmental and ecosystem degradation, as well as health issues (Myeni and Moeletsi, 2023).

Addressing this challenge is crucial for enhancing the resilience of these communities in the face of ongoing and anticipated climatic changes. Therefore, the dissemination of information and the demonstration of the effectiveness of innovative technologies can be facilitated through agricultural extension advisory services. This can further contribute to increased awareness and appropriate use of new technologies and sustainable practices amongst farmers, which will help to improve their livelihoods and income (Kotey et al., 2017). Hence, there is a need to explore and investigate the role of agricultural extension on the technical efficiency of Genetically Modified seed adopters and non-adopters in the Eastern Cape Province, South Africa

1.3 Main Objective of the Study

To evaluate the impact of agricultural extension services on the technical efficiency of maize farmers in the Eastern Cape Province.

Specific Objectives

I. To assess the adoption intensity of GM seeds by maize farmers in Eastern Cape Province.

II. To assess the impact of agricultural extension services on the technical efficiency of maize farmers.

III. To analyse farmers' GM maize seed selection choices among smallholder farmers.

IV. To assess the effects of GM maize seed adoption by smallholder farmers on farm returns in the Eastern Cape.

V. To evaluate genetically modified maize seed adoption on input elasticities and productivity among smallholder farmers in the Eastern Cape Province.

1.4 Research Questions

I. What is the adoption intensity of GM seeds by maize farmers in the Eastern Cape Province?

II. What is the impact of agricultural extension services on the technical efficiency of maize farmers in the Eastern Cape Province?

III. What are the farmers' GM maize seed selection choices among smallholder farmers in the Eastern Cape Province?

IV. What are the effects of GM maize seed adoption by smallholder farmers on farm returns in the Eastern Cape Province?

V. What are the effects of genetically modified maize seed adoption on input elasticities and productivity among smallholder farmers in the Eastern Cape Province?

1.5 Justification of the Study

The global population is projected to reach approximately 9.1 billion by 2050 (Shakankale, 2023). A continuously rising population with no corresponding increase in agricultural production results in a net trend towards food insecurity and poverty (Shakankale, 2023). This has led to an ongoing debate on the most effective ways to feed the rapidly growing population, along with the related implications for research and development (Grote et al., 2021). Grote et al. (2021) further explained that there are calls for a new green revolution to keep up with the demand for staple foods across the world, and the importance of expanding and improving people's diet. Therefore, there is a need to increase the production of food, especially stable crops, to feed the 870 million people who are currently food insecure (Makwela, 2021). High population density has put a lot of pressure on the available land, as more land is also required for human settlement. This has resulted in the division of the land, which has affected production and the issue of food security.

There is a notion that Smallholder farming can be used as one of the vehicles to mitigate or reduce the issue of poverty across the world. Despite this, Smallholder farmers are still characterized by low production because of poor technical efficiency, which consequently affects their outputs. A study conducted by the Department of Agriculture, Land Reform and Rural Development (2021) noted that commercial agriculture accounts for about 98% of maize production in South Africa, while the remaining 2% is contributed by the developing agricultural sector, including smallholder farmers. This clearly shows that smallholder farmers are still constrained by several production factors that hamper their production. These include climate change effects, poor infrastructure, lack of production inputs such as fertilizer and production credits, technology, and labour costs (Dhillon and Moncur, 2023). The same was reported by Nyambo et al. (2022), who also noted that smallholder farmers struggle with production and marketing constraints, poor access to resources for on-farm infrastructure and inputs that hinder their optimal utilization of their lands.

Consequently, this undermines the United Nations' goal of eliminating hunger, achieving food security, and promoting sustainable agriculture by 2050 (Gonzalez, 2022).

Maulu (2021) argues that extension programmes in rural areas play an important role in connecting farmers with other stakeholders involved in rural development initiatives. Though the significance of extension programs in rural agriculture is mostly dependent on their ability to address the felt needs of the farmers at the grassroots (Maulu, 2021). The connection between agricultural extension services, technical efficiency, and technology adoption underlines the growth of agricultural productivity in rural communities. Therefore, improving the efficiency of maize production is essential for strengthening global food security and ensuring a stable supply of agricultural products. Extension advisory services can only be effective when the new information and technology developed is adopted by the end users. With that regard, effective advisory services that are informed by the current socioeconomic status and the wellbeing of the rural population are important in the development of sustainable agricultural practices and fighting the issue of food security in South Africa.

Hence, it is necessary to conduct a study on the effects of agricultural extension services on enhancing the technical efficiency of adopters and non-adopters of GM seeds in South Africa. Conducting the study will help in providing valuable insights into the effectiveness of agricultural extension services in promoting agricultural productivity and sustainability, informing policy decisions, technology adoption dynamics, smallholder farmers welfare and improve the knowledge gap; **For Policy implications**: it is significant to understand how agricultural extension services can impact both the technical efficiency levels of both adopters and non-adopter of GM maize seeds as this will help inform policy makers or developers about the effectiveness of their current agricultural programs. This will lead to more need-based extension programs and efficient allocation of resources, such as production resources (seeds, fertilizers, and equipment) to support farmers in adopting new improved technologies, such GM maize seeds, to improve their production which will subsequently improve their production levels.

Secondly, **GM maize seeds adoption:** adoption of these seeds has the potential to increase production and resistance to diseases and pests. Nevertheless, the adoption of GM maize seeds may be impacted by numerous factors, such as extension services. Therefore, examining the impact of extension services on the technical efficiency of adopters and non-adopters of GM seeds will allow researchers to be able to identify the factors influencing the adoption of GM seeds in the Eastern Cape Province. This knowledge will be significant in assisting extension services in introducing interventions designed to meet the specific needs and concerns of different smallholder farmers in the province. Thirdly, **sustainable implications**: understanding the Impact of agricultural extension services on the technical efficiency of adopters and non-adopters of GM maize seeds will help in understanding the sustainable implications of adopting the GM seeds. This information is necessary for guiding agricultural policies that are aimed at promoting sustainable farming practices.

Fourthly, **Smallholder farmers` welfare:** Several challenges are affecting smallholder farmers, such as limited access to production resources, improved technologies, and production information. Studying the technical efficiency of adopters and non-adopters of GM maize seeds will shed light on the potential welfare implications of these services and contribute to improving the livelihoods and welfare of farmers. This knowledge is significant for policymakers, agricultural extension practitioners, and other developmental organizations that are aiming at developing effective extension programs aimed at improving the livelihoods of the smallholder farmers. Fourth, **contributes to the knowledge gap:** though South Africa is signatory to the use of GM maize seeds, there is still a significant gap regarding their adoption, use, and impact among the smallholder farmers, including maize farmers in the Eastern Cape Province. Hence, conducting a study on the technical efficiency of adopters and nonadopters of GM maize seeds will help fill the gap by providing empirical evidence on the impact of extension and factors affecting adoption and its effect on farm productivity of smallholder farmers. Therefore, this can serve as a guide for future research agendas and help to inform and help in developing more effective extension regimes that fit the socio-economic status of smallholder farmers in South Africa.

1.6 Study Assumptions

This study was built on the assumption that the instruments to be used will elicit reliable responses from the participants in the study and that the respondents will answer the survey or interview questions honestly and factually. This will be done by ensuring that all information identities of participants will be concealed, and their confidentiality preserved, and all data will be used for research purposes only. The respondents will fully understand the questions they will be asked. Though the questionnaires will be crafted in English, trained enumerators will be available to assist in explaining all questions to the farmers in a language that they would understand. The study further assumes that the extension services are available to the smallholder farmers being studied. These include infrastructure, extension programs, and funding to support the farmers. Furthermore, the study assumes that farmers have information available to them by the agricultural extension services, and the information is relevant to their needs. This relevant information will build the capacity and skills of the farmers. Lastly, the study assumes that a reliable method to measure the technical efficiency levels of the farmers is using the quantitative research method, through measuring both the inputs and the outputs respectively.

1.7 Organization of the thesis

This study is divided into 8 chapters. Each chapter follows a paper format starting with an abstract showing the material and methods, and the key findings of each paper: introduction, methods, results, and discussion, and ends with the conclusion and recommendations.

Chapter 1 provides the introduction, the state of agriculture in South Africa, and maize productivity in the country. Followed by the objectives, research questions, and the limitations of the study.

Chapter 2: Presents a comprehensive literature review that synthesizes literature on the technical efficiency of GM maize adoption in Sub-Saharan Africa. This chapter establishes the broader continental context, synthesizes existing evidence on an overview of smallholder farming, maize production, and

genetically modified maize in Sub-Saharan Africa. It further focuses on technical efficiency in agriculture, the role of extension services in enhancing efficiency, and the impact of extension services on adopters of GM maize in sub-Saharan Africa.

Chapter 3: Examines the determinants and Intensity of GM Maize Seed Use among Maize Farmers in the Eastern Cape Province. This chapter presents the different factors that influence both the adoption and intensity of GM maize seed use. Based on this chapter, several factors influenced the adoption and the intensity of adoption among maize farmers.

Chapter 4: Looks at assessing the productivity effects of agricultural extension on smallholder maize efficiency through a Meta-Frontier and Endogenous Switching Framework in the Eastern Cape Province, South Africa. The chapter highlights the results on the technical efficiency of farmers, factors affecting inefficiency, and the impact of agricultural extension services on both income and productivity of maize farmers.

Chapter 5: Focuses on unpacking smallholder maize farmers' preferences for genetically modified maize seeds in the Eastern Cape Province, South Africa. The chapter further discusses the different maize seed types adopted by the maize farmers and the factors affecting the adoption of each maize seed type.

Chapter 6: Examines the productivity-profitability trade-offs and the welfare effects of GM maize adoption among smallholder farmers in the Eastern Cape Province. Further assesses the impact of GM adoption on both productivity and income of maize farmers.

Chapter 7: Assessed genetically modified maize seed adoption on input elasticities and productivity among smallholder farming systems, insights from Eastern Cape Province, South Africa. The chapter further revealed the input responsiveness of adopters and non-adopters of GM maize seeds.

Chapter 8: This section provides an overall summary of the study, including its main findings, conclusions, and recommendations. It also highlights the key results in relation to the study's aim and objectives.

References

Abdul Aziz, M., Brini, F., Rouached, H. and Masmoudi, K., 2022. Genetically engineered crops for sustainably enhanced food production systems. *Frontiers in plant science*, *13*, pp.1027828

Adam Makhteshim and Agan, 2023. Maize Farming in South Africa. https://www.adama.com/south-africa/en/maize-farming/maize-farming-south-africa [accessed online: 23 May 2024].

Agriculture and Rural Development, 2021. South Africa Yearbook 2020/2021. https://www.gcis.gov.za/sites/default/files/docs/gcis/3.%20Agriculture%20and%20Ru ral%20Development.pdf [accessed online: 23 May 2024].

Agwu, A.E., Suvedi, M., Chanza, C., Davis, K., Oywaya-Nkurumwa, A., Mangheni, M.N. and Sasidhar, P.V.K., 2023. Agricultural Extension and Advisory Services in Nigeria, Malawi, South Africa, Uganda, and Kenya.

Ala-Kokko, K., Nalley, L.L., Shew, A.M., Tack, J.B., Chaminuka, P., Matlock, M.D. and
D'Haese, M., 2021. Economic and ecosystem impacts of GM maize in South Africa. *Global Food Security*, *29*, pp.100544.

Antwi-Agyei, P. and Stringer, L.C., 2021. Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, pp.100304.

Ashton, G., 2021. Southern African civil society responds to false claims about benefits to food and nutrition security.

Beeckman, D.S. and Rüdelsheim, P., 2020. Biosafety and biosecurity in containment: a regulatory overview. Frontiers in bioengineering and biotechnology, 8, pp.650.

Biswas, B., Mallick, B., Roy, A. and Sultana, Z., 2021. Impact of agriculture extension services on technical efficiency of rural paddy farmers in southwest Bangladesh. *Environmental Challenges*, *5*, pp.100261.

Brookes, G. and Dinh, T.X., 2021. The impact of using genetically modified (GM) corn/maize in Vietnam: results of the first farm-level survey. *GM Crops & Food*, *12*(1), pp.71-83.

Brookes, G., & Barfoot, P. 2018. Global income and production impacts of using GM crop technology 1996–2016. GM Crops & Food, 9(2), pp. 139-172.

Brookes, G., 2022. Farm income and production impacts from the use of genetically modified (GM) crop technology 1996-2020. *GM Crops & Food*, *13*(1), pp.171-195.

Catherine, K.N., Mugiira, B.R. and Muchiri, N.J., 2024. Public Perception of Genetically Modified Organisms and the Implementation of Biosafety Measures in Kenya. *Advances in Agriculture*, *2024*.

Chimonyo, V.G.P., Mutengwa, C.S., Chiduza, C. and Tandzi, L.N., 2020. Characteristics of maize growing farmers, varietal use and constraints to increase productivity in selected villages in the Eastern Cape province of South Africa. *South African Journal of Agricultural Extension*, *48*(2), pp.64-82.

Cooper, B., Eva, N., Fazlelahi, F.Z., Newman, A., Lee, A. and Obschonka, M., 2020. Addressing common method variance and endogeneity in vocational behavior research: A review of the literature and suggestions for future research. *Journal of Vocational Behavior*, *121*, pp.103472.

Degefa, K., 2021. Malnutrition, A Major Health Challenge in Kersa, Ethiopia: Opportunities for Action from the CHAMPS network. Ethopia, Hararghe Health Research, Haramaya University.

Dhillon, R. and Moncur, Q., 2023. Small-scale farming: a review of challenges and potential opportunities offered by technological advancements. *Sustainability*, *15*(21), pp.15478

Dokyi, E., Anang, B.T. and Owusu, V., 2021. Impacts of Improved Seed Maize Technology Adoption on Productivity and Technical Efficiency in Northern Ghana. *Open Economics*, *4*(1), pp.118-132.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B.M., 2022. Global maize production, consumption and trade: Trends and R&D implications. *Food security*, *14*(5), pp.1295-1319.

Gbadegesin, L.A., Ayeni, E.A., Tettey, C.K., Uyanga, V.A., Aluko, O.O., Ahiakpa, J.K.,
Okoye, C.O., Mbadianya, J.I., Adekoya, M.A., Aminu, R.O. and Oyawole, F.P., 2022. GMOs in Africa: status, adoption and public acceptance. *Food Control*, *141*, pp.109193.

Ghimire, B.K., Yu, C.Y., Kim, W.R., Moon, H.S., Lee, J., Kim, S.H. and Chung, I.M., 2023. Assessment of Benefits and Risk of Genetically Modified Plants and Products:
Current Controversies and Perspective. *Sustainability*, *15*(2), pp.1722.

Gonzalez, C.G., 2022. SDG 2: End Hunger, Achieve food security and improved nutrition, and promote sustainable agriculture.

Grote, U., Fasse, A., Nguyen, T.T. and Erenstein, O., 2021. Food security and the dynamics of wheat and maize value chains in Africa and Asia. *Frontiers in Sustainable Food Systems*, *4*, pp.617009.

Hamasalih, C.M. and Layeeq, T.M., 2023. The importance of agricultural extension program in technology transfer for rural farmers: a review. *Zagazig Journal of Agricultural Research*, *50*(3), pp.387-394.

Harder, A.M., Benge, M., Diaz, J.M., Roberts, G. and Warner, L.A., 2021. Fundamentals of an extension education doctoral specialization: The University of Florida framework. *The Journal of Extension*, *59*(2), pp.5.

Herrera, J.P., Rabezara, J.Y., Ravelomanantsoa, N.A.F., Metz, M., France, C., Owens, A., Pender, M., Nunn, C.L. and Kramer, R.A., 2021. Food insecurity related to agricultural practices and household characteristics in rural communities of northeast Madagascar. *Food security*, *13*(6), pp.1393-1405.

Jena, P.R., 2021. Development and Opportunities in the Maize Sector in Eastern and
Southern Africa. https://www.cambridgescholars.com/resources/pdfs/978-1-5275-

8188-3-sample.pdf [accessed online: 24 May 2024

Jiba, P., Obi, A., Mdoda, L. and Mzuyanda, C., 2024. The Impact of Smallholder Irrigation Scheme on Household Welfare in Farm-Managed Irrigation Scheme Communities in the Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, *52*(1), pp.48-72.

Jolex, A., 2022. Influence of agricultural extension services on technical efficiency of maize farmers in Malawi. *African Journal of Agricultural and Resource Economics*, *17*(1), pp.92-105.

Kavhiza, N.J., Zargar, M., Prikhodko, S.I., Pakina, E.N., Murtazova, K.M.S. and Nakhaev, M.R., 2022. Improving crop productivity and ensuring food security through the adoption of genetically modified crops in sub-Saharan Africa. *Agronomy*, *12*(2), pp.439.

Kedisso, E.G., Maredia, K., Guenthner, J. and Koch, M., 2022. Commercialization of genetically modified crops in Africa: opportunities and challenges. *African Journal of Biotechnology*, *21*(5), pp.188-197.

Kovak, E., Blaustein-Rejto, D. and Qaim, M., 2022. Genetically modified crops support climate change mitigation. *Trends in Plant Science*, *27*(7), pp.627-629.

Liao, W., 2022, May. Economic impacts of commercialization of genetically modified crops in China. In *Proceedings of the 5th International Conference on Economic Management and Green Development* (pp. 234-244). Singapore: Springer Nature Singapore.

Loki, O., Aliber, M. and Sikwela, M.M., 2021. Assessment of socio-economic characteristics that determine farmers' access to agricultural extension services in Eastern Cape, South Africa. *South African Journal of Agricultural Extension*, *49*(1), pp.198-209.

Maake, M.M.S. and Antwi, M.A., 2022. Farmer's perceptions of effectiveness of public agricultural extension services in South Africa: an exploratory analysis of associated factors. *Agriculture & Food Security,* 11(1), pp.34.

Mahlatsi, K., 2021. Achieving sustainable development goals (SDGs) in Africa: Challenges and prospects. *The Thinker*, *87*(2), pp.61-69.

Makgoba, M.C., Tshikhudo, P.P., Nnzeru, L.R. and Makhado, R.A., 2021. Impact of fall armyworm (Spodoptera frugiperda) (JE Smith) on small-scale maize farmers and its control strategies in the Limpopo province, South Africa. *Jàmbá: Journal of Disaster Risk Studies*, *13*(1).

Makwela, M.A., 2021. *Determinants of smallholder maize farmers' varietal choice: a case study of Mogalakwena Local Municipality Limpopo Province, South*
Africa (Doctoral dissertation).

Mamashila, M.J. and Antwi, M.A., 2025. Assessment of profit efficiency of smallholder maize farmers in Limpopo province, South Africa: A stochastic frontier approach. *Journal of Agribusiness and Rural Development*, (1 [75]).

Maulu, S., Hasimuna, O.J., Mutale, B., Mphande, J. and Siankwilimba, E., 2021. Enhancing the role of rural agricultural extension programs in poverty alleviation: A review. *Cogent Food & Agriculture*, *7*(1), pp.1886663.

Mbajiorgu, D.G. and Odeku, K.O., 2022. Fighting food insecurity, hunger, and poverty: the content and context of the socio-economic right of access to sufficient food in South Africa. *Obiter*, *43*(3), pp.467-488.

Mdiya, L. and Mdoda, L., 2021. Socio-economic factors affecting home gardens as a livelihood strategy in rural areas of the Eastern Cape province, South Africa. *South African Journal of Agricultural Extension*, *49*(3), pp.1-15.

Mdoda, L., Obi, A., Christian, M. and Jiba, P., 2021. Technical efficiency of maizebased farm irrigators in the Eastern Cape Province. *Journal of Agribusiness and Rural Development*, *62*(4), pp.371-381.

Merga, G., Sileshi, M. and Zeleke, F., 2023. Welfare impact of improved maize varieties adoption among smallholder farmers in Amuru district of Horo Guduru Wollega, Ethiopia. *Cogent Economics & Finance*, *11*(1), pp.2207923.

Mirza, H., Bellalem, F. and Mirza, C., 2023. Ethical Considerations in Qualitative Research: Summary Guidelines for Novice Social Science Researchers.

Mosoma, K.C., Bohlmann, H.R., Ntombela, S.M. and Van Eyden, R., 2023. Quantifying the Economic Effects of Land Reform Policy in South Africa: A

Computable General Equilibrium Analysis. Department of Economics, University of Pretoria.

Mpundu, M. and Bopape, O., 2022. Analysis of Farming Contribution to Economic Growth and Poverty Alleviation in the South African Economy: A Sustainable Development Goal Approach. *International Journal of Economics and Financial Issues,* 12(5), pp.151-159.

Mudigere Sannegowda, U.B. and Garkoti, S.C., 2022. Traditional community-led seed system for maintaining crop vigour, diversity and socio-cultural network in view of the changing climate: a case study from western Himalaya, India. *Climate Action*, *1*(1), pp.1-16.

Mujuru, N.M. and Obi, A., 2020. Effects of cultivated area on smallholder farm profits and food security in rural communities of the Eastern Cape Province of South Africa. *Sustainability*, *12*(8), pp.3272.

Mujuru, N.M., Obi, A., Mdoda, L., Mishi, S. and Lesala, M.E., 2022b. Investigating the contribution and effect of cash transfers to household food security of rural smallholder farmers in the Eastern Cape Province of South Africa. *Cogent Social Sciences*, *8*(1), pp.2147138.

Mujuru, N.M., Obi, A., Mishi, S. and Mdoda, L., 2022a. Profit efficiency in family-owned crop farms in Eastern Cape Province of South Africa: a translog profit function approach. *Agriculture & Food Security*, 11(1), pp.20.

Muzhinji, N. and Ntuli, V., 2021. Genetically modified organisms and food security in Southern Africa: conundrum and discourse. *GM Crops & Food*, *12*(1), pp.25-35.

Myeni, L. and Moeletsi, M.E., 2023. Assessing the adoption of improved seeds as a coping strategy to climate variability under smallholder farming conditions in South Africa. *South African Journal of Science*, *119*(9-10), pp.1-7.

Myeni, L., Moeletsi, M.E., Nyagumbo, I., Modiselle, S., Mokoena, L. and Kgakatsi, I.B., 2021. Improving the food and nutritional security of smallholder farmers in South Africa: Evidence from the InnovAfrica project. *Sustainability*, 13(17), pp.9902.

Myers, D., 2020. *An assessment of hybrid maize adoption by small-scale farmers in Southern Africa: some evidence from Malawi, Zambia and Zimbabwe*. Nottingham Trent University (United Kingdom).

Nachum, L., 2023. Africa's agribusiness sector should drive the continent's economic development: Five reasons why. https://theconversation.com/africas-agribusinesssector-should-drive-the-continents-economic-development-five-reasons-why-198796 [accessed online: 22 May 2024].

Namibia Agronomic Board, 2023. Grain value-added products processed grain products in Number: Market intelligence report.

Ngqulana, A. and Obi, A., 2019. The impact of extension intensities on income of sheep producers in the Eastern Cape Province of South Africa. *South African Journal of Agricultural Extension*, *47*(1), pp.54-60.

Nkosi, C.S., Olorunfemi, O.D. and Khwidzhili, H., 2023. Data on climate change effect and use of adaptation strategies among smallholder maize farmers: Evidence from a microlevel survey in Ehlanzeni District, South Africa. *Data in Brief*, *48*, pp.109106.

Noko, K., 2023. Small-scale maize farmers' perceptions and adaptations towards climate change in Makhuduthamaga Local Municipality, Sekhukhune District, Limpopo Province (Doctoral dissertation).

Nowamukama, M., 2022. Public perceptions, knowledge and factors associated with the acceptability of genetically modified foods in Kampala city, Uganda. *bioRxiv*, pp.2022-11.

Nyambo, P., Nyambo, P., Mavunganidze, Z. and Nyambo, V., 2022. Sub-Saharan Africa Smallholder Farmers Agricultural Productivity: Risks and Challenges. In *Food security for African smallholder farmers* (pp. 47-58). Singapore: Springer Nature Singapore.

Pardo, N.J.C., Robayo, D.E.R., Lizarazo, J.C.F., Peña-Quemba, D.C. and McGale, E.,
2023. Exploring the future of GM technology in sustainable local food systems in Colombia. *Frontiers in Genome Editing*, *5*.

Phetoe, P., 2023. *Modelling willingness to pay for genetically modified Tela BT maize seed technology in Mpumalanga Province, South Africa* (Doctoral dissertation).

Shakankale, K.T., 2023. *Assessing technical efficiency of traditional and hybrid maize farmers in Malawi* (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Sihlobo, W. and Qobo, M., 2021. Addressing Constraints to South Africa's Agriculture Inclusiveness. Southern Centre for Inequality Studies, University of Witwatersrand.

Sikwela, M.M., 2013. *The impact of farmer support programmes on market access of smallholder farmers in the Eastern Cape and KwaZulu-Natal provinces, South Africa* (Doctoral dissertation, University of Fort Hare).

Somanje, A.N., Mohan, G. and Saito, O., 2021. Evaluating farmers' perception toward the effectiveness of agricultural extension services in Ghana and Zambia. *Agriculture & Food Security*, *10*, pp.1-16.

Statistics South Africa, 2021. Focus on food inadequacy and hunger in South Africa in 2021. https://www.statssa.gov.za/?p=16235 [accessed online: 22 May 2024].

Statistics South Africa, 2022. Eastern Cape home to over 7.2 million people. https://www.statssa.gov.za/?p=16760#:~:text=Eastern%20Cape%20is%20the%20fo urth,latest%20population%20and%20housing%20census. [Accessed online: 14 June 2024].

Statistics South Africa, 2022. Contribution of agriculture, forestry, and fishing sector to the Gross Domestic Product (GDP) in Africa as of 2022, by country. https://www.statista.com/statistics/1265139/agriculture-as-a-share-of-gdp-in-africaby-country/ [Accessed online: 23 May 2024].

Statistics South Africa. 2023. Employment in agriculture as a share of total employment in Africa from 2010 to 2021. https://www.statista.com/statistics/1230868/employment-in-agriculture-as-share-oftotal-in-africa/ Tenaye, A., 2020. Technical efficiency of smallholder

agriculture in developing countries: The case of Ethiopia. *Economies*, *8*(2), pp.34.

Wale, E. and Mkuna, E., 2023. Smallholder satisfaction with the quality of agricultural information, and their preferences among the sources: Empirical evidence from KwaZulu-Natal, South Africa. *Journal of Agriculture and Food Research*, *14*, pp.100715.

Wale, E., Chipfupa, U. and Hadebe, N., 2021. Towards identifying enablers and inhibitors to on-farm entrepreneurship: evidence from smallholders in KwaZulu-Natal, South Africa. *Heliyon*, *7*(1).

Wu, Z., Hua, W., Luo, L. and Tanaka, K., 2022. Technical Efficiency of Maize Production and Its Influencing Factors in the World's Largest Groundwater Drop Funnel Area, China. *Agriculture*, *12*(5), pp.649.

Zamisa, O. and Taruvinga, A., 2022. Drivers of genetically modified maize production among rural farming households in Ngqushwa local municipality, South Africa: a triple hurdle approach. *Journal of Agribusiness and Rural Development*, 65(3), pp.229-241.

Zantsi, S., Cloete, K. and Möhring, A., 2021. Productivity gap between commercial farmers and potential emerging farmers in South Africa: implications for land redistribution policy.

CHAPTER 2

A Systematic Review on Enhancing the Technical Efficiency of Genetically Modified Maize Adoption in Sub-Saharan Africa: The Role of Agricultural Extension Services and Barriers to Success

This chapter was published as: Ngqulana, A., Oladele, O.I., Nontu, Y., Mdiya, L. and Mdoda, L., 2025. A systematic review on enhancing the technical efficiency of genetically modified maize adoption in Sub-Saharan Africa: the role of agricultural extension services and barriers to success. *Frontiers in Sustainable Food Systems*, *9*, p.1609417.

Abstract

Genetically modified (GM) maize holds significant potential to enhance agricultural productivity, food security, and farm returns. Yet, varying technical efficiency levels have been reported across countries, coupled with different levels of effectiveness of agricultural extension services, which could enhance high efficiency. This systematic review examines the impact of agricultural extension services on the technical efficiency of GM maize adoption in sub-Saharan Africa. A literature search across multiple databases identified 68 peer-reviewed studies (2011-2024) that focused on technical efficiency and extension services. The review found that effective extension services significantly improve technical efficiency in GM maize adoption. However, challenges such as limited information, strict regulations, high seed costs, and biosafety concerns hinder adoption. The review highlights the importance of targeted support for smallholder farmers and calls for tailored extension programs that address farmers' specific needs. Additionally, encouraging collaboration between government agencies, NGOs, and local communities is essential for developing inclusive extension strategies that bridge knowledge gaps and promote sustainable agricultural practices.

Keywords: Agricultural extension services, technical efficiency, Genetically modified maize, sub-Saharan Africa, Adoption rates, Productivity

2.1 Introduction

The world population is anticipated to surge to 9 billion people by the year 2050, with

Sub-Saharan Africa (SSA) having the fastest-growing population rate globally (Somanje et al., 2021). Over 250 million people in sub-Saharan Africa were undernourished in 2019, representing 19% of the population (Kimani, 2024). According to Giller (2020), ensuring national food security in countries of the sub Saharan African region is crucial, as this will necessitate a more sustainable and sufficient supply of affordable, nutritious food that is culturally acceptable and meets the demands of the ever-increasing population.

Agriculture is a key driver of poverty reduction and economic growth in sub-Saharan Africa, offering a path to prosperity for millions of rural households (Viana et al., 2022). The sector is dominated by smallholder farmers, who are central to rural development and poverty alleviation (Nyambo, 2022). Around 33 million smallholders typically farm less than 2 hectares using low-input, mixed crop-livestock systems (Wiggins & Keats, 2013; Nyambo, 2022). Agriculture is vital to achieving the region's Sustainable Development Goal 1 (zero hunger). In Uganda, it contributes 50% of household income, 73% of employment, and 21% of GDP (Pan et al., 2018). Across sub-Saharan Africa, agriculture employs over 60% of the active population, except in oil-producing countries like Nigeria, South Africa, and Cameroon (Djoumessi, 2022). In 2010, it accounted for 54% of the region’s economically active population; in 2015, it contributed 17.5% to GDP (Odusola, 2017).

To ensure the sustainability of agriculture in Sub-Saharan Africa, agricultural extension services have been implemented to equip farmers with the knowledge, skills, and resources to adopt innovative practices (Nwafor, 2021). These services guide and develop farmers, connecting them with the latest agricultural information, technologies, and practices (Somanje et al., 2021; Jolex, 2022). Extension services have evolved into a multi-stakeholder approach involving public, non-profit, and private sectors, improving farm productivity and the overall agricultural value chain (Nwafor, 2021). Baiyegunhi (2019) found that farmers

who participated in extension programs earned higher net income than those who did not.

Genetically modified (GM) maize is an innovation in Sub-Saharan Africa, introduced to tackle climate change, land degradation, and a growing population (Di-Falco, 2018).

It offers solutions to enhance productivity and resilience by resisting pests, tolerating drought, and increasing yields, improving food security and livelihoods for smallholder farmers (Muzhinji & Ntuli, 2021). Agriculture remains central to many regional economies, so adopting GM maize could help mitigate environmental challenges. However, widespread adoption faces socio-economic, regulatory, and cultural barriers. GM maize, a key biotechnology, improves crop characteristics, enhances nutritional quality, and reduces the need for fertilizers, pesticides, and water (Muzhinji & Ntuli, 2021). In South Africa, GM crops brought economic benefits of $2.3 billion between 1998 and 2016, with 97% of these gains from GM maize (Ala-Kokko et al., 2021). In Burkina Faso, GM maize boosted yields by 30% (Schnurr & Dowd-Uribe, 2021).

However, the adoption of GM maize remains uneven across sub-Saharan Africa, influenced by many factors that vary from one context to another (Habib, 2024). Commercial farms have received more gains using GM crops, while smallholder farmers, particularly black smallholder farmers, remain marginalized (Habib, 2024). This situation hinders the region's efforts to achieve sustainable agricultural growth, prolonging poverty, food insecurity problems, and environmental degradation.

Despite increasing studies on GM maize adoption and extension services, there remains limited evidence on how extension interventions directly affect technical efficiency outcomes among GM maize participants in Sub-Saharan Africa. Previous research has mostly focused on factors influencing adoption, often undermining the mediating role of extension services or systems and common constraints faced by smallholder farmers. This systematic review contributes to the literature by mapping empirical evidence linking extension service provision and technical efficiency in GM maize production across the region, identifying

structural, institutional and informational challenges that hinder efficiency gains, and highlighting policy frameworks for enhancing farmer support systems. Moreover, this systematic review uniquely synthesizes evidence on how extension service models influence the technical efficiency of GM maize production across sub-Saharan Africa. This focus fills an important gap in existing literature by incorporating insights from numerous scientific studies. This review advances an understanding of how targeted extension services may enhance both productivity and adoption rates. Hence, this study seeks to evaluate the impact of agricultural extension services on the technical efficiency of genetically modified maize adopters in sub-Saharan Africa.

2.2 Methodology

Search Strategy, Inclusion, and Exclusion Criteria

A comprehensive literature search was conducted across Scopus, Google Scholar, ScienceDirect, and Web of Science to ensure thorough coverage and reduce publication bias. Search terms included combinations such as “Maize farmers,” “Smallholder farming,” “Sub-Saharan Africa,” “Technical efficiency,” “Genetically Modified Maize,” and “Agricultural Extension Services.”

Inclusion criteria were: studies focused on sub-Saharan Africa, assessed the impact of agricultural extension services on GM maize farmers’ technical efficiency, published in English, and dated between 2011 and 2024. Studies not meeting these criteria were excluded.

Data extracted included study characteristics, methodologies, findings on technical efficiency, and the role of extension services. From 4,049 retrieved papers, 231 titles and abstracts were screened, and 68 studies met the criteria for final inclusion (Figure
2.1).

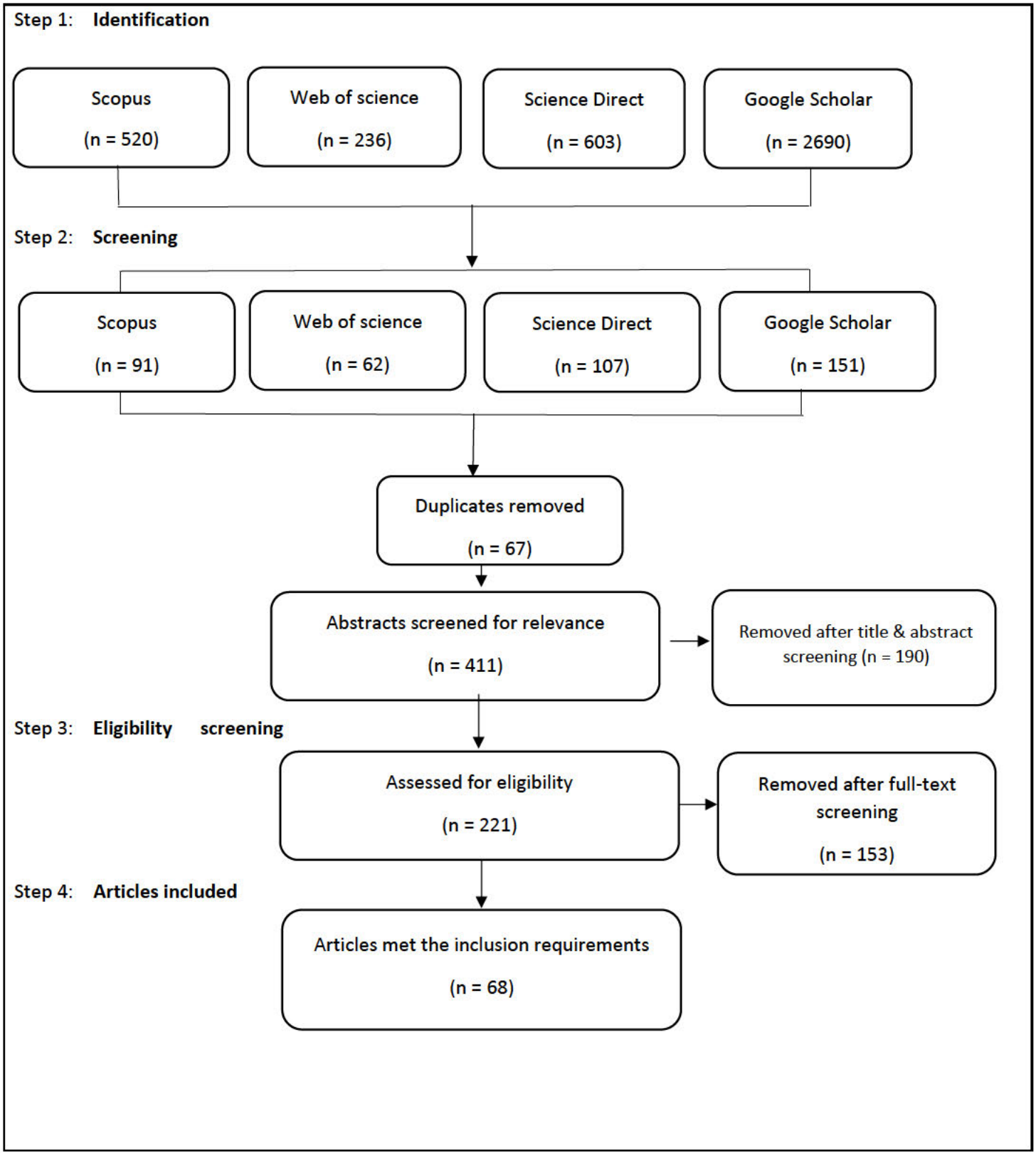


Figure 2.1: A systematic step-by-step data search and collection process was followed.

Source: Author's Computerization.

Data Recording, Management, and Analysis

Data were recorded using a standardised extraction form in Microsoft Word to capture key details on study characteristics, methods, technical efficiency, GM maize adoption, and extension services. Extracted data were stored and managed in a Microsoft Excel database, with careful entry, error checks, and data cleaning to ensure accuracy and consistency. The database was secured on a password-protected laptop with regular institutional backups to prevent data loss. Analysis involved narrative synthesis and meta-analysis to summarise and interpret the findings.

2.3 Results and Discussion

The results show varied contributions from 2011 to 2024, with 19 studies at the regional level. Among country-specific studies, South Africa led with 14, followed by Ethiopia (13), Ghana (8), Zimbabwe, Uganda, Nigeria, Malawi, and Kenya (3 each). Zambia had 2 studies, while only one was found for the DRC, Kenya, and Malawi (Figure 2.2).

This uneven distribution has policy implications. Countries like South Africa, with more research, are better positioned to use evidence-based strategies to boost smallholder maize farmers' technical efficiency. In contrast, countries such as the DRC, Zambia, and Malawi face research gaps that must be addressed. These disparities may also reflect regional differences in agricultural development, with South Africa having more advanced systems. Several studies have also assessed GM maize efficiency regionally in South Africa and Ethiopia (Gcaba et al., 2024; Habib, 2024; Kotey et al., 2016; Belete, 2020; Ahmed et al., 2014; Debebe et al., 2015).

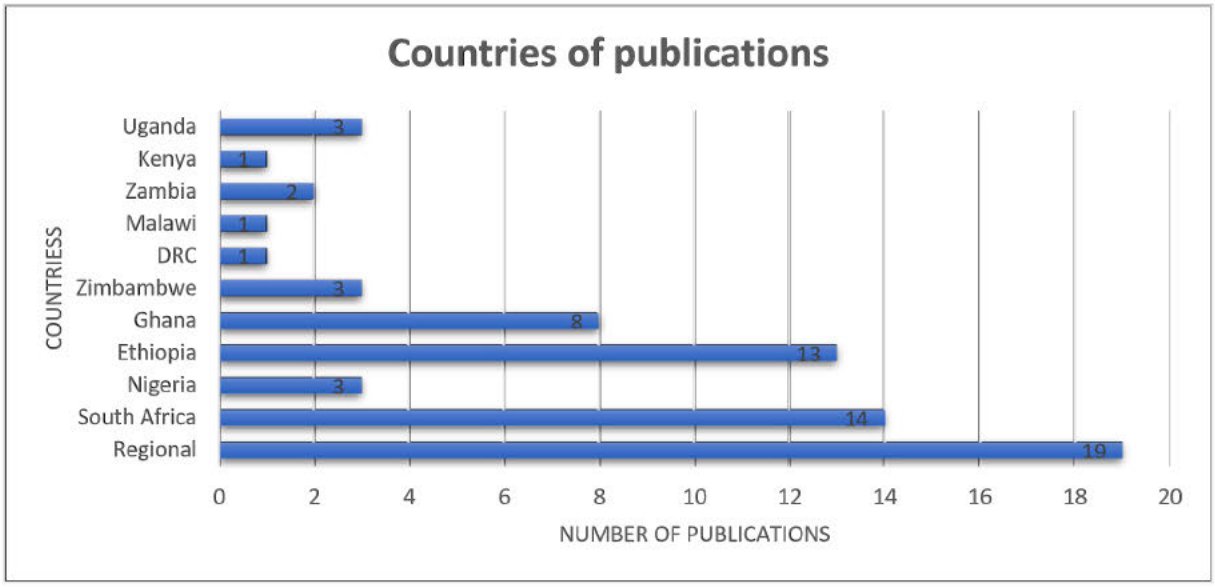


Figure 2.2: Showing countries on publication based on the current review

2.3.1 Annual Research Trends in Maize Efficiency and Extension (2011–2024)

Figure 2.3 shows a steady rise in research output from 2011 to 2024, reflecting growing interest in GM crop adoption and its impact on maize productivity. This trend highlights the recognized importance of agricultural extension services in enhancing farmers' technical efficiency. The continued increase in publications suggests ongoing knowledge gaps, reinforcing the need for further research to inform policies and raise awareness about the benefits of GM maize for smallholder farmers. This aligns with Arowosegbew (2024), who emphasized the critical role of extension services in improving awareness of GM crops.

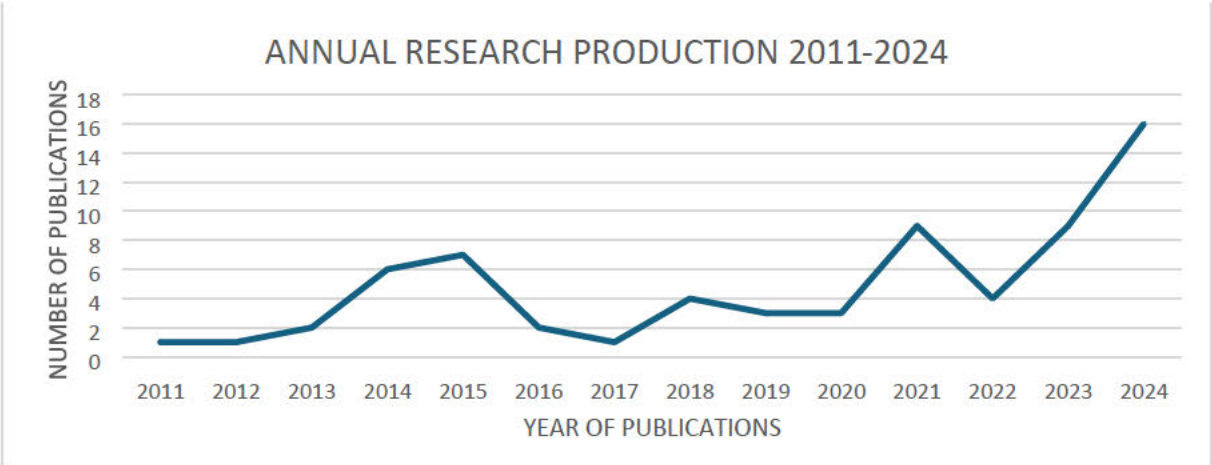


Figure 2.3: Shows annual research production from the current review for 2011-2024.

2.3.2 Overview of Smallholder Farming in sub-Saharan Africa

Smallholder farmers' definitions vary by region and farming systems (Nyambo et al., 2019; Martey et al., 2020; Kapari et al., 2023). Generally, they produce for household consumption and the market, with farming as a key income source (Carelsen et al., 2021). They can transition into commercial farming with technical, financial, and managerial support. Due to limited land, many focus on cash crops like maize, rice, and vegetables (Magakwe & Olorunfemi, 2024). Smallholder farms are crucial for food security, supporting families averaging seven people.

These farmers play a key role in rural development and poverty reduction, typically practicing low-input, mixed farming on plots under 2 hectares (Nyambo et al., 2022). Research in Sub-Saharan Africa shows variations in farm types, soil fertility, and nutrient management (Chikowo et al., 2014). In Kenya, for example, high-resource farmers have larger farms, more cattle, and use more fertilizer, while low-resource farmers have smaller plots, no cattle, and limited fertilizer. Similar patterns are seen in Zimbabwe and Malawi, highlighting the need for tailored policies to address diverse smallholder needs.

The diversity of smallholder farmers across sub-Saharan Africa illustrates those agricultural interventions, particularly extension services, cannot be effectively implemented using a one-size-fits-all approach. As shown in Table 2.1, high-resourceendowed (HRE) farmers tend to have better access to inputs, training, and markets, while medium- and low-resource-endowed (MRE and LRE) farmers face significant constraints in land size, livestock ownership, fertilizer use, and access to advisory services. Therefore, extension support should be context-specific: for HRE farmers, emphasis should be on scaling advanced technologies such as GM maize hybrids, precision input management, and market linkages; for MRE farmers, strategies should focus on improving access to credit, cooperatives, and community-based training; and for LRE farmers, priorities should include foundational capacity-building, subsidized input programs, and targeted extension demonstrations that reduce entry barriers.

This stratified approach recognizes the heterogeneity of smallholders across SSA and provides a foundation for the country-specific recommendations.

Policy responses should be tailored to national resource endowments and institutional capacities. In high-resource countries such as South Africa and Kenya, where extension systems are relatively strong, efforts should prioritize scaling technology transfer, promote digital extension platforms, and support private sector participation in GM maize dissemination. In medium-resource countries like Zimbabwe and Ghana, policies should focus on strengthening farmer–extension linkages through cooperatives, enhancing credit access, and incentivizing extension–research collaboration. In low-resource countries such as Malawi and Burkina Faso, where smallholder farmers remain marginalized, emphasis should be placed on improving extension coverage, ensuring affordability of GM seed, addressing biosafety awareness gaps, and fostering donor–government partnerships for inclusive outreach. Differentiated strategies across these contexts will enhance the overall efficiency and equity of GM maize adoption in SSA. See Table 2.1 below.

Table 2.1: Smallholder Farm Typologies in sub-Saharan Africa

Study area/site	**Key farm typology/resource group characteristics**
Kenya	High resource endowment (HRE) —> 1.6 ha farm size, farmers own at least three cattle, do not have maize grain deficits as annual production >3 t. Annual fertilizer use >120 kg
	Medium resource endowment (MRE) —> about 0.8 ha farm size, fertilizer use is limited and usually none at all, farmers own a woodlot but often supplement household fuel needs with crop residues. Farmers do not produce any fodder grass.
	Low resource endowment (LRE) —> as low as 0.2 ha farm size, farmers do not own cattle. Farmers do not use fertilizer; their annual grain production is>900 kg. Over 50 % of farmland is cropped with beans, and all the crop residues are used as fuel. Household income from off-farm activities is as high as 70 %
Zimbabwe	Type 1—Resource-endowed (RG1) —> own house with brick under galvanized iron sheets or asbestos; farm implements include a plough, an ox-drawn cart; livestock ownership >10 cattle; >3 ha arable land; regular contact with extension and employ extension recommendations, through direct training (e.g. the master farmer program); high capacity to secure inputs, use >250 kg fertilizer; generally, >20 years farming experience
	Type 2—Intermediate (RG2) —> varying resource ownership (e.g. may have a plough but not enough draught animals); own ≥4 cattle; include the eager-to-learn type farmers but are limited by resource base -most of the relatively young farming households; Seek to enhance their production through communal social arrangements (e.g. combining draught animals); fair engagement with extension agencies; landholding 2 ha; no regular pattern for hiring-in or hiring-out labour; use 50–150 kg fertilizer

	Type 3—Resource-constrained (RG3) —> lack farming implements, draught power (0–3 cattle), and cash to buy inputs; variable farm size (0.5 to >3 ha), but those with large landholdings typically utilize a small proportion of their arable land; limited or no source of remittances and constituted by a significant number of female-headed and the old (>60 years)
Kenya	Type 1—Farms that rely mainly on permanent off-farm employment, farm small pieces of land (0.6–1.1 ha); animal manure used at intensities as high as 8 t ha^{-1} $year^{-1}$; farms have a net accumulation of C and macronutrients
	Type 2—Wealthier farms growing cash crops; farm relatively large land areas (1.6–3.8 ha)
	Type 3—Medium resource endowment; food self-sufficient farms; farm size intermediate
	Type 4—Medium to low resource endowment relying partly on non-farm income, farm size intermediate; perennial food deficits
	Type 5—Poor households with family members employed locally as agricultural laborers by wealthier farmers; farm small pieces of land (0.4–1.0 ha), the intensity of use of mineral fertilizers ranges between 0–12 kg ha^{-1}, perennial food deficits
Zimbabwe	Type 1—Very rich (RG1): farm size about 3 ha, owns more than 10 cattle, owns a range of farm implements, can afford to hire labour, uses large quantities of fertilizers (>500 kg per season) and manure, and market-oriented production
	Type 2—Rich (RG2): farm size about 3 ha, own <10 cattle, own farm implements but rarely scotch carts, do not regularly hire labour, use fertilizers but <500 kg per season
	Type 3—Poor (RG3): farm sizes less than 3 ha, livestock limited to goats and chickens. Only small implements such as hoes, axes, and wheelbarrows; no draught power; grain crops grown for subsistence; little mineral fertilizer use
	Type 4—Very poor (RG4): Farm sizes <ha, do not own cattle but have goats and chickens, own only small implements such as hoes, grain crops grown for subsistence, do not regularly use mineral fertilizers, sell labour locally
Malawi	Better-resource endowment (RG1) —> have iron sheet roofed houses, household assets, own large fields (>5 ha), grow more tobacco for commercial purposes, buy and use more fertilizers, hire in *ganyu* (labour), food secure (bumper yield every year)—any food shortages are mild, own more livestock e.g. cattle, goats, pigs; Have good toilets with suitable sanitation measures
	Medium-resource endowment (RG2) —> have a brick house, grass-thatched, or ironroofed, household assets, use fertilizer on valuable crops such as tobacco and maize, hire in labour, food secure but may experience periodic or seasonal food insecurity, own livestock e.g., cattle, goats, have good sanitation facilities
	Less well resource endowment (RG3) —> have grass thatched houses, own about 2 ha farmland, grow mainly maize, sell off labour, occasionally use fertilizer (about 10 kg N/ha), limited food (lasts up to August), involved in work for food programs, usually have chickens but may rear goats, have poor sanitary facilities
	Least-resource endowment (RG4)—> have thatched houses, illiteracy is very high, have <1 ha land, generally use no fertilizer, chronic food insecure, survive on kinship and *ganyu* labour, have no livestock except for a chicken or a goat given by others or through *ganyu* labour, have no sanitation facilities

Source: Chikowo et al. (2014)

2.3.3 Overview of maize production in sub-Saharan Africa

Maize is a key crop in Sub-Saharan Africa, cultivated on over 40 million hectares (Cairns et al., 2021). It is the main crop in more than half of the SSA countries

and ranks among the top two cereals in most. In Zimbabwe, 80% of the population grows maize for food and income (Madzivanzira et al., 2024). Many SSA countries consume over 100 grams of maize daily (Cairns et al., 2021). In Ethiopia, 9 million farmers grow maize, with productivity exceeding 3 metric tonnes per hectare (Abate, 2024).

South Africa, the second-largest maize producer after Nigeria, harvested 11.2 million tonnes in 2019 from 2.3 million hectares and exported 3 million tonnes in 2021/2022 (Simanjuntak et al., 2023). Maize is crucial for the region's agriculture, food security, and livelihoods (Gcaba, 2024; Jolex, 2022). Ekpa et al. (2018) identified six main maize-based foods in SSA: whole maize, wet-ground maize, bread, snacks, porridge, and drinks.

2.3.4 Overview of extension services in sub-Saharan Africa

Though defined in various ways, agricultural extension broadly aims to support resource-poor farmers by enhancing production, marketing, processing, and consumption to improve livelihoods (Somanje et al., 2021; Makate & Makate, 2019). Jolex (2022) found that extension services boost smallholders' capacity by linking them to new knowledge, technologies, and resources in Malawi. Similarly, DansoAbbeam (2018) reported positive impacts on farm productivity and income in Ghana.

An evaluation across 11 countries and 7 extension models (Table 2.2) highlighted the Training and Visit model as effective in Kenya and Somalia, but less so in the Ivory Coast and Rwanda. Other models, such as Uganda's National Agricultural Advisory Services [NAADS], Zimbabwe's National Extension and Research Project, and Farmer Field Schools in Kenya, Uganda, and Tanzania, also showed positive effects, especially in yield improvement, knowledge, and technology adoption. Comparative analysis of extension models across SSA reveals that success depends heavily on institutional support, farmer participation, and contextual adaptation. The Training and Visit (T&V) model performs well where extension agents receive adequate logistical support but struggles in resource-limited districts due to high supervision costs. In contrast, Farmer Field Schools (FFS) thrive in community-driven contexts that emphasize experiential learning, yet their scalability remains constrained by

resource intensity. NAADS in Uganda shows mixed results, effective in areas with consistent funding, but vulnerable to political interference and uneven implementation. These variations underscore that no single model is universally superior; effectiveness hinges on the alignment between model design, resource availability, and governance structure.

Table 2.2: Impact of agricultural extension services by country.

Country	Agricultural extension models	Indicator	Impact status reported
Kenya	T&V	-	Satisfactory
Somali	T&V	-	Satisfactory
Ivory Coast	T&V	-	Unsatisfactory
Rwanda	T&V	-	Unsatisfactory
Burkina Faso	T&V	-	Positive impact
Kenya	T&V	-	Positive impact
Kenya	T&V	-	Non-significant change
Uganda	NAADS	Availability and quality of services	Positive impact
Zimbabwe	National extension and research project (not T&V)	Productivity	Satisfactory
Uganda	NAADS	Yield growth	Non-significant effect
Mozambique	Public and private extension	Rural livelihoods & farm production	Statistically significant positive effect
Zimbabwe	Public extension	Crop productivity	Statistically significant effect
Ethiopia	PADETES and other rural services	Agricultural productivity	Significant effect
Ethiopia	PADETES	Agricultural productivity and farm income	Non-significant effect
Tanzania	Rural services and infrastructure	Agricultural production	Significant impact
Kenya	FFS	Productivity and income	Significant change
Uganda	FFS	Productivity and income	Non-significant change
Tanzania	FFS	Productivity and income	Significant change
Ethiopia	Extension and road	Poverty and consumption growth	Positive effect
Ivory Coast	Public extension	Yields	Positive impact
Uganda	NAADS	Knowledge and utilization of improved technologies/practices	Significant impact
			15 (71%)

			6 (29%)

Source: Taye (2013)

2.3.5 Genetically Modified Maize in Sub-Saharan Africa

Adoption trends of genetically modified maize in sub-Saharan Africa

This review synthesizes the findings of numerous studies on the adoption rates and trends of genetically modified (GM) crops in Sub-Saharan Africa, as highlighted in the selected articles (Table 2.3).

Table 2. 3: Adoption trends of genetically modified maize in sub-Saharan Africa

Countries	**Studies**	**CROP**	**Description**	**YEAR**
South Africa	Ala-Koko (2021)	GM MAIZE *bt* yellow maize	Commercialized	1998-1999,
		GM Maize *bt* white maize	Subsistence maize	2001–2002
		HT maize	Commercial adoption	2003–2004 and 2007–2008
South Africa	Ngcinela (2019)	GM Maize	90% are planted	2015
Eswatini	African Centre for Biodiversity (ACB) (2017)	Insect-resistant cotton	Commercial adoption	2019
Regional	Kedisso et al. (2022)	GM Crops	Commercialized	2008-2012
Ghana	DansoAbbeam (2018)	Improved Maize Varieties	Improved maize varieties cultivated by farmers nationwide	2015 -
SSA	Fisher et al. (2015)	Drought Tolerant Maize for Africa (DTMA)	Commercial maize	2007 -2013.
Regional	Mmbando (2024)	Bt cotton and maize	Commercialized after Seven-year ban on GM crops lifted	2020

South Africa	Gouse et al. (2016)	GM Maize	Commercial maize adoption	2007–2008
SSA	Kavhiza et al. (2022)	GM Maize	Commercial maize adoption	2020
Eswatini	Abbas, 2018	GM Bt cotton	Commercial adoption	2016
SSA	Ekpa et al. (2018)	GM maize	Commercial maize	2016

Note: Data derived from the articles selected for this literature review

Genetically modified (GM) crop adoption in Sub-Saharan Africa (SSA) varies widely, with South Africa leading in GM maize commercialization. It introduced Bt yellow maize in 1998–1999, followed by Bt white maize (2001–2002) and herbicide-tolerant maize (2003–2004) (Ala-Koko, 2021). By 2015, nearly 90% of its maize was GM, driven by pest resistance, higher yields, climate resilience, supportive policies, and strong biotech infrastructure (Gouse et al., 2016).

In contrast, countries like Eswatini and Ghana have progressed more slowly. Eswatini began with insect-resistant cotton in 2016 and expanded to Bt cotton in 2019 (Abbas, 2018; ACB, 2017). Ghana has grown improved maize since 2015 but is still in the early stages of GM maize adoption (Danso-Abbeam, 2018). Regional trends show growing interest in GM crops for food security, climate resilience, and pest control, with drought-tolerant maize playing a central role.

Tanzania's 2020 lifting of a seven-year GM ban, allowing Bt cotton and maize, signals a broader regional shift toward biotechnology (Mmbando, 2024). While South Africa remains the frontrunner, other countries are gradually adopting GM crops, shaped by economic, policy, and environmental factors. These differing adoption rates underscore the role of local context in shaping GM crop uptake in SSA (Kavhiza et al.,

2022).

Evidence on the Benefits of Genetically Modified Maize Adoption in sub-Saharan Africa

The current review highlights numerous advantages of adopting genetically modified (GM) maize throughout the sub-Saharan region. Key benefits include

enhanced resistance to insect pests, which significantly reduces crop damage and reliance on chemical pesticides.

Table 2.4: Benefits of adoption of GM maize in sub-Saharan Africa

COUNTRY	STUDY	BENEFITS
Regional	Mmbando (2024)	Resistant to insects, improved yields, and decreased chemical pesticide usage
South Africa	Mulaudzi and Oyekale, 2015	Improved productivity
South Africa	Ala-Kokko et al., (2021)	Improved productivity and food security
Ethiopia	Gebretsadik and Kiflu (2018)	Reduction in the usage of pesticides and Improved productivity
South Africa	Dowd-Uribe and Schnurr, 2016	Reduced pesticide applications and increased productivity
Eswatini	African Centre for Biodiversity (ACB), 2017	Improved productivity and farm returns
Ethiopia	Merga (2023)	Increase in calorie consumption per day
Uganda	Zambrano et al. (2022)	Improved farm returns and productivity
Ghana	Dokyi (2021)	Improve productivity
Eswatini	Abbas (2018)	Cost reduction in pesticides applied, improved productivity
South Africa	Ala-Kokko (2021)	ecosystem impacts and reduced herbicide usage
Tanzania	Zambrano et al. (2022)	Enhanced farm returns
Regional	Kavhiza (2022)	Reducing Postharvest Losses

Note: Data derived from the articles selected for this literature review

Resistance to insect pests

Mmbando (2024) highlighted the significant benefits of genetically modified (GM) crops in Africa, especially regarding pest resistance, productivity, and sustainability. In South Africa, the commercialization of Bt maize and cotton,

engineered to resist pests like the stem borer, has been highly successful. These crops have increased productivity and reduced the need for chemical pesticides, lowering production costs and environmental pollution. Adopting Bt crops has contributed to more sustainable agricultural practices, reducing chemical inputs and minimizing the negative impacts of pesticides. South Africa's success with GM crops demonstrates their potential to address challenges such as pest resistance, food security, and environmental sustainability across Africa.

Improved productivity

South Africa was the first African country to commercialize GM crops, introducing Bt maize in the 1998/1999 season. This led to a significant increase in maize production, with the country harvesting 66.4 million tonnes of white maize and 5.4 million tonnes of yellow maize, achieving yields of 39 tons per hectare for white maize and 4.7 tons per hectare for yellow maize (Mulaudzi & Oyekale, 2015). These results highlight the productivity boost GM maize provides. Similarly, Dokyi (2021) found that adopting GM maize in Northern Ghana led to a 33.8% increase in production, demonstrating the potential of GM crops to enhance productivity and technical efficiency for smallholder farmers.

Reduced pesticide use

Gebretsadik and Kiflu (2018) reviewed Ethiopia's challenges and opportunities with GM crop production, highlighting a 37% reduction in pesticide use after adopting GM maize. This decrease benefits the environment by reducing pesticide impact and lowers farmers' costs by decreasing the need for chemical inputs. Additionally, GM maize adoption led to a 21% yield increase, demonstrating higher productivity and reduced pesticide reliance. The study emphasizes the importance of extension agents in helping smallholder farmers adopt GM technologies, improving sustainability and farming efficiency in Ethiopia and beyond.

Increased calorie consumption

Merga (2023) studied the welfare impact of adopting improved maize varieties in the Amuru district, Ethiopia, surveying 263 households. The study found that households adopting improved maize had an average daily caloric intake of

2470.71 kilocalories, compared to 2241.91 kilocalories for nonadopters, a 229.8-kilocalorie increase. This highlights the role of improved maize varieties in enhancing food security and nutrition. The findings suggest that adopting higher-yielding maize boosts productivity and improves farmers' access to calories. However, Merga (2023) notes that further research is needed on the broader nutritional impacts of GM maize, particularly in terms of nutrient diversity and overall diet quality

Ecosystem impacts and reduced herbicide usage

Ala-Kokko et al. (2021) studied the ecosystem impacts of GM maize adoption and found significant environmental benefits, especially in herbicide usage. GM maize farming uses half the amount of pyrethroid herbicide compared to conventional maize. This reduction helps minimize soil and water pollution, reduces agrochemical runoff, and protects biodiversity by safeguarding beneficial insects and soil microorganisms harmed by conventional pesticide use.

Reducing postharvest losses

Kavhiza et al. (2022) found that genetic engineering in GM crops can delay cell-walldegrading enzymes, slowing crop aging and maintaining structural integrity after harvest. This reduces spoilage and infection by pathogens, helping to prevent postharvest losses, a significant challenge for food security in sub-Saharan Africa. GM crops can ensure a more stable food supply and improve availability by minimizing these losses.

2.3.6 Challenges of GM maize adoption in sub-Saharan Africa

Despite the benefits of GM crops, adoption in Sub-Saharan Africa has been slow, with only eleven countries approving their cultivation as of 2024 (Mmbando, 2024). This slow uptake is due to a mix of cultural, economic, and environmental factors, including societal attitudes, regulatory challenges, concerns about environmental impact, and market access, all contributing to the cautious integration of GM crops in the region.

Table 2.5: Challenges to GM maize adoption reported in reviewed studies

Countries	CHALLENGES	Studies
Regional	Strict country by-laws on the use of GM maize, and Accessibility of GM seeds	Mabaya et al. (2015), Azadi et al. (2016)
Regional	Regulations and policies	(Mmbando, 2024; Roba, 2023)
Uganda	Public perception and acceptance, Limited knowledge or information on GM maize	Mustafa et al. (2023)
South Africa	High seed costs, high cost of labour	Mulaudzi and Oyekale, 2015
Ethiopia	Biosafety concerns	Gebretsadik and Kiflu (2018)
South Africa	Not readily available in local shops, poorly labelled maize packages, lack of knowledge	Sigigaba et al. (2021)
Ethiopia	Human health concerns	Khan et al. (2024)
Uganda	Public perception and acceptance	Mustafa et al. (2023)

Note: Data derived from the articles selected for this literature review

Stringent national regulations

A key challenge in adopting GM maize in Sub-Saharan Africa is the strict bylaws and regulatory frameworks of many countries (Table 2.5). According to Mabaya et al. (2015), GM maize approval often requires clearance from multiple ministries, making the process more influenced by political will than technology. While these laws aim to ensure safety and environmental protection, they can be restrictive, with some countries having lenient policies and others imposing lengthy approval processes or outright bans. Such regulations can delay GM maize introduction, limit availability, and create uncertainty for farmers and investors, ultimately reducing the potential benefits for agricultural productivity and food security.

Accessibility of GM crops

In many rural areas in SSA, the availability of GM seeds is limited due to supply chain inefficiencies, financial constraints, and local policy restrictions (Mabaya et al., 2015; Azadi et al., 2016). Underdeveloped distribution networks and high seed costs make it difficult for smallholder farmers to access GM seeds.

Additionally, local policies may restrict or regulate seed sales, making them harder to obtain. Lack of awareness and misconceptions about GM crops further complicate adoption. Overcoming these barriers is crucial for improving GM maize accessibility to needy farmers.

Biosafety concerns

A study by Gebretsadik and Kiflu (2018) identified biosafety concerns as a significant barrier to GM maize adoption in Ethiopia. These concerns include environmental pollution, gene transfer to wild plants, and the creation of invasive species. Fears about cross-contamination between GM and non-GM crops, loss of genetic diversity, and potential impacts on soil health and non-target organisms are prevalent. Ethiopian farmers rely on traditional farming and are particularly wary due to the country's agricultural biodiversity. The lack of proper risk assessment frameworks further deepens this reluctance. Addressing these concerns with clear communication, awareness, and thorough risk assessments could help overcome these barriers and promote GM maize adoption.

Regulations and policies

Restrictive GM crop policies can discourage investment in GM technologies, while neighbouring countries with lenient regulations may adopt GM maize more quickly, creating disparities in agricultural practices. Studies by Mmbando (2024) and Roba
(2023) highlight how regulatory differences hinder GM maize's spread regionally and globally. Delays in policy implementation, lack of harmonization, and conflicting frameworks can limit cross-border trade and international collaboration. Inconsistent regulations also challenge companies wishing to introduce GM maize in multiple countries, as they must navigate complex, costly legal requirements. These obstacles emphasise the need for regional cooperation and streamlined frameworks to facilitate GM maize adoption.

Human health concerns

Human health concerns are a significant barrier to GM maize adoption in sub-Saharan Africa, with farmers fearing health risks, allergies, and toxicity due to misinformation and limited understanding. Despite scientific consensus on the

safety of regulated GM crops, public unease persists. Khan et al. (2024) note fears about antibiotic-resistant illnesses from GM crops, especially the transfer of antibiotic-resistant genes to humans, fueling skepticism and mistrust. Health concerns dominate public discourse, affecting attitudes and hindering acceptance. Addressing these concerns through clear communication and transparency is crucial to building consumer confidence and overcoming this barrier.

Public perception and acceptance

Public perception and acceptance of GM maize are key to its adoption, especially in places like Uganda, where cultural beliefs, safety concerns, and ethics shape opinions (Mustafa et al., 2023). Many fear health risks and environmental impacts from GM foods, driven by limited understanding, misinformation, and a lack of scientific information. Despite evidence supporting their safety, there's a widespread belief that GM foods could harm health or cause long-term effects. Fischer (2015) noted that the lack of information about Bt maize is a significant barrier to adoption. Addressing these concerns and improving public knowledge is essential for greater acceptance of GM crops.

High seed and labour costs

A significant challenge in adopting GM maize is the high cost of seeds, which are more expensive than conventional varieties, placing a financial burden on smallholder farmers. Additionally, the intensive farming practices required for GM maize, including specialized knowledge, equipment, and extra inputs like fertilizers or pesticides, drive up labor costs (Mulaudzi and Oyekale, 2015). For small-scale farmers, these combined costs can outweigh the benefits of GM maize, such as higher yields and pest resistance. Addressing these financial barriers through subsidies, financing, or cost-reduction programs is essential to increasing adoption.

Limited knowledge of GM maize

In much of SSA, particularly Uganda and South Africa, limited knowledge about GM maize hinders its adoption, causing resistance from farmers, consumers, and policymakers. Many in Uganda, for example, do not understand how GM

maize is developed, its benefits, and potential risks (Mustafa et al., 2023). This ignorance leads to misconceptions, such as beliefs that GM maize is toxic or harmful to health, the environment, or biodiversity. To overcome this, educational campaigns offering clear, evidence-based information on GM technology are crucial for reducing fears, fostering acceptance, and encouraging supportive policies.

Limited availability, poor labelling, and knowledge gaps

In many SSA countries, including South Africa, challenges in logistics and education hinder the widespread acceptance of GM maize. Key issues include limited availability in local shops and poorly labeled packaging, which causes consumer uncertainty. The packaging often fails to indicate that the maize is genetically modified or provide information on its benefits and safety (Sigigaba et al., 2021). This lack of transparency leads to confusion and mistrust. Furthermore, many consumers lack knowledge about the advantages of GM maize, such as higher yields, pest resistance, and improved food security. To address these barriers, improving accessibility, clear labeling, and education campaigns are essential to boost consumer confidence and acceptance.

Stakeholder perspectives on GM maize adoption

The current review highlights varying perspectives among stakeholders regarding the adoption of GM maize crops. These differing viewpoints on the use of GM maize are summarized in Table 2.6 below.

Table 2.6: Stakeholders' perspectives on GM maize adoption

Countries	**STAKEHOLDERS PERSPECTIVE**	**Studies**
Regional	Dignity of nature and biodiversity, spiritual beliefs, and ties to the land influence	Mmbando (2024)
Kenya	Solution to the issue of food security, GM is harmful	Catherine et al. (2024)
Regional	Cleaning of pollutants and developing new drugs used for disease treatment.	Adenle (2014)
South Africa	GM eliminates problems associated with conventional agriculture, simplifies farm	Mushunje at al. (2011)

	management, reduces the use of agricultural chemicals, and improves the quality and nutritional value of products	

Cultural, Spiritual, and Environmental Concerns Regarding GM Crops

Mmbando (2024) examined the role of cultural and spiritual beliefs in shaping opinions on genetically modified (GM) crops in Africa. Many communities view the genetic modification of crops, like maize, as a threat to biodiversity, cultural practices, and the sanctity of nature. In regions where agriculture is intertwined with spiritual beliefs, altering a key crop like maize disrupts deeply rooted traditions. Additionally, the concept of 'biopiracy,' or exploiting natural resources for profit, influences opposition to GM crops. For these communities, agriculture is not just economic but integral to their identity and connection to the land. Therefore, resistance to GM maize stems from concerns about environmental harm, violating sacred relationships with the land, and undermining traditional, sustainable farming practices. Engaging local communities, respecting their values, and conducting thorough cultural and environmental impact assessments are essential to promote GM crops effectively.

GM Maize: Food Security versus Potential Risks

Adopting GM maize in Kenya is a contentious issue with divided opinions. Supporters argue that GM maize could help address food insecurity by increasing yields, improving resilience, and reducing reliance on food aid. However, critics worry about potential health and environmental risks, along with ethical concerns about genetic manipulation and the influence of multinational corporations on food sovereignty. A study by Catherine et al. (2024) found that 57% of respondents saw GMOs as a solution to food security, while 25% viewed them as harmful. This mixed perception creates skepticism and slows adoption. To navigate this, a collaborative approach involving multiple stakeholders is necessary to ensure GM maize is adopted responsibly, maximizing benefits and minimizing risks for farmers, consumers, and the environment.

Environmental and medical benefits of GM maize

Genetically modified (GM) maize has potential environmental and medical benefits. It could aid in soil remediation by absorbing or breaking down pollutants, improving soil health, and reducing environmental impacts, especially in areas with industrial pollution. Additionally, GM maize could be used to produce compounds for new drugs. However, safety, efficacy, long-term health, and environmental effects must be carefully assessed. A study by Adenle (2014) in Ghana and Nigeria highlighted GM crops' advantages, such as improved productivity and drug development. As recognition of GM technology grows, its adoption in sub-Saharan Africa may increase, with government and regulatory support. However, strict evaluations and regulatory frameworks are essential to manage risks and maximize benefits.

GM maize and simplified farm management

South Africa views GM maize positively for its ability to improve agricultural efficiency. As a leader in GM crop adoption, the country uses GM maize to address issues like pest infestations, crop diseases, and excessive chemical use. GM maize reduces reliance on pesticides and herbicides, lowering environmental impact and production costs. It also offers resilience to environmental stressors, simplifying farm management, reducing labor, and enhancing overall farming efficiency. This suggests that wider GM maize adoption could improve food security and technical efficiency in sub-Saharan Africa, particularly in maize-dependent regions.

2.3.7 Technical efficiency in agriculture

Technical efficiency in agriculture refers to maximising output with a given set of inputs or achieving specific output levels with minimal input (Belete, 2020; Tumuri, 2024). Studies often use stochastic frontier or truncated-normal models to assess inefficiency and its determinants (Tenaye, 2020; Gcaba et al., 2024).

Production factors influencing the technical efficiency of maize farmers

Farmers' characteristics, farm traits, and institutional factors influence technical efficiency in maize production. Key variables include seed quality, fertilizer use,

oxen per hectare, and labour input, with higher-quality seeds and adequate fertilizer boosting efficiency. Institutional support, like extension services, credit, and market access, is vital. Farmers' education, experience, and risk preferences also affect their resource management. To improve efficiency, policymakers must enhance access to quality inputs, support institutional frameworks, and address farmers' specific needs (Belete, 2020; Chiona et al., 2024; Ahmed et al., 2014; Bempomaa & Acquah, 2014).

Table 2.7 below shows different production factors.

Table 2.7: Production factors utilized by smallholder farmers

Countries	VARIABLES	COEFFICIENT	Studies
Ethiopia	Maize seed	0.006 Positive	Belete, 2020
Zambia	Fertilizer used per hectare	0.763 Positive	Chiona et al. (2024)
Ethiopia	Oxen used per hectare	0.135 Positive	Ahmed et al., 2014
Ethiopia	Number of farm labour	0.140 Positive	Debebe et al. (2015)

Note: Data derived from the articles selected for this literature review

Belete (2020) found that maize seed use in Ethiopia positively affects productivity, with every additional unit of seed increasing yield by 0.006 per hectare. While important, the impact of seed is modest compared to factors like fertilizers and labour. High-quality seeds improve germination, plant growth, and pest resistance. Still, their full potential is realized only when factors like soil fertility, water availability, labour, and timely management are optimized.

Chiona et al. (2024) found a strong positive correlation (0.763) between fertilizer use and maize productivity in Zambia, emphasizing fertilizer's crucial role in boosting yields. Proper fertilizer application significantly improves crop growth and yields in regions with nutrient-deficient soils, like Zambia. Fertilizers provide essential nutrients, such as nitrogen, phosphorus, and potassium, vital for plant development. However, challenges like high costs, limited access, and lack of knowledge hinder proper fertilizer use among smallholder farmers in Sub-Saharan Africa.

In Ethiopia, oxen use positively impacts maize productivity with a coefficient of 0.135, mainly through land preparation and transportation. Oxen are vital for ploughing and ensuring proper seedbed preparation, which is crucial for crop success. However, their impact on productivity is less significant than factors like fertilizer use. While oxen are essential for practical farming, their full potential is maximized with other inputs like fertilization and efficient labour. Due to affordability and availability issues, limited access to oxen can restrict their benefits, especially in areas lacking mechanization (Ahmed et al., 2014).

In Ethiopia, the number of farm labourers positively affects productivity, with a coefficient of 0.140 (Debebe et al., 2015). More laborers improve productivity, especially in planting, weeding, and harvesting. However, the modest coefficient suggests that labour alone is not the primary driver of productivity. Its impact is enhanced with inputs like fertilizers, improved seeds, or mechanization. Labour shortages, particularly during peak seasons, challenge many smallholder farmers, limiting their ability to hire additional help. Addressing labour shortages, improving efficiency, and integrating labour with other productivity-boosting resources are key to maximizing farm output.

Technical inefficiency variables affecting maize production

This review highlights various factors that influence the technical inefficiency of farmers, as summarized in Table 2.8 below.

Table 2.8: Showing factors affecting the technical inefficiency of maize farmers

Countries	**IN-EFFICIENCY VARIABLES**	**SIGNIFICANCE LEVELS & SIGNS**	**Studies**
Ethiopia	Age of household head	-0.235 negative	Tenaye (2020)
Ethiopia	Educational level	−0.0728344 negative	Tumuri et al. (2024)
Ghana	Access to credits	-0.429 negative	John and Seini (2013)
Ghana	Farming experience	−0.003 negative	Wongnaa and Awunyo-Vito (2018)
Ethiopia	Extension contacts	-0.045759 negative	Ahmed and Endrias (2014)
Ethiopia	Land tenure security	−0.0729732 negative	Belete (2020)

Ethiopia	Distance to markets	-0.1257748 negative	Weldegebriel (2015)
Ethiopia	fertile soils	−0.005 negative	Tenaye (2020)

Note: Data derived from the articles selected for this literature review

The negative coefficient of -0.235 for the age of the household head suggests older farmers are more technically efficient (Tenaye, 2020). Their experience enhances farm management, resource allocation, pest control, and crop suitability, leading to higher outputs. Older farmers are better attuned to local conditions, optimizing productivity. However, despite their experience, older farmers may be less inclined or financially able to adopt modern technologies, such as advanced machinery or GM crops, preferring traditional methods.

The negative coefficient of -0.0728344 for the household head's education (Tumuri et al., 2024) indicates that higher education reduces technical inefficiency in farming. Educated farmers are more efficient as they can implement modern techniques and make informed decisions. Education also helps farmers access and interpret agricultural information. However, the small coefficient suggests education is not the sole factor influencing productivity; access to resources like extension services and credit also plays a key role. Tumuri et al. (2024) and Mdoda et al. (2021) noted that education is most effective when combined with support and resources.

The study shows a negative coefficient of -0.429 for access to credit, indicating that financial support improves technical efficiency among smallholder farmers in subSaharan Africa (John and Seini, 2013; Kodua and Onumah, 2022). Access to credit enables farmers to invest in critical inputs like seeds, fertilizers, and machinery, boosting productivity and reducing inefficiencies. Farmers struggle with outdated methods, poor management, and lower crop yields without credit. Therefore, credit access is vital for improving efficiency and sustainability in farming, especially in resource-scarce regions, highlighting the need for better credit delivery mechanisms.

The study found a coefficient of -0.003 for farming experience, indicating a negative relationship between years of farming and technical inefficiency, meaning more experienced farmers are typically less inefficient (Wongnaa and

Awunyo-Vito, 2018). Experience helps farmers make better decisions regarding soil conditions, crop cycles, and pest management, improving efficiency. However, the benefit of experience is relatively small compared to factors like credit access or education. While experience improves efficiency, its impact can be limited without modern technologies or favourable market conditions.

The number of extension contacts influences technical efficiency in smallholder farming, with a negative coefficient of -0.045759 indicating a positive relationship between regular extension contact and reduced inefficiency. Farmers with frequent extension service interactions are more efficient, benefiting from knowledge, training, and guidance on modern agricultural practices (Ahmed and Endrias, 2014). Extension services help farmers manage crops, pests, soil fertility, and irrigation, but the extension-to-farmer ratio can limit their impact. Combining these services with other resources like improved seeds, fertilizers, and market information can enhance their effectiveness in improving farm productivity.

The negative coefficient of -0.0729732 for land tenure security indicates that farmers with secure land rights are less technically inefficient (Belete, 2020). Secure land tenure encourages investment in farming practices, such as soil conservation and new technologies, as farmers can make long-term decisions without fear of losing access. In contrast, insecure land rights discourage such investments, leading to higher inefficiency. Therefore, land tenure security promotes agricultural stability, reducing inefficiency and improving productivity.

The negative coefficient of -0.1257748 for distance to markets suggests that farmers closer to markets are less technically inefficient. Proximity to markets provides easier access to selling produce, better prices, and essential inputs like seeds and fertilizers. It also facilitates the exchange of knowledge and technologies, improving farming practices. In contrast, farmers farther from markets face higher transportation costs, delays, and limited access to inputs and information, leading to inefficiency. This highlights the challenges smallholder farmers in sub-Saharan Africa face due to poor market access, which reduces productivity.

The negative coefficient of -0.005 for fertile soils suggests that soil fertility reduces technical inefficiency. Fertile soils support higher yields, allowing farmers to achieve better productivity with fewer inputs like fertilizers or labour. However, the small coefficient indicates that while soil fertility is beneficial, other factors such as access to credit, extension services, or modern technologies may have a greater impact on efficiency. This underscores the need for a holistic approach to farming, combining good soil health with access to essential resources.

Role of extension services in enhancing efficiency

A summary of the findings regarding the impact of these services on the technical efficiency of maize farmers in the region is presented in Table 2.9 below.

Table 2.9: Role of extension services in enhancing the technical efficiency of farmers

Type of Extension Services Provided	**Frequency of use**	**TECHNICAL EFFICIENCY SCORES**	**STUDIES**
Planting of improved seeds, thinning, plant spacing, use of chemicals, seed protection, fertilizer application, disease management, weed control, storage, and processing.	(100.0%) of the maize farmers, all used the identified extension training recommendations	Contact with extension services (0.9138) and without contact (0.5129)	Oluwole et al. (2021)
-	-	technical efficiency score without access to extension services (63%), and access to extension services technical efficiency increases by 4%	Jolex (2022)
-	-	Participants (57%) and Non-Participants (52%)	Adem and Gebregziabher, 2014
-	-	Access to extension services reduces technical inefficiency by 2.473 units.	Addai and Owusu (2014)

Command Agriculture Maize Scheme (Government Project in Zimbabwe)	-	Two Districts' technical efficiency scores = Chegutu 85% and Zvimba districts 94%	Muzeza et al. (2023)

Note: Data derived from the articles selected for this literature review

Oluwole et al. (2021) show that extension services significantly improve technical efficiency among maize farmers. Farmers using services like improved seeds, spacing, fertilization, pest control, and storage achieved an efficiency score of 0.9138, compared to 0.5129 for those without access. This highlights the role of extension in boosting productivity through better resource use.

Similarly, Jolex (2022) found a 4% increase in efficiency among farmers using extension services, with non-users scoring 63%. Even small gains can have a significant impact when scaled. Extension services enhance knowledge in crop management, input use, pest control, and soil health, which are key to improving efficiency and sustainability.

Adem and Gebregziabher (2014) found 57% efficiency among participants versus 52% for non-participants, while Addai and Owusu (2014) confirmed reduced inefficiency in Ghanaian maize farms due to extension support. These studies show that even modest gains from extension can enhance yields and resource management.

Muzeza et al. (2023) highlighted the Command Agriculture Maize Scheme in Zimbabwe, where coordinated extension services led to high efficiency: 94% in Zvimba versus 85% in Chegutu. The difference suggests that targeted support can further improve outcomes. These findings underline the value of investing in and expanding extension services to boost technical efficiency and support smallholder farmers.

Impact of extension services on adopters of GM maize in sub-Saharan Africa

This review highlights several benefits and outcomes resulting from the impact of extension services on adopting genetically modified (GM) maize, as summarized in Table 2.10 below.

Table 2.10: Illustrating the Impact of Extension Services on GM Maize Adopters

STUDIES	LOCATION	EXTENSION SERVICES	YIELD ADVANTAGE OR OUTCOME
Kotey et al. (2016)	South Africa	Group formation, production inputs	Improved crop production
Badu-Apraku (2023)	Regional	-	20-30% yield advantage
Gouse (2012)	South Africa	-	Distribution of bags of Bt maize seed (CRN 4549 and 250g of conventional nearisoline maize seed (CRN 3549) to farmers
Akinbode & Bamire (2015)	Nigeria	-	1 unit of extension contact increased the adoption of GM maize by 3.97
Kazaara (2024)	Uganda	Contact with extension services	150.6 kg/acre yield advantage
Makate and Makate (2019)	Zimbabwe		GM maize increases yield, output per capita, and consumption.

Note: Data derived from the articles selected for this literature review

Kotey et al. (2016) emphasize the value of group formation in extension services, showing it boosts agricultural productivity in South Africa. Farmer groups promote peer learning, shared resources, and collective problem-solving, while improving access to inputs, credit, and new technologies like GM maize. Group-based extension enhances outcomes, especially in resource-limited areas.

Badu-Apraku (2023) notes that GM maize offers 20–30% higher yields than conventional varieties, addressing pest resistance and yield instability. Extension services are key to adoption by providing knowledge and support. Gouse (2012) found Bt maize in South Africa reduced pesticide use and costs, with extension services helping farmers understand and adopt the technology. Akinbode & Bamire (2015) showed that each extension contacts in Nigeria

increased GM maize adoption by 3.97 units, stressing the impact of frequent, quality support.

Kazaara (2024) reports a 150.6 kg/acre yield increase among Ugandan farmers using extension services, showing the benefits of guidance on GM seeds, fertilizers, and pest control. Similarly, Makate and Makate (2019) found GM maize adoption in Zimbabwe improved yields, household consumption, and income. In all cases, extension services were vital in helping farmers unlock the full potential of GM maize and improve food security.

2.3.8 Barriers to adoption and efficiency gains from the adoption of GM maize

This systematic review has identified several key constraints that hinder smallholder farmers' adoption of GM maize. Based on the reviewed articles, these constraints are highlighted in Table 2.11 below.

Table 2.11: Constraints to the adoption of GM maize and efficiency gains

Constraints to the Adoption of GM Maize	**Country**	**Reference**
Regulations and policies	Regional, Ethiopia	(Mmbando, 2024; Roba, 2023)
High seed costs	South Africa	Mulaudzi and Oyekale (2015)
Limited knowledge or information on GM maize	Uganda	(Mustafa et al. 2023)
Biosafety concerns	Ethiopia	(Khan et al., 2024)
Accessibility of GM seeds	Regional	Azadi et al. (2016)

Regulations and policies on genetically modified (GM) crops, especially GM maize, pose significant challenges for farmers in regions like Ethiopia. Mmbando (2024) and Roba (2023) note that strict regulations limit access to GM seeds, hindering adoption. In many cases, cultivation, sale, and importation of GM seeds are heavily controlled or banned. Often shaped by political resistance and delays, these policies create uncertainty for farmers, discouraging long-term

investments in GM technologies. While concerns about environmental and health risks drive such regulations, they should be addressed with transparent, science-based frameworks that balance safety and the benefits of GM crops.

The high cost of GM maize seeds is a significant barrier to adoption, especially for smallholder farmers in South Africa with limited financial resources. Mulaudzi and Oyekale (2015) note that the high price stems from investments in biotechnology, intellectual property rights, and patents held by seed companies. Additionally, farmers must invest in complementary inputs like fertilizers and pesticides, further increasing costs. For those on tight budgets, these expenses can be prohibitive. Solutions like subsidies, public-private partnerships, and competitive pricing should be explored to make GM maize seeds more affordable and accessible.

Limited knowledge about GM maize is a key barrier to its adoption in Uganda, as Mustafa et al. (2023) noted. Many farmers lack exposure to modern agricultural technologies, leading to misconceptions about GM crops. These farmers may not understand how GM maize differs from conventional varieties and may have concerns about its safety and environmental impact. Misinformation can prevent them from recognizing the benefits, such as higher yields and pest resistance. Even when extension services are available, they may not effectively dispel myths. Educating farmers through outreach programs and demonstrations is essential to overcoming this challenge.

Biosafety concerns are a significant challenge to adopting GM maize in Ethiopia, as noted by Khan et al. (2024). These concerns focus on environmental risks, such as the impact on biodiversity, pest resistance, and cross-contamination with non-GM crops. There are also fears about the long-term health effects on humans and animals consuming GM crops. The lack of conclusive, long-term safety studies contributes to public uncertainty, hindering acceptance and slowing adoption, especially in regions with limited knowledge of agricultural biotechnology. These concerns lead to stricter regulations and social resistance to GM crops.

The accessibility of GM seeds is a significant barrier to adoption, especially in rural and remote areas, as Azadi et al. (2016) highlight. Even when GM maize is legally approved, logistical challenges, such as limited distribution networks, high transportation costs, and a lack of local suppliers, restrict seed availability. Smallholder farmers in isolated areas often struggle to access and afford GM seeds due to these barriers, preventing them from fully benefiting from the advantages of GM maize. This underscores the need for targeted strategies to improve seed accessibility for these farmers.

2.4 Limitations of the review

This review focused solely on studies from Sub-Saharan Africa, which may not fully reflect agricultural systems, policies, or socio-economic conditions in other regions. It included only studies from 2011 to 2024, excluding relevant research outside this period. The review may have overlooked other crop varieties with different implications for extension services and technical efficiency by concentrating on GM maize. Additionally, the review only included published studies, omitting potentially valuable unpublished sources like grey literature.

2.5 Summary of key findings

This review highlights the impact of agricultural extension services on the technical efficiency of GM maize adoption in sub-Saharan Africa. Models like Training and Visit, NAADS, and Farmer Field Schools effectively boost farmer knowledge, technology adoption, and productivity. Access to extension services increased GM maize adoption, leading to greater efficiency through pest resistance, higher yields, and reduced pesticide use.

Key factors influencing efficiency include inputs and variables like age, education, credit access, and land tenure. However, adoption still faces hurdles such as regulatory barriers, high costs, limited awareness, and biosafety concerns. Stakeholder opinions vary; some raise environmental and health concerns, while others view GM maize as vital for food security. The study recommends tailored extension services and stronger collaboration among

governments, NGOs, and communities to support sustainable farming, raise productivity, and strengthen regional food security.

2.6 Recommendations for future research

Future research could focus on the impact of agricultural extension services on the income of smallholder maize farmers. This could include the effect of extension services' income on adopters and non-adopters of GM maize seeds. Future research should explore the impact of extension services on technical efficiency in other regions and countries to provide a more comprehensive understanding of the topic. Furthermore, future research can also investigate the potential of digital technologies, such as mobile apps and online platforms, to improve the delivery and effectiveness of extension services for GM maize adoption.

2.7 Authors Contributions

Conceptualization: Athenkosi and Lelethu led the study's design and framework. Methodology: Athenkosi and Lelethu conducted the study's methodology and data management. Data collection: Athenkosi conducted data collection and analysis. Writing: Athenkosi wrote the original draft of the paper, and Lelethu, Oladele, Yanga, and Lwandiso assisted in reviewing and editing the manuscript for intellectual content.
Supervision: Lelethu and Oladele supervised the research and provided guidance.

2.8 Funding

The original research was not funded, and only the publication fee was funded for the article.

2.9 Conflict of Interest

The authors declare that there was no conflict of interest during the study.

2.10 Generative AI statement

The authors declare that no AI generative models were used to conduct this study.

2.11 Publisher's note

All claims expressed in this article are the authors' views and not those of the affiliated organization, editor, and publisher.

References

Abate, T.W., 2024. Analysis of agricultural technology adoption: the use of improved maize seeds and its determinants in Ethiopia, evidence from Eastern Amhara. *Journal of Innovation and Entrepreneurship*, *13*(1), pp.61.

Abdi, A.H., Mohamed, A.A. and Mohamed, F.H., 2024. Enhancing food security in subSaharan Africa: Investigating the role of environmental degradation, food prices, and institutional quality. *Journal of Agriculture and Food Research*, p.101241.

Addai, K.N. and Owusu, V., 2014. Technical efficiency of maize farmers across various agro ecological zones of Ghana. *Journal of Agriculture and Environmental Sciences*, *3*(1), pp.149-172.

Adelesi, O.O., Kim, Y.U., Schuler, J., Zander, P., Njoroge, M.M., Waithaka, L., Abdulai, A.L., MacCarthy, D.S. and Webber, H., 2024. The potential for index-based crop insurance to stabilize smallholder farmers' gross margins in Northern Ghana. *Agricultural Systems*, *221*, pp.104130.

Adem, M. and Gebregziabher, K., 2014. The effect of agricultural extension program on technical efficiency of rural farm households' evidence from northern Ethiopia:
stochastic frontier approach. *International Researchers Volume*, (3).

Adenle, A.A., 2014. Stakeholders' perceptions of GM technology in West Africa: Assessing the responses of policymakers and scientists in Ghana and Nigeria. *Journal of agricultural and environmental ethics*, *27*, pp.241-263.

Ahmed, M.H., Lemma, Z. and Endrias, G., 2014. Technical efficiency of maize producing farmers in Arsi Negelle, central rift valley of Ethiopia: stochastic frontier approach. *Agriculture & Forestry/Poljoprivreda i šumarstv*, *60*(1).

Akinbode, W.O. and Bamire, A.S., 2015. Determinants of adoption of improved maize varieties in Osun State, Nigeria. *Journal of Agricultural Extension and Rural Development*, *7*(3), pp.65-72.

Ala-Kokko, K., Nalley, L.L., Shew, A.M., Tack, J.B., Chaminuka, P., Matlock, M.D. and
D'Haese, M., 2021. Economic and ecosystem impacts of GM maize in South Africa. *Global Food Security*, *29*, pp.100544.

Arowosegbe, O.B., Alomaja, O.A. and Tiamiyu, B.B., 2024. The role of agricultural extension workers in transforming agricultural supply chains: enhancing innovation, technology adoption, and ethical practices in Nigeria. *World Journal of Advanced Research and Reviews*, *23*(3), pp.2585-2602.

Azadi, H., Samiee, A., Mahmoudi, H., Jouzi, Z., Rafiaani Khachak, P., De Maeyer, P. and Witlox, F., 2016. Genetically modified crops and small-scale farmers: main opportunities and challenges. *Critical reviews in biotechnology*, *36*(3), pp.434-446.

Badu-Apraku, B., Fakorede, M.A., Nelimor, C., Osuman, A.S., Bonkoungou, T.O., Muhyideen, O. and Akinwale, R.O., 2023. Recent advances in breeding maize for drought, heat and combined heat and drought stress tolerance in sub-saharan Africa. *CABI Reviews*, (2023).

Bashiru, M., Ouedraogo, M., Ouedraogo, A. and Läderach, P., 2024. Smart Farming Technologies for Sustainable Agriculture: A Review of the Promotion and Adoption Strategies by Smallholders in Sub-Saharan Africa. *Sustainability*, *16*(11), pp.4817.

Belete, A.S., 2020. Analysis of technical efficiency in maize production in Guji Zone: stochastic frontier model. *Agriculture & Food Security*, *9*, pp.1-15.

Bempomaa, B. and Acquah, H.D.G., 2014. Technical efficiency analysis of maize production: evidence from Ghana. *Applied Studies in Agribusiness and Commerce*, *8*(2-3), pp.73-79.

Benjamin, E.O., Ola, O., Lang, H. and Buchenrieder, G., 2021. Public-private cooperation and agricultural development in Sub-Saharan Africa: a review of Nigerian growth enhancement scheme and e-voucher program. *Food Security*, *13*(1), pp.129140.

Bonye, S.Z., Alfred, K.B. and Jasaw, G.S., 2012. Promoting community-based extension agents as an alternative approach to formal agricultural extension service delivery in Northern Ghana. *Asian Journal of Agriculture and Rural Development*, *2*(1), pp.76-95.

Cairns, J.E., Chamberlin, J., Rutsaert, P., Voss, R.C., Ndhlela, T. and Magorokosho,
C., 2021. Challenges for sustainable maize production of smallholder farmers in subSaharan Africa. *Journal of Cereal Science*, *101*, pp.103274.

Carelsen, C.P.R., Ncube, B. and Fanadzo, M., 2021. Classification and characterisation of smallholder farmers in South Africa: a brief review. *South African Journal of Agricultural Extension*, *49*(2), pp.97-106.

Catherine, K.N., Mugiira, B.R. and Muchiri, N.J., 2024. Public perception of genetically modified organisms and the implementation of biosafety measures in Kenya. *Advances in Agriculture*, *2024*(1), pp.5544617.

Chagwena, D.T., Sithole, B., Masendu, R., Chikwasha, V. and Maponga, C.C., 2019. Knowledge, attitudes and perceptions towards genetically modified foods in Zimbabwe. *African Journal of Food, Agriculture, Nutrition and Development*, *19*(3), pp.14752-14768.

Chikowo, R., Zingore, S., Snapp, S. and Johnston, A., 2014. Farm typologies, soil fertility variability and nutrient management in smallholder farming in Sub-Saharan Africa. *Nutrient cycling in agroecosystems*, *100*, pp.1-18.

Chiona, S., Kalinda, T. and Tembo, G., 2014. Stochastic frontier analysis of the technical efficiency of smallholder maize farmers in Central Province, Zambia. *Journal of Agricultural Science*, *6*(10), pp.108.

Choruma, D.J., Dirwai, T.L., Mutenje, M., Mustafa, M., Chimonyo, V.G.P., JacobsMata, I. and Mabhaudhi, T., 2024. Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in subSaharan Africa. *Journal of Agriculture and Food Research*, pp.101286.

Danso-Abbeam, G., Ehiakpor, D.S. and Aidoo, R., 2018. Agricultural extension and its effects on farm productivity and income: insight from Northern Ghana. *Agriculture & Food Security*, *7*(1), pp.1-10.

Debebe, S., Haji, J., Goshu, D. and Edriss, A.K., 2015. Technical, allocative, and economic efficiency among smallholder maize farmers in Southwestern Ethiopia: Parametric approach. *Journal of development and Agricultural Economics*, *7*(8), pp.282-291.

Di Falco, S., 2018. Adapting to climate change in sub-Saharan Africa. *Berck C, Berck P, Di Falco S (2018) Agricultural adaptation to climate change in Africa. Resources of the Future Press, New York*.

Djoumessi, Y.F., 2022. New trend of agricultural productivity growth in sub-Saharan Africa. *Scientific African*, *18*, pp.e01410.

Dokyi, E., Anang, B.T. and Owusu, V., 2021. Impacts of improved seed maize technology adoption on productivity and technical efficiency in northern Ghana. *Open Economics*, *4*(1), pp.118-132.

Ekpa, O., Palacios-Rojas, N., Kruseman, G., Fogliano, V. and Linnemann, A.R., 2018. Sub-Saharan African maize-based foods: technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. *Global food security*, *17*, pp.48-56.

Fischer, K., van den Berg, J. and Mutengwa, C., 2015. Is Bt maize effective in improving South African smallholder agriculture?. *South African Journal of Science*, *111*(1-2), pp.01-02.

Gcaba, K., Christian, M. and Usapfa, L., 2024. Does the Adoption of Genetically Modified Seeds Improve the Technical Efficiency of Family-Owned Maize Farms? A Case of Alfred Nzo in the Eastern Cape. *South African Journal of Agricultural Extension*, *52*(4), pp.148-165.

Gebretsadik, K. and Kiflu, A., 2018. Challenges and opportunities of genetically modified crops production; future perspectives in ethiopia, review. *The Open Agriculture Journal*, *12*(1).

Giller, K.E., 2020. The food security conundrum of sub-Saharan Africa. *Global Food Security*, *26*, pp.100431.

Giller, K.E., Delaune, T., Silva, J.V., van Wijk, M., Hammond, J., Descheemaeker, K., van de Ven, G., Schut, A.G., Taulya, G., Chikowo, R. and Andersson, J.A., 2021. Small farms and development in sub-Saharan Africa: Farming for food, for income or for lack of better options?. *Food Security*, *13*(6), pp.1431-1454.

Gouse, M., 2012. GM maize as subsistence crop: The South African smallholder experience.

Habib, N., 2024. Omission in Adoption: Whole of Systems Approach Applied to Case Study Analysis of Genetically Modifi ed (GM) Maize Adoption in Eastern Cape Province South Africa. *MSD Journal of Agricultural Science and Applied Economics, 1(1),* pp. 001-022.

Hlophe-Ginindza, S.N. and Mpandeli, N.S., 2021. The role of small-scale farmers in ensuring food security in Africa. *Food Secur. Afr*, *10*.

John, K.M. and Seini, W., 2013. Technical efficiency analysis of maize farmers in the Eastern Region of Ghana. *Journal of Social and Development Sciences*, *4*(2), pp.84-
99.

Jolex, A., 2022. Influence of agricultural extension services on technical efficiency of maize farmers in Malawi. *African Journal of Agricultural and Resource Economics*, *17*(1), pp.92-105.

Kaazara, A.G., 2024. Biotechnology and Agricultural Productivity: A Case Study of Maize Farmers in Iganga. *Metropolitan Journal of Business & Economics*, 3(10), pp.
386-395.

Kapari, M., Hlophe-Ginindza, S., Nhamo, L. and Mpandeli, S., 2023. Contribution of smallholder farmers to food security and opportunities for resilient farming systems. *Frontiers in Sustainable Food Systems*, *7*, pp.1149854.

Kavhiza, N.J., Zargar, M., Prikhodko, S.I., Pakina, E.N., Murtazova, K.M.S. and Nakhaev, M.R., 2022. Improving crop productivity and ensuring food security through the adoption of genetically modified crops in sub-Saharan Africa. *Agronomy*, *12*(2), pp.439.

Kedisso, E.G., Maredia, K., Guenthner, J. and Koch, M., 2022. Commercialization of genetically modified crops in Africa: opportunities and challenges. *African Journal of Biotechnology*, *21*(5), pp.188-197.

Khan, G.M., Seid, E. and Abdu, S., 2024. Genetically modified crops: their advantages, challenges and role in food security in pastoral region afar, ethiopia: a review: Genetically Modified Crops. *life sciences leaflets*, *170*, pp.15-27.

Khonje, M., Manda, J., Alene, A.D. and Kassie, M., 2015. Analysis of adoption and impacts of improved maize varieties in eastern Zambia. *World development*, *66*, pp.695-706.

Kimani, S., 2024. The Role of Agricultural Innovation in Enhancing Food Security in Sub-Saharan Africa. *International Journal of Developing Country Studies*, *6*(1), pp.58-
73.

Kotey, D.A., Assefa, Y., Obi, A. and Van den Berg, J., 2016. Disseminating genetically modified (GM) maize technology to smallholder farmers in the Eastern Cape province of South Africa: extension personnel's awareness of stewardship requirements and dissemination practices. *South African Journal of Agricultural Extension*, *44*(1), pp.59-
74.

Mabaya, E., Fulton, J., Simiyu-Wafukho, S. and Nang'ayo, F., 2015. Factors influencing adoption of genetically modified crops in Africa. *Development Southern Africa*, *32*(5), pp.577-591.

Madzivanzira, T., Mvumi, B.M., Nazare, R.M., Nyakudya, E., Mtambanengwe, F. and Mapfumo, P., 2024. A review of appropriate mechanisation systems for sustainable traditional grain production by smallholder farmers in sub-Saharan Africa with particular reference to Zimbabwe. *Heliyon*.

Magakwe, N. and Olorunfemi, O. A. 2024. Systematic Review of the Trends, Effects, and Deterrents of Collective Marketing Participation Among Smallholder Farmers in Sub-Saharan Africa. *Sustainability*, *16*, 9578.

Makate, C. and Makate, M., 2019. Interceding role of institutional extension services on the livelihood impacts of drought tolerant maize technology adoption in Zimbabwe. *Technology in Society*, *56*, pp.126-133.

Mangani, R., Gunn, K.M. and Creux, N.M., 2023. Projecting the effect of climate change on planting date and cultivar choice for South African dryland maize production. *Agricultural and Forest Meteorology*, *341*, pp.109695.

Mapiye, O., Makombe, G., Molotsi, A., Dzama, K. and Mapiye, C., 2021. Towards a revolutionized agricultural extension system for the sustainability of smallholder livestock production in developing countries: The potential role of icts. Sustainability, 13(11), pp.5868.

Martey, E., Etwire, P.M. and Kuwornu, J.K., 2020. Economic impacts of smallholder farmers' adoption of drought-tolerant maize varieties. *Land use policy*, *94*, pp.104524.

Mdoda, L., Obi, A., Christian, M. and Jiba, P., 2021. Technical efficiency of maizebased farm irrigators in the Eastern Cape province. *Journal of Agribusiness and Rural Development*, *62*(4), pp.371-381.

Merga, G., Sileshi, M. and Zeleke, F., 2023. Welfare impact of improved maize varieties adoption among smallholder farmers in Amuru district of Horo Guduru Wollega, Ethiopia. *Cogent Economics & Finance*, *11*(1), pp.2207923.

Mignouna, D.B., Manyong, V.M., Rusike, J., Mutabazi, K.D.S. and Senkondo, E.M., 2011. Determinants of adopting imazapyr-resistant maize technologies and its impact on household income in Western Kenya.

Mmbando, G., 2024. The Adoption of Genetically Modified Crops in Africa: the Public's Current Perception, the Regulatory Obstacles, and Ethical Challenges. *GM Crops & Food*, *15*(1), pp.1-15.

Mugambiwa, S.S., 2023. Sustainable agriculture and sustainable developmental goals: a case study of smallholder farmers in sub-Saharan Africa. In *Sustainable Agriculture and the Environment* (pp. 91-103). Academic Press.

Mukembo, S.C. and Edwards, C.M., 2015. Agricultural extension in Sub-Saharan
Africa during and after its colonial era: The case of Zimbabwe, Uganda, and
Kenya. *Journal of International Agricultural and Extension Education*, *22*(3), pp.50-68.

Mukembo, S.C. and Edwards, C.M., 2015. Agricultural extension in Sub-Saharan Africa during and after its colonial era: The case of Zimbabwe, Uganda, and
Kenya. *Journal of International Agricultural and Extension Education*, *22*(3), pp.50-68.

Mulaudzi, V.S. and Oyekale, A.S., 2015. Smallholder farmer's adoption intensity of genetically modified maize varieties in Thulamela municipality, Limpopo province, South Africa. *Environmental economics*, (6, Iss. 1), pp.104-112.

Mushunje, A., Muchaonyerwa, P., Mandikiana, B.W. and Taruvinga, A., 2011. Smallholder farmers' perceptions on Bt maize and their relative influence towards its adoption: The case of Mqanduli communal area, South Africa. *African Journal of Agricultural Research*, *6*(27), pp.5918-5923.

Mustafa, A.S., Ssenku, J.E., Nyachwo, E.B., Ruto, G.C., Bunani, N., Musimami, G., Maseruka, R. and Anywar, G., 2023. Assessing knowledge and willingness to use genetically modified crops in Uganda. *Agriculture & Food Security*, *12*(1), pp.28.

Muzeza, N.T., Taruvinga, A. and Mukarumbwa, P., 2023. Analysis of factors affecting technical efficiency of A1 smallholder maize farmers under command agriculture scheme in Zimbabwe: The case of Chegutu and Zvimba Districts. *Cogent Economics & Finance*, *11*(1), pp.2163543.

Muzhinji, N. and Ntuli, V., 2021. Genetically modified organisms and food security in Southern Africa: conundrum and discourse. *GM Crops & Food*, *12*(1), pp.25-35.

Ndhleve, S., Obi, A. and Nakin, M.D.V., 2017. Public spending on agriculture and poverty in Eastern Cape Province, South Africa. *African Studies Quarterly*, *17*(2), pp.23-46.

Ndona, A., Kambashi, B., Beckers, Y., Moulin, C.H. and Bindelle, J., 2024. Contribution of traditional goat farming systems to the sustainable intensification of smallholder agriculture in sub-Saharan Africa: The example of the western part of the Democratic Republic of Congo. *Farming System*, *2*(2), pp.100079.

Ng'Atigwa, A.A., Hepelwa, A., Manyong, V. and Feleke, S., 2022. Analysis of technical efficiency among youth involved in crop production in Njombe Region, Tanzania. *Cogent Economics & Finance*, *10*(1), pp.2103923.

Ngcinela, S., Mushunje, A., Taruvinga, A., Ngarava, S. and Mutengwa, C.S., 2019. Determinants of genetically modified (GM) maize adoption and the intensity of adoption in OR Tambo District Municipality, Eastern Cape Province, South Africa. *GM Crops & Food*, *10*(1), pp.1-11.

Nwafor, C.U., Ogundeji, A.A. and Nwafor, I.C., 2021. Review of agricultural extension and advisory services in Sub-Saharan African countries. Progress with private sector involvement. *Journal of Agribusiness and Rural Development*, *3*.

Nwafor, C.U., Ogundeji, A.A. and Nwafor, I.C., 2021. Review of agricultural extension and advisory services in Sub-Saharan African countries. Progress with private sector involvement. *Journal of Agribusiness and Rural Development*, *3*.

Nyambo, D.G., Luhanga, E.T. and Yonah, Z.Q., 2019. A review of characterization approaches for smallholder farmers: Towards predictive farm typologies. *The Scientific World Journal*, *2019*(1), pp.6121467.

Nyambo, P., Nyambo, P., Mavunganidze, Z. and Nyambo, V., 2022. Sub-Saharan Africa smallholder farmers agricultural productivity: risks and challenges. In *Food security for African smallholder farmers* (pp. 47-58). Singapore: Springer Nature Singapore.

Nyambo, P., Nyambo, P., Mavunganidze, Z. and Nyambo, V., 2022. Sub-Saharan Africa smallholder farmers agricultural productivity: risks and challenges. In *Food security for African smallholder farmers* (pp. 47-58). Singapore: Springer Nature Singapore.Odusola, A., 2017. Agriculture, rural poverty and income inequality in subSaharan Africa. *Income Inequality Trends in Sub-Saharan Africa: Divergence, Determinants and Consequences (2017)*.

Olayemi, S.S., Alo Adeola Ope-Oluwa, A.A.O.O. and Angba, C.W., 2021. Evolution of agricultural extension models in Sub-Saharan Africa: A critical review. *International Journal of Agricultural Extension and Rural Development Studies*, *8*(1), pp.29-51.

Oluwole, A.J., Segun, A.O., Bayonle, R.S., Samuel, B.B. and Oladeji, O.I., 2021. Effect of extension training on technical efficiency of maize farmers in Ogbomoso agricultural zone of Oyo State, Nigeria. *Int J Res Rev*, *8*(9), pp.210-217.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E. and Chou, R., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *bmj*, *372*.

Pan, Y., Smith, S.C. and Sulaiman, M., 2018. Agricultural extension and technology adoption for food security: Evidence from Uganda. *American Journal of Agricultural Economics*, *100*(4), pp.1012-1031.

Roba, H.M., 2023. The Issue of Genetically Modified Organizim (GMO) And Assess to Food in Ethiopia. *Journal of Biotechnology and Immunology*, *5*(1), pp.2.

Schnurr, M.A. and Dowd-Uribe, B., 2021. Anticipating farmer outcomes of three genetically modified staple crops in sub-Saharan Africa: Insights from farming systems research. *Journal of Rural Studies*, *88*, pp.377-387.

Sigigaba, M., Mdoda, L. and Mditshwa, A. 2021. Adoption Drivers of Improved OpenPollinated (OPVs) Maize Varieties by Smallholder Farmers in the Eastern Cape
Province of South Africa. Sustainability, 13, 13644. https://doi.org/10.3390/su132413644.

Simanjuntak, C., Gaiser, T., Ahrends, H.E., Ceglar, A., Singh, M., Ewert, F. and Srivastava, A.K., 2023. Impact of climate extreme events and their causality on maize yield in South Africa. *Scientific Reports*, *13*(1), pp.12462.

Somanje, A.N., Mohan, G. and Saito, O., 2021. Evaluating farmers' perception toward the effectiveness of agricultural extension services in Ghana and Zambia. *Agriculture & Food Security*, *10*, pp.1-16.

Taye, H., 2013. Evaluating the impact of agricultural extension programmes in subSaharan Africa: Challenges and prospects. *African Evaluation Journal*, *1*(1), pp.9.

Tenaye, A., 2020. Technical efficiency of smallholder agriculture in developing countries: The case of Ethiopia. *Economies*, *8*(2), pp.34.

Tumuri, A., Geleta, D. and Sime, G., 2024. Technical efficiency of maize production and their determinants among smallholder farmers in Ethiopia: a case study in Sidama Region. *Cogent Food & Agriculture*, *10*(1), pp.2392045.

Tweneboah Kodua, T., Ebo Onumah, E. and Mensah-Bonsu, A., 2022. Technical efficiency of improved and local variety seed maize farms in Ghana: A meta-frontier analysis. *Cogent Economics & Finance*, *10*(1), pp.2022858.

Viana, C.M., Freire, D., Abrantes, P., Rocha, J. and Pereira, P., 2022. Agricultural land systems importance for supporting food security and sustainable development goals: A systematic review. *Science of the total environment*, *806*, pp.150718.

Wamatsembe, I.M., Asea, G. and Haefele, S.M., 2017. A survey: potential impact of genetically modified maize tolerant to drought or resistant to stem borers in Uganda. *Agronomy*, *7*(1), pp.24.

Wanyama, R., Mathenge, M.W. and Simba, Z., 2016. Agricultural information sources and their effect on farm productivity in Kenya.

Weldegebriel, H., 2015. The determinants of technical efficiency of farmers in Teff, Maize and Sorghum production: empirical evidence from Central Zone of Tigray Region. *Ethiopian Journal of Economics*, *23*(2), pp.1-36.

Weldegebriel, H., 2015. The determinants of technical efficiency of farmers in Teff, Maize and Sorghum production: empirical evidence from Central Zone of Tigray Region. *Ethiopian Journal of Economics*, *23*(2), pp.1-36.

Wiggins, S. and Keats, S., 2013. Leaping and Learning: Linking smallholders to markets in Africa.

Wollburg, P., Bentze, T., Lu, Y., Udry, C. and Gollin, D., 2024. Crop yields fail to rise in smallholder farming systems in sub-Saharan Africa. *Proceedings of the National Academy of Sciences*, *121*(21), pp.e2312519121.

Wongnaa, C.A. and Awunyo-Vitor, D., 2018. Achieving sustainable development goals on no poverty and zero hunger: Does technical efficiency of Ghana's maize farmers matter?. *Agriculture & Food Security*, *7*, pp.1-13.

Wudil, A.H., Usman, M., Rosak-Szyrocka, J., Pilař, L. and Boye, M., 2022. Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *International Journal of environmental research and Public Health*, *19*(22), pp.14836.

CHAPTER 3

Determinants and Intensity of GM Maize Seed Use among Maize Farmers in the Eastern Cape Province, South Africa

Abstract

Maize is South Africa's most important staple crop and a central pillar of food security. Yet, its production is increasingly constrained by climate variability, pest outbreaks such as Fall Armyworm, rising input costs, and persistent yield gaps across Africa. In response, Genetically Modified (GM) maize seeds have been promoted as productivity-enhancing technologies that reduce production risks and improve farm incomes, positioning South Africa as a continental leader in agricultural biotechnology and a signatory to international agreements such as the Chatham Convention on the use of GMOs. Despite this enabling policy environment, the adoption of GM crops remains relatively slow and is often analysed as a binary decision, masking important variations in the intensity of adoption, including land allocation to GM seeds and consistency of use over time. These variations are strongly influenced by socioeconomic conditions, institutional support, market access, and agro-ecological factors. The limited empirical evidence on adoption intensity constrains a nuanced understanding of how GM technology contributes to productivity, resilience, and food security outcomes. Consequently, this knowledge gap undermines the development of targeted policies and extension strategies to foster inclusive and sustainable maize production in South Africa. Hence, this study investigated the adoption intensity of GM seeds by maize farmers in the Eastern Cape Province using a quantitative approach. A multistage sampling method was used to collect data from 306 maize farmers using a semi-structured questionnaire. Descriptive statistics and the DoubleHurdle Model using Probit regression and truncated regression were employed to examine the adoption intensity in the Eastern Cape Province. The overall pool revealed female dominance (56.9%), with an average age of 61 years, 7 years spent at school, managing about 8 hectares, and an average income of ZAR 6637.52. Different maize varieties were adopted by the farmers, such as GM maize (BT), GM (BT/HT), and traditional seeds. Farmers

indicated that they had adopted GM seeds for several reasons, which included improved yields, drought tolerance, pest and herbicide resistance. Despite the benefits, the study revealed several challenges regarding the adoption of GM maize seeds, such as lack of access to information, technological factors, high costs and biosafety concerns. The probit model indicated several significant variables that affected GM adoption such as gender (p=0.091), years spent in school (p=0.032), marital status (p=0.003), household size (p=0.004), household monthly income (p=0.006), land size (p=0.038) access to extension services (p=0.000), amount of credits (p=0.001) were positively influencing the adoption of GM maize seeds by farmers, while distance to markets was negatively associated with adoption of GM seeds. The truncated regression model revealed household size (p=0.003), household income (p=0.000), land size (p=0.000), amount of credits (p=0.000), positively influenced adoption intensity, distance to markets (p=0.068) was negatively associated with the intensity of adoption of GM maize seeds by farmers. Based on these results, the study suggests that the government should develop policies that strengthen farmer education and extension services, improve access to affordable housing credit and mechanisms that will promote income support, promote efficient land use strategies, and enhance market access by improving infrastructure and farmer organizations. Furthermore, policymakers should provide household-centered and labour interventions that include mechanization support, which will encourage both adoption and intensity of use of GM maize among smallholder farmers in the Eastern Cape Province.

Keywords: Genetically modified maize; Adoption intensity; Smallholder farmers; Agricultural biotechnology; Seed technology; Productivity; Eastern Cape Province; South Africa

3.1 Introduction

Cereal crops are among the most significant and widely traded commodities across the world (Yamini et al., 2025). These crops cover about half of the world's harvested agricultural land, and they cover approximately 736 million

hectares and contribute about 3.0 billion metric tonnes to global production (Yamini et al., 2025). According to Tse and Reaney (2025), wheat, maize, and rice constitute the main dietary staples for a large proportion of the world's population. With the global population expected to surpass 9 billion by 2050, alongside increasing pressures from climate change, there is an urgent need to boost global cereal production by roughly 70% (Tse and Reany, 2025). At the continental level, particularly in Africa, crop production continues to be the dominant subsector as it contributes an average of 85% of the total agricultural output between 1990 and 2013 (Musse et al., 2025). Although its importance differs across regions, it represents about 53% in Southern Africa and more than 90% in Western Africa (Musse et al., 2025).

Maize is the most significant cereal crop and is cultivated in almost every part of the world (Dragomir et al., 2022). Along with rice and wheat, maize provides at least 30% of the global food calories, and it is also a very important source of protein for about 4.5 billion people across over 90 developing countries (Dragomir et al., 2022). The growth in maize production is driven by its wide adaptability to different ecological conditions, as well as its high demand for bioethanol, animal feed, and its use in producing sweeteners and various non-food industrial products, including biodegradable packaging materials (Dragomir et al. 2022). For instance, the global maize area (for dry grain) is around 197 million hectares, which includes bigger areas in sub-Saharan Africa (SSA), Asia, and Latin America (Erenstein, 2022). Hence, maize plays a multifaceted and significant role in the world's agri-food systems, including both food and nutritional security (Erenstein, 2022).

In South Africa, maize has an estimated annual production of more than 10 million tons (Seti and Madini, 2025). As one of the leading maize producers within the SADC region, producing 13.4 million metric tons from 3 million hectares, followed by Nigeria with 11.05 million metric tons produced from 5.7 million hectares. Ethiopia maintained a stable output of 10.2 million metric tons from 2.55 million hectares, while Egypt recorded maize production of 7.2 million metric tons during the 2023/2024 marketing year (Milling Middle East & Africa, 2023). The maize industry in the country plays a vital role in job creation, income

generation, and foreign exchange earnings, with employment in primary agriculture increasing by 6% year-on-year to 941,000 in the first quarter of 2024 (Seti and Madini, 2025; Sihlobo, 2024). For instance, in the year 2020, the value of maize exports from South Africa exceeded R9 billion, which contributed to the extensive total agricultural exports that reached R168 billion (Geyser, Pretorius and Fourie, 2024). The country has two major deep-sea grain ports, one in Durban and has three big grain exports including import terminals, and the other in East London, which has only one terminal. When operating at its full capacity, the terminals located in Durban can collectively handle exports of around seven supermax vessels with each having a carrying capacity of around 55,000 tonnes a year (Geyser et al., 2024). Maize is grown in all provinces of South Africa, and the dominant provinces are the Free State (43.8%), Mpumalanga (22.0%), and Northwest province (16.8%), while the Eastern Cape is among the least contributors at (1.5%) (Statistics South Africa, 2025). Roughly 90% of the country's maize is cultivated under dryland (rainfed) environments, whereas the remaining 10% is reported to be produced under irrigation (Department of Agriculture, Land Reform and Rural Development, [DALRD], 2021).

Since the deregulation of agricultural marketing, the SA maize market has improved tremendously (National Agricultural Marketing Council [NAMC], 2024). South African producers, traders, and other value chain actors participate freely in the maize marketing of the country. The majority of maize produced in the country is consumed locally, with the local market being a significant part of the maize industry and the major driver of its stability and growth (NAMC, 2024). Table 3.1 below shows the production of both white and yellow maize around the various provinces from 2014/15 up to the 2022/23 production seasons.

Table 3.1: Showing maize production from 2014/15 to 2022/23 production seasons in South Africa

White Maize Production ('000 t)									
Province	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23
Free State	2236	1190.5	5110	3350	2795	4700	4492	3801.9	4446
Northwest	1046	816	2599	1670	1274	2196	2130	2047.5	2188.8

Mpumalanga	824	752	1088	812	797.5	872	1100.5	1072.5	1032.9
Gauteng	193.6	207	390	275	259.2	297	371.2	361.6	364
Kwazulu-Natal	224	215	350	280	270	298.4	310	322.4	298.9
Limpopo	156.75	178	300	90	83.2	105	112.2	102.3	114.24
Eastern Cape	15.6	10	30.8	21.7	23	35.2	39	40.8	40.25
Northern Cape	35	35	46.2	41.3	39.5	40.3	40.3	36	12.5
Western Cape	4.05	5	2	0	3.6	3.6	4.8	4.75	2.375
Total	**7710.00**	**4735.00**	**3408.50**	**9916.00**	**6540.00**	**5545.00**	**8547.50**	**8600.00**	**7789.75**
Yellow Maize Production ('000 t)									
Province	2014/15	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**
Free State	1708.5	1023	2252	1925	1758	2209	2542	2547.2	2686.7
Mpumalanga	1605.3	1567	2342.5	2005	1977.3	2347.5	2820	2537.5	2587.2
Northern Cape	644	675	666	628	630.75	633.9	627.3	672	696
Northwest	444	325	561	428.55	399	522	556	554.6	590
Kwazulu-Natal	283.5	307	390	380	399.6	434.5	451	489.7	533
Gauteng	292.5	235	414	356.5	348	330	380	403.2	390
Eastern Cape	84	66	66.5	71.5	69.75	119	133.2	157.85	192.5
Limpopo	124	132	192	141.7	117	126	172.2	202.5	186.96
Eastern Cape	34.2	40	20	33.75	30.6	30.6	33.3	32.9	32.9
Total	**5220.00**	**4370.00**	**6904.00**	**5970.00**	**5730.00**	**6752.50**	**7715.00**	**7597.45**	**789526**

Source: NAMC, 2024

According to the data depicted above in Table 3.1, showing trends on white maize and yellow maize production across the country's provinces from the year 2014/15 to 2022/23 production seasons. The overall production shows

significant year-to-year fluctuations in maize production, and this was influenced by climatic conditions and market dynamics. Provinces like Free State, Mpumalanga, and the Northwest continue to dominate the country's production for both white and yellow. Table 3.1 shows that the production peaked in 2016/17 at more than 9.99 million tonnes for white maize and was followed by slight variations in the following years. This shows the sector's sensitivity to the impact of drought and rainfall changes. While yellow maize production reached a notable 7.7 million tonnes in the year 2020/21, with Mpumalanga and the Free State accounting as the key contributors.

In South Africa, the agricultural sector operates under a dual farming system, which comprises commercial and smallholder farmers (Msomi and Zenda, 2024). The commercial farmers are mostly white and benefit from historical advantages, such as apartheid-era subsidies, which enable them to farm large areas and use advanced technologies (Msomi and Zenda, 2024). While Smallholder farmers are predominantly black and are located in former homeland areas, they cultivate small plots. The productivity of these farmers remains very low due to limited access to modern technologies, climate variability, pest outbreaks such as Fall Armyworm, rising input costs, and persistent yield gaps (Msomi and Zenda, 2024). In response to this, the adoption of genetically modified (GM) maize technologies can help improve maize production in South Africa by increasing yields, enhancing resistance to pests and diseases, and reducing the reliance on chemical inputs by farmers (Ngqulana et al., 2025). Despite the potential benefits of GM maize, the adoption in South Africa remains relatively low, particularly among smallholder farmers. With empirical evidence on determinants, extent, and impacts of GM maize adoption being limited, as few studies provide comprehensive provincial insights. Hence, there is a need to further research that will help in understanding the adoption patterns and the factors that affect the wider use of GM maize by smallholder farmers. This will assist in informing policies and interventions which are aimed at improving maize productivity in the Eastern Cape Province.

3.2 Theoretical Framework

The Technology Acceptance Model [TAM], the Diffusion Theory, and the Scaling Theory were adopted to explain the process behind the acceptance, diffusion, and scaling of GM maize seed technologies among smallholder farmers. Together, these theories offer a comprehensive framework for explaining the factors that influence both the adoption and the level of use of GM maize among smallholder farmers in the Eastern Cape Province of South Africa. The use [TAM] (Figure 3.1) below helps to predict the adoption behaviour of the farmers and offers a theoretical basis for the successful implementation of agricultural technologies like GM maize (Marikyan and Papagiannidis, 2024). TAM stands as one of the most influential models that predicts the farmers' behaviour towards technology usage, as it focuses on two crucial determinants, such as usefulness and the user-friendliness of the accepted technology.

The usefulness of GM maize technology is influenced by demographic factors, which include the farmers' gender, educational level, age, and income levels (Medani, 2024). Therefore, if the maize farmers believe that the use of GM maize technologies has higher yield potential, drought resistance, disease tolerance, and a shorter maturity period. Then these features are likely to shape the perception of the usefulness and ease of use of GM maize seeds. In the context of agriculture, several studies have shown that observable agronomic and economic benefits, such as improved yields, pest and disease resistance, and drought resistance, increase the adoption of GM technologies (Muzhinji and Ntuli, 2021; Ngqulana et al., 2025; Mukhtar, 2021). This means that if farmers see clear, visible benefits, they are more likely to adopt them GM maize seeds. Furthermore, the farmers will be more likely to allocate larger proportions of their land for GM cultivation and thereby increase the adoption intensity. When looking at the perceived ease of use, this speaks to compatibility, complexity, including how manageable the GM maize technology is under the farmers' existing knowledge, labour potential, and resource availability. Therefore, the manageability of these technologies by farmers is influenced by agricultural extension services through the sharing of new agricultural information to farmers, which results in capacity development (Antwi-Agyei and Stringer,

2021). Once the farmers are capacitated and perceive that the use of GM maize is less complex and straightforward to use, the chances of adoption will increase and improve the intensity of use. All in all, the usefulness and ease of use of GM maize are heavily influenced by the attributes of GM maize, which all shape the attitude of the farmer towards using the technology.

The Diffusion of Innovation Theory complements this perspective by emphasizing the social and communication mechanisms that influence GM maize uptake by the smallholder farmers (Wani and Ali, 2015). The relationship between the adoption of GM and diffusion theory is very important to understand how innovations spread throughout the social system. Therefore, the manner in which GM maize seeds are communicated across different segments of society, along with the perceptions and attitudes surrounding them, plays a key role in influencing the speed of their diffusion and adoption. The theory explains that the spread of innovations is shaped by multiple factors, including the characteristics of the innovation, the communication channels used, and the structure of the social system (Wani and Ali, 2025). Therefore, the diffusion of GM maize will follow these principles as mentioned in the diffusion theory:

Genetically Modified Maize characteristics: these will influence the rate of adoption of GM maize by smallholder farmers, and these may include compatibility, complexity, trialability and observability. If the GM diffused to the farmers offers clear advantages over the ones that are currently used, in line with the current farming systems, and the results are observable to farmers, then the technology will be spread quickly among the farmers. Communication channels are also emphasized in the diffusion theory; they may include the traditional means of communication (rituals, ceremonies, funerals and weddings), radios, televisions, farm visits, and demonstrations by extension officers (Makamane et al.,2024; Tegene et al., 2023). If the extension officer uses a correct channel of communication, then the adoption of the GM by smallholder farmers will improve significantly.

Time is also very significant in the diffusion of innovation; the diffusion theory outlines that innovations will follow a certain pattern of adoption over time, and this will be characterised by an S-shaped curve. This illustrates that an

innovation will be adopted by a few individuals, then followed by most of the farmers. In the social system, the socio-demographic characteristics influence whether the farmers will adopt an innovation or not (Mwaipungu et al., 2023). These may include the availability of farm income, the culture, labour, available credits and support to the farmers. The theory states that the social system acts as a catalyst in the adoption of innovation by smallholder farmers. Hence, the relationship between the adoption of GM and diffusion theory highlights the significance of having a clear understanding of how innovations spread within a group of farmers. If all these principles could be considered by both policy makers and agricultural extension advisors when disseminating innovations to farmers, then the adoption of innovations would improve, consequently improving efficiency.

The Scaling theory complements the diffusion theory as it explains how adoption of GM technology deepens and expand a time goes on. The ST is a very significant method for the exploration of dynamic systems and can be utilized in understanding how social networks evolve (Davey and Darvizeh, 2023). When it comes to the intensity of GM maize seeds, the ST does not only focus on whether the farmer adopts GM maize seeds, but also how extensively the farmers allocate the GM seeds in his/her land and continue to use them. Based on the ST, the intensity of adoption increases when farmers pass the experimentation and start expanding and sustaining the use of technology (Dicaglio, 2021). Therefore, this will be influenced by the demographic profile of the farmers, which includes having access to production resources, having enough knowledge, and having market access. For GM seeds, scaling will occur when maize farmers allocate bigger areas of their land to GM seeds and invest more in complementary production inputs such as seeds, fertilizers, and herbicides and mix GM seeds with their traditional farming practices.

Furthermore, when looking at the household level, human capital in the form of education and experience, financial capability in the form of household income and credit access, and labour availability will determine whether the farmer will intensify adoption. Literate farmers stand a good chance of managing GM seeds and enhancing their production practices, whereas those with higher household

income will be able to purchase good-quality seeds and production inputs needed for large-scale production. Likewise, land size and secured land access allow farmers to increase the scale of production without compromising their food security. ST also emphasizes the role of having access to reliable markets, infrastructure, and storage, and supportive policies. Therefore, the ST emphasises that GM maize seed adoption intensity will increase once maize farmers face fewer production challenges than the higher expected returns from GM maize seeds (Schut et al., 2020).

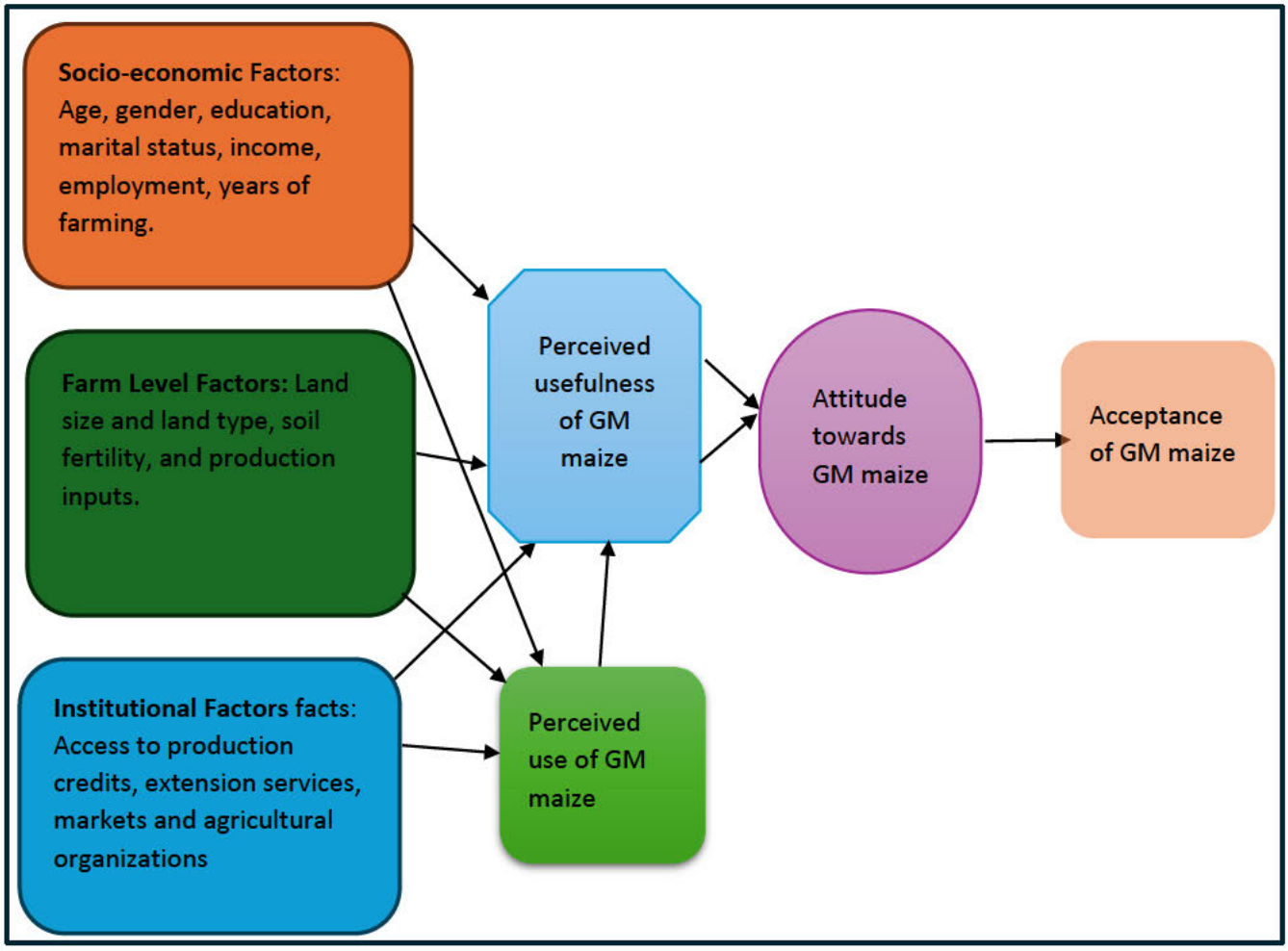


Figure 3.1: The Technology Acceptance Model [TAM]

3.3 Research Methodology

The methodological structure of this study comprises the study area, the design of the study, and the model specification.

3.3.1 Description of the Study Area

This research was carried out in the Eastern Cape Province, which is one of the nine provinces in South Africa, located along the country's southern coast (Gadu et al., 2025). The province consists of two metropolitan municipalities and six district municipalities, which are further divided into 29 local municipalities (Gadu et al., 2025). Despite its administrative diversity, the province is seen as one of the poorest provinces in the country. The Eastern Cape Province was chosen because maize is the primary staple crop for rural households, yet productivity among smallholder farmers remains persistently low. For instance, a report released by Statistics South Africa indicated that Eastern Province contributes only 1.5% of the total maize output produced in the country. Furthermore, the Eastern Cape Province is known for a high level of poverty, food insecurity, and climate vulnerability, making smallholder maize production central to both livelihoods and rural households' food security. Against this background, the study was carried out in two purposively selected district municipalities within the Eastern Cape Province: namely the OR Tambo District and the Chris Hani District Municipality [CHDM].

The CHDM is situated in the northern part of the province and is regarded as one of the largest district municipalities in the region, comprising six local municipalities and a population of approximately 840,000 people, which accounts for about 12% of the
Eastern Cape's total population and 1.5% of South Africa's population (Sotenjwa, 2021). Furthermore, it is a comparatively poor district, in which 75% of the population is considered poor or inadequate. While the OR Tambo District Municipality is in the former Transkei in the Eastern Cape and is predominantly rural, encompassing most of the area’s settlements, with its five local municipalities (Ngquza Hill, Port St Johns, Nyaneni, Kumkani Hintsa, and King

Sabatha Dalindyebo local municipality) accounting for 2.7% of South Africa's population (Pongco, 2023). The reason for choosing these districts out of the six districts is that they are one of the District Municipalities with many smallholder farmers involved in Maize production (Department of Rural Development and Agrarian Reform, 2021).

The Smallholder maize farmers found in these districts have small pieces of land, ranging between 2 hectares to 50 hectares. The mean annual rainfall ranges from 550–700 mm, and temperatures range from 24.5–26°C (Department of Corporative and Traditional Affairs, 2021). In Winter (April to August), the temperatures range from 7º to 20º C. In summer, the temperatures range from 16º to 26º C (Fanteso, 2020).

In the province, smallholder farmers work under different market and production environments, and these shape both their marketing choices and level of mechanization. Within the study sites, smallholder farmers utilize various market channels such as farm gates, wholesalers, and retailers (Mdoda et al., 2024). Though farm gates remain as their main source and the most accessible, as it has fewer requirements than wholesale sales and retailers (Mdoda et al., 2024). While in terms of mechanization, Mdoda et al. (2022) cites are characterized by different levels of mechanization, which reflects that smallholder farmers are resource-constrained. Farmers use mixed mechanization to grow their maize, such as tractors, planters, draft power, manual production tools, feed blockers, and spreaders (Mdoda et al., 2022).



Figure 3.2: Map showing the Eastern Cape Province

Source: Google Maps

3.3.2 Sampling Procedure, Size, and Frame

The study was quantitative in nature and employed a cross-sectional research design. This research design allowed the researcher to gather primary data from a large number of farmers in the Eastern Cape Province at once, which made it the most efficient and cost-effective research design. Furthermore, the cross-sectional research design also allows for the identification of relationships between socio-economic factors, farm factors, institutional factors, and the dependent variable, which is the adoption of GM maize. Therefore, this study employed a multi-stage sampling method to select both the adopters and non-adopters of GM maize seeds in the study area. The first stage was purposively selecting the district municipalities in the Eastern Cape

Province. The selected districts were the OR Tambo and Chris Hani District Municipalities. The main reason these districts were chosen is that they are the districts with the highest number of maize farmers across all six districts. These two district municipalities were purposively selected because they are among the key smallholder maize-producing areas in the province. Moreover, these two districts are among those that are priority areas for government support and extension services, yet their maize production remains very low, particularly for smallholder maize farmers. The distribution of farmers across the two districts

under study is as follows: 511 maize farmers in the OR Tambo District and 410 maize farmers in the Chris Hani District Municipality, respectively (Department of Rural Development and Agrarian Reform, 2023). In the first stage, Eastern Cape Province was the study area.

The second stage involved selecting the local municipalities within these districts and villages where smallholder maize farmers were located. This stage allows representation of different municipalities across all the selected districts, as well as taking into effect different ecological environments of these municipalities. This helped to capture any variations in terms of both infrastructure and agricultural practices. This stage allowed the study to capture the perspectives and experiences of smallholder maize farmers at the municipal- village level, which is very important in understanding the use of GM maize seeds. The third and the last stage involved randomly selecting the smallholder maize farmers in these areas to come up with the desired sample size. The desired sample size of the study is 391 maize farmers in the study area, with 279 being the adopters of GM maize seeds and 112 being non-adopters of GM maize seeds, and the unit of analysis was smallholder maize farmers.

For a representative sample size, the researcher employed the Yamani formula, described as follows:

$$n = \ /((1 + Ne\text{^}2))$$

$$n = \ 921/((1 + 921\ (\ 〚0.05)〛\ \text{^}2))$$

$$n = \ 921/((1 + 921\ (0.00250)))$$

$$n = 279$$

The study used the above formula to sample 279 smallholder maize farmers who adopted genetically modified maize in the Eastern Cape Province. In addition, the researcher included an extra 40% of 279 (112 respondents) in the sample, bringing the total number of respondents to 391. This percentage (40%) ensures a sufficient number of observations for statistical analysis, while creating a credible comparison group. Although the initially planned sample consisted of 391 maize farmers, data were successfully collected from 306 maize farmers,

representing 78.3% of the planned sample. The shortfall was chiefly due to time and financial constraints, which limited repeated visits to widely dispersed rural households. Furthermore, the limited availability of farmers during peak farming periods, like harvesting, reduced participation. Some of the sampled farmers were unavailable at the time of the survey. Despite this, the collected sample remains adequate and representative for the intended analysis, maintaining sufficient statistical power to detect significant relationships among variables.

3.3.2 Data Collection

The Primary data was obtained by conducting face-to-face interviews with maize farmers in the study area with the use of a structured questionnaire. The questionnaire included comprehensive information on farmers' socio-demographic characteristics, farm-level attributes, and institutional factors influencing the adoption and intensity of use of genetically modified (GM) maize seeds. To enhance accuracy, reliability, and inclusivity, the questionnaire was translated into the local languages spoken by the respondents. The study made use of 5 well-trained enumerators who were employed to administer the interviews and to assist respondents throughout the data collection period. Before the commencement of the main survey, the questionnaire was subjected to a pre-testing process to enhance clarity, validity, and consistency of the research instrument. A pilot survey involving 49 maize farmers, representing approximately 10% of the study population, was conducted in areas with similar characteristics to the main study sites. The farmers involved in the pilot survey were excluded from the final sample. Feedback from the pre-test was used to refine the questionnaire, including adjustments to question wording, sequencing, and relevance. The Lecturers from UKZN and CPUT were the ones responsible for refining the questionnaire before the actual data collection based on the results of pre-testing.

During the data collection process, several challenges were encountered, including the late arrival of participants, poor road infrastructure, and the unavailability of some respondents due to competing commitments. Late arrivals were managed by adjusting interview schedules and engaging local leaders,

who assisted in mobilising participants and encouraging punctuality. Accessibility challenges resulting from poor road conditions were addressed by hiring a bakkie to reach remote and difficult-to-access areas. An ethical certificate for this research was granted by the University of KwaZulu-Natal (Protocol Number: HSSREC/00007889/2024). Before data collection, written informed consent was obtained from all study participants. This ensured the protection of participants' rights, promoted transparency, and upheld the ethical integrity of the study.

3.3.3 Data analysis

Data were coded, captured, and processed using Excel, and transported to STATA version 30 for further analyses and to fulfil the objective of the study. Descriptive statistics were used to analyze the demographics of the farmers, including farm characteristics, using frequencies, means, and percentages in a tabular form, pie charts, and graphs. This was followed by using the Double Huddle model. The first stage involved the use of a Probit model to analyse the factors affecting the adoption by maize farmers. This was followed by the truncated regression model in stage two to analyse the extent of adoption of GM maize seeds by maize farmers.

Model Specification

The study adopted a double huddle regression as it has been used by previous studies to analyse the adoption intensity. This model has been used by several studies to assess adoption and the extent of adoption in several countries, such as Ethiopia, South Africa, and Kenya (Keba et al., 2020; Zondo, 2020; Kiprotich et al., 2024). The double-hurdle model was used because it allows for the separation of the adoption decision from the decision regarding the intensity or level of use (Gebru et al., 2021). Unlike the Probit and Tobit regression models, the model can treat adoption and intensity separately. Furthermore, the model can handle zero observations properly. The model is also flexible and widely applied in agricultural research (Eric et al., 2025; Beshir et al., 2022; Ngcinela et al., 2019). The double-hurdle model assumes that an individual goes through

two stages: the first involves deciding whether or not to adopt GM maize seeds, while the second concerns the degree or intensity of adoption. The first stage of the model analyses the decision of the maize farmer to adopt GM seeds or not. The dependent variable takes two values (dummy) in the first stage. The decision equation represents a binary choice and was estimated using a Probit model. The use of the Probit model helps in estimating the functional relationship between the dichotomous dependent and independent variables (Jose, 2020). The Probit was applied due to the inclusion of credible error term distribution and truthful probabilities (Jiba et al., 2024). Hence, this model fits well with the study as it predicts whether the farmer will adopt GM maize or not (Jose, 2020). Therefore, this will help in ensuring that probabilities remain between 0 and 1 and allows estimation of marginal effects to interpret the influence of socio-economic and institutional factors on the adoption of GM maize seeds. The probit model is expressed as follows:

Adoption Decision Model:

$$P_i = pr[Y_i = 1[x]$$

$$= \int_{-\infty}^{x_{i'}\beta} (2\Pi)^{-\frac{1}{2}} exp|\left(\frac{t^2}{2}\right) dt = \emptyset^{(x_i'\beta)}$$

Where: P_i represents the probability that a farmer adopts GM maize seeds, $\emptyset$ denotes the cumulative distribution function of the standard normal distribution, and $y = 1$ with $_1$ representing the set of independent variables. The marginal effect of x_k on the probability $[Y_i = 1|x]$ holding other variables constant is given by

$$^{(y_i}{}_{\partial=x}{}^{1}{}_{i}{}^{|X_i)} = \theta(X_i'\beta)\beta \quad (2)$$

Where θ represents the probability density function of a standard normal variable. The marginal effects of dummy variables Δ on the decision to adopt GM maize varieties was estimated using discrete changes in the predicted probabilities.

$$\Delta \quad = \emptyset(x\beta, d = 1) - \emptyset(x_i\beta, d = 0) \quad -$$

(3) where *d* = dummy variable.

Equation (1) can then be expanded to

$$\emptyset^{-1}(\rho_i) = \sum_{k=0}^{k=n} \beta_k x_{ik}$$

$$= \emptyset\big(\alpha + \beta_1 x_{1_i} + \beta_2 x_{2_i} + \cdots + \beta_k x_i\big) \qquad (4)$$

$$P_i = \beta_1 HHGEND + {}_1AGE + \beta_2 EDUL + \beta_3 MARITAL + \beta_3 FARMEXP$$

$$+ {}_3HHSIZE + \beta_3 EMPLYMNT + \beta_3 MNTINCME + \beta_3 ACCSEXT +$$

$$\beta_3 MEMBERORG$$

The second hurdle, which captures the intensity of adoption, is estimated using a regression model truncated at zero. In this formulation, Y_* represents the intensity of GM maize seed use, measured as the proportion of land allocated to GM maize

$$Y^* = \beta_0 + \beta_1 x_{1_i} + \beta_2 x_{2_i} + \cdots + \beta_k x_i + \mu_i$$

$$= (x_i) \qquad (5)$$

Where

x_1 are the set of independent variables, β a vector of Tobit maximum likelihood estimates, and μ_i is the independent and normally distributed error term, with mean zero and constant variance . $[P(Y_i > 0)]$It follows expression (1). The expected intensity of use of the GM maize seeds $E(Y^*)$ is

$$(Y^*) = X\beta F\,(Y) + \sigma f\,(Y_m) \qquad (6)$$

The marginal effect of an explanatory variable on the expected value of the dependent variable is:

$$\frac{\partial E}{\quad}(Y_i) = F\,(Y_{\sigma m})\,\beta_i \qquad (7)$$

Equation (5) can then be expanded to

$$Y^* = \alpha + \beta_1 GEND + {}_2AGE + \beta_3 EDULEVEL + \beta_4 MARITSTATUS + \beta_5 LNDACES + \beta_6 LANDSIZ$$

3.3.4 Data

This section provides the actual data that was collected. The variables included in the

Double Hurdle Model and their expected outcomes. Table 3.2 presents the explanatory variables used in the Double Hurdle Model and their expected outcomes in the analysis of the adoption intensity of GM seeds by maize farmers in the Eastern Cape Province. The study employs a two-stage analytical approach, in which the first stage examines the adoption of GM maize seeds by maize farmers in Eastern Cape Province. The first stage is a binary decision whether the maize farmers adopt or do not adopt (1 = adopted; 0 = not adopted), whereas the second stage of the double hurdle looks to examine the intensity of adoption, measured by the proportion of land under GM maize. The independent variables are gender, household age, educational level, marital status, household size, household income, access to land, access to credits, infrastructure access, farming experience, membership of farm organization, market access, and the distance to markets. Furthermore, the expected outcomes depict the hypothesis direction of influence of each variable based on the literature reviewed. Therefore, Table 3.2 provides a clear summary of variables used in the regression model, including their expected outcomes on both adoption likelihood and the degree of uptake among adopters of GM seeds in the Eastern Cape Province.

Table 3.2: Description of Study Variables and Expected Outcomes of Explanatory variables used in the Double Hurdle Model to analyze the adoption intensity of GM maize by smallholder farmers in the Eastern Cape Province

Variable	**Description and measurement (Type)**	**Expected Outcome (+/-)**
Adopt GM Maize	Whether a farmer adopts GM maize or not (1=Yes; 0=No) (dummy)	
Gender	Maize farmers gender (0=male; 1 = female)	+/-
Household Head Age	The actual age of the Household head in years (continuous)	+/-
Education	Number of years spent in school (Continuous)	+
Marital Status	Marital status of the maize farmers (0=Married; 1=Single; 2=Divorced and 3=Widowed	+/-
Household Size	Total number of members in the family (continuous)	+
Household Income	Monthly income received per household (continuous)	+
Land Size	The size of the land the farmer has access to	+
Credit access	The access to credit by the farmer (1=Yes;0=No) (Dummy)	+
Access to Extension Services	Whether a farmer receives Extension Services or not (1=Yes; 0=No) (dummy)	+
Infrastructure Access	Whether the farmer has access to farm infrastructure (Yes=1; No=0) (Dummy)	+

Farming Experience	The number of years the farmers have been involved in maize farming (continuous)	+
Membership of the Organization	Whether the farmer is a member of a farm organization (1=Yes; No=0)	+
Market Access	Whether the farmer has access to markets or not (1=Yes; 0=No) (Dummy)	+
Distance to Markets	The distance that the farmers should travel to the markets (continuous)	-

Note: +/− Depicts the direction of influence (positive/negative)

Source: author's own computerization (2025)

3.4 Results and Discussion

This section is two-fold, first it deals with descriptive results that profile the farmers, and the second stage deals with the econometric findings for adoption and intensity of GM maize seeds in the Eastern Cape Province.

3.4.1 The Demographic Characteristics of adopters and non-adopters of GM maize seeds in Eastern Cape Province.

Table 3.3 below depicts the gender distribution of maize farmers, which reveals notable patterns. The overall sample indicates that 43.1% were males compared to 56.9% females. This shows that women often constitute most household members involved in agricultural and domestic food production activities. These findings were consistent with Mokhele (2022), who noted that in South Africa, women contribute more than 60% of the food supply, and they are the largest supply of the labour force and perform more than 70% of agricultural work. The majority of the adopters and nonadopters in the study area had formal education. The overall pool showed that 39.5% of the adopters and non-adopters had primary, 33.7% had secondary, 12.1% tertiary, and only

14.7% of the adopters and non-adopters had no formal education. The maize farmers had spent 7 years on schooling, which in the South African education system is primary education. Educated farmers have the ability to seek information, understand, and adopt innovations like GM maize seeds. These findings are similar to the results of Mdoda (2025) and Ngcinela (2019), who revealed that literate smallholder farmers have the capacity to make informed farm management decisions and can seek, analyse, process, and utilise information significant to the acceptance of innovations.

Considering marital status, the overall sample comprised 68.6% married farmers, 18.9% widowed, 10.8% single, and only 1.6% divorced. Marital status helps in making sound decisions, as married households tend to make joint decisions regarding farming and the adoption of agricultural technologies. The results are similar to the findings of Mpiira et al. (2024), who noted that having a spouse in a family may increase and enhance bargaining power over production resources, which can improve the acceptance of innovations. In terms of employment status, the overall pool shows that 6.2% were employed, 19.3% were self-employed, 40.5% were retired and only 33.9% were unemployed. These findings indicate that the majority of respondents in the study area were unemployed, suggesting that most households in the Eastern Cape rely on smallholder agriculture as their primary source of livelihood. The findings were similar to Mdiya et al. (2025), who revealed that most people living in rural communities are unemployed, and smallholder farming contributes about 50% of their monthly income. The farmers were old, with an average age of 61 years. The results indicate that agriculture was practised by old farmers, as youth are less interested in agriculture and see it as old-fashioned. This is supported by Onumah et al. (2025), who noted that youth are not actively involved in farming activities as they relocate to cities for better-paying jobs.

The results for household size indicated a mean household size of 8.19 members, which indicates a larger household size. In this study, household size represents labour availability in the homestead. Therefore, larger households have more members who can assist in farming activities such as preparing the land, planting, and harvesting, which may result in adopting technologies that

increase outputs. These results were in line with Ramokgopa (2021), who pointed out that the size of the household has a positive impact on farmers adopting new practices of farming practices, because of enough labour to execute farming tasks and the adoption of labour-intensive technologies. The findings show a notable monthly income difference between the two groups (Table 3). The adopters reported a much higher average income of R7,871.94 compared to non-adopters, who reported an average income of R4,274.48. While the pooled income indicated an average of R6,637.52. The findings suggest that families with higher incomes are most likely to adopt GM maize technologies due to affordability, as these farmers can absorb the higher cost associated with the adoption of improved varieties. These results correspond to Muleta and Getahun (2022), who found a positive influence of household monthly income and the adoption of innovations.

The farmers had larger land sizes of 8.42 hectares. This indicates that families with bigger land sizes are more likely to adopt GM technologies as they have more flexibility to allocate plots for new, improved practices without compromising household food needs. This is similar to the findings of Manzoor et al. (2025), who also revealed that farmers with bigger land are most likely to adopt agricultural technologies. The overall pool for credit access indicated an average of R5149.26 on credits in the study area. These findings correspond with Dimo et al. (2022), who indicated that access to production credits has a positive influence on the adoption of innovations.

Table 3.3: Demographic characteristics of GM maize seed adopters and nonadopters.

Variable	**Adopters of GM maize (200)**	**Non-adopters of GM maize (106)**	**Overall Pool= (306)**
	Frequency (%)	Frequency (%)	Frequency (%)
GENDER			
Male	93 (46.5%)	39 (36.8%)	132 (43.1%)
Female	107 (53.5%)	67 (63.2%)	174 (56.9%)

EDUCATIONAL LEVEL			
No formal	14 (7.0%)	31 (29.2%)	45 (14.7%)
Primary	80 (40.0%)	41 (38.7%)	121 (39.5%)
Secondary	70 (35.0%)	33 (31.1%)	103 (33.7%)
Tertiary	36 (18.0%)	1 (0.9%)	37 (12.1%)
MARITAL STATUS			
Married	141 (70.5%)	69 (65.1%)	210 (68.6%)
Single	26 (13.0%)	7 (6.6%)	33 (10.8%)
Divorced	2 (1.0%)	3 (2.8%)	5 (1.6%)
Widowed	31 (15.5%)	27 (25.5%)	58 (18.9%)
EMPLOYMENT STATUS			
Employed	17 (8.5%)	2 (1.9%)	19 (6.2%)
Self Employed	43 (21.5%)	16 (15.1%)	59 (19.3%)
Unemployed	68 (34.0%)	36 (34.0%)	104 (33.9%)
Retired	72 (36.0%)	52 (49.1%)	124 (40.5%)
Access to extension services			
Yes	161 (80.1)	22 (21.0%)	183 (59.8%)
No	40 (19.9%)	83 (79.0%)	123 (40.2%)
Membership of farm organization			
Yes	165 (82.5%)	67 (63.2%)	232 (75.8%)
No	35 (17.5%)	39 (36.8%)	74 (24.2%)
Variables	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
Age	59.82 (10.79)	62.80 (9.93)	60.84 (10.58)
Years spent in school	8.58 (4.65)	5.10 (3.96)	7.38 (4.72)
Household Size	9.29 (2.77)	8.85 (3.64)	9.14 (3.09)
Household Monthly Income	7871.94 (5942.88)	4274.48 (1662.31)	6637.52 (5198.85)
Land Size	9.19 (30.97)	1.80 (2.41) (3.41)	8.42 (28.50)

Amount of Credits	6959.04 (6339.64)	1000 (438.18)	5149.26 (5959.57)

3.4.2 The Distribution of Maize Seed Types Among Sampled Farmers in the Study Area

According to Table 3.4 below, 200 farmers had adopted GM maize while 106 were non-adopters. Of the 200 farmers who adopted GM maize, 88.5% of the farmers indicated to adopt GM maize with both herbicide-tolerant and Bt traits, while 11.5% planted GM Bt maize only. While the remaining 106 non-adopters relied exclusively on traditional maize varieties. From the farmers who adopted GM (Bt/HT), these farmers indicated to be using various seed types such as DEKALB DKC 74-26 R, DEKALB 73-74 R, PAN 54-90 R, PAN5P-990PW, PAN 5R-590R, Planner 590R, while those who adopted GM Bt maize only reported to be using DKC 73-74 BR. The reason most farmers adopted GM (B/HT) is that the seeds contain stacked traits, which provide both insect resistance and herbicide tolerance. Therefore, these kinds of seed varieties allow farmers to utilize various herbicides for weed control without causing any damage to the crop. Whilst GM (Bt) is genetically modified insects, especially the stem borer. These benefits were supported by findings of Sharma and Jadhav (2024), who note that the cultivation of both Bt and HT cultivars has increased and has resulted in changes in some of the agronomic practices, which include reduced tillage and lower energy requirements, resulting in simpler production systems. However, the nonadopters indicated the high cost of GM maize seed as one of the major challenges to the adoption of GM crops.

Table 3.4: Distribution of maize seed types among sampled farmers (n = 306)

Adoption Group	**Seed Type**	**Frequency**	**Percentage%**
Adopters	GM (HT/BT)	118	38.6%
	GM (BT)	82	26.8%
Non-Adopters	Traditional maize	106	34.6%

3.4.3 Reasons for Adopting GM Maize Seeds by Farmers in the Eastern Cape Province

Figure 3.3 below shows four key reasons for maize farmers to adopt GM maize seeds in the Eastern Cape Province related to their production environment. The highest percentage (100%) was reported for improved maize yields, indicating that all farmers had experienced significant improvements in their yields due to the adoption of GM maize in the study area. Therefore, this provides a suggestion that yield improvement was the most visible and mostly experienced benefit by maize farmers, which suggests that improvement in yield was the key motivator for adopting GM maize seeds in the study area. The findings are consistent with those of Mailula et al. (2023), who indicated that TELA® *Bt.* Maize yields increased by 61.1% among adopters compared to non-TELA® Bt maize farmers. The gross margin analysis further revealed that TELA® Bt maize farmers earned higher incomes (R2,834.93) than their non-TELA® Bt counterparts (R2,124.96).

About (63.4%) of the farmers reported that GM maize seed adoption helped them to control drought impact, which has been prolonged in the province since 2011, 43.8% of the respondents indicated that they use GM maize seeds as they are pest resistant, with only 24.2% of the respondents indicating that they adopted GM maize for herbicide resistance. In a nutshell, these results indicate that smallholder maize farmers adopted GM maize seeds to adapt to climate change and enhance their farming activities. Since all the respondents indicated that they adopted GM maize seeds for improving their yields in the study area, this outcome can be used as the entry point by agricultural extension practitioners in enhancing the use of GM maize technologies in the study area. These findings were similar to a review paper conducted by Ngqulana (2025), which reported that the adoption of GM maize seeds in Ghana resulted in a 33.8% improvement in maize production, and this highlights the potential of GM crops in enhancing the productivity of maize farmers.

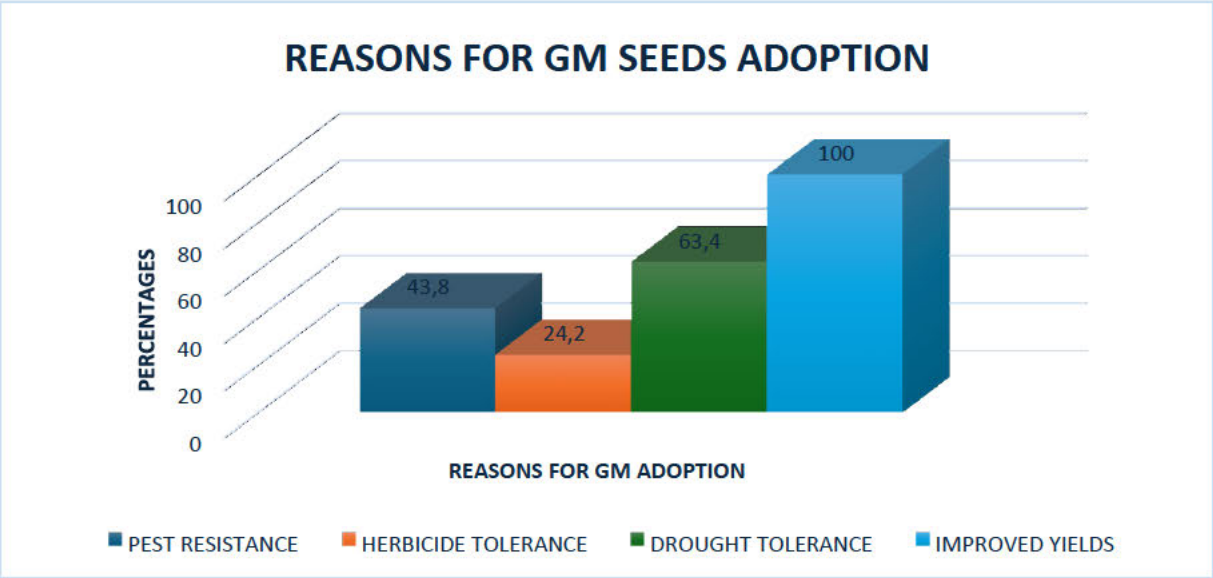


Figure 3.3: Reasons for adopting GM maize seeds

Note: these variables were coded as binary dummy variables (Yes = 1, No = 0)

3.4.4 Sources of Information for GM maize of smallholder Farmers in the Eastern Cape Province

Table 3.4 presents the findings of the sources of GM maize information for participants in the study area. The results show that farmers received the GM information through several communication channels, which included radio shows, newspapers, mobile cell phones, and through field visits by extension officers. A substantial number of the respondents (61.8%) reported receiving GM maize information through field visits in the form of meetings with the local agricultural extension officers and Imbizo. While 41.2% of the respondents indicated receiving GM information through mobile cell phones, 31.0% indicated receiving GM maize information through local radio stations, and a small number (8.85) of respondents reported receiving GM maize through newspapers. These results imply that maize farmers do receive information about GM maize seeds in the study area, and multiple sources are being used by the local extension officers to make sure that they cover all farmers. A number of the respondents were operating in remote areas with limited extension coverage; therefore, using different channels also helped to close the gap between the maize farmers and agricultural knowledge, and this ensured that even the farmers who are hard to

reach had access to critical up-to-date production information. These findings were in line with the findings of Makamane (2024), who highlighted the importance of expanding the use of diverse communication channels, including non-interpersonal methods such as radio, television, and the internet, as well as interpersonal approaches like extension officers and field demonstrations, to enhance the delivery and effectiveness of agricultural information for smallholder farmers.

Table 3.5: Sources of Information for GM maize seed by maize farmers

SOURCES OF INFORMATION	FREQUENCY	PERCENTAGE
Radio	95	31.0%
Newspapers	27	8.8%
Mobile Cell phones	126	41.2%
Field Visits (meetings)	189	61.8%

Note: these variables were coded as binary dummy variables (Yes = 1, No = 0)

3.4.5 Challenges to the adoption of GM maize seeds by Smallholder farmers in the study area

Table 3.5 below depicts several challenges affecting the use of GM maize seeds by smallholder farmers in the area. The results revealed the high costs as a notable challenge to the adoption of GM maize seeds. Specifically, 93.4% of the sample indicated high cost as a limiting factor to their adoption of GM maize seeds. While 51 of the respondents, which is 48.1% of the sample, selected the lack of access to information. 27.1% of the sample indicated technological factors, while only 5.7% of the sample indicated biosafety concerns. Therefore, these challenges indicate both structural and resource- related challenges that impede the smallholder capacity to adopt GM maize efficiently. One of the most reported challenges was the high cost. This implies that financial constraints continue to play a huge role in the lack of acceptance of GM maize by smallholder farmers. These findings are like the findings of Ngongolo and Mmbando (2025), who observed that the high cost of seeds that are often more

expensive than conventional varieties is one of the key factors limiting the adoption of GM maize seeds among smallholder farmers. The second identified challenge was a lack of access to information, which implies information gaps and limited extension support, which affect farmers' awareness of available seed varieties and their potential benefits. The results are consistent with a review study by Azadi et al. (2016), who revealed that a lack of information about the pests that *Bt* toxin would kill resulted in farmers in China and India misunderstanding the function of GM crops, which has led to limited adoption of GM crops. All in all, the identified challenges suggest that it is of paramount importance to improve the adoption of GM maize seeds through an integrated intervention that addresses financial, informational, and structural barriers at the same time.

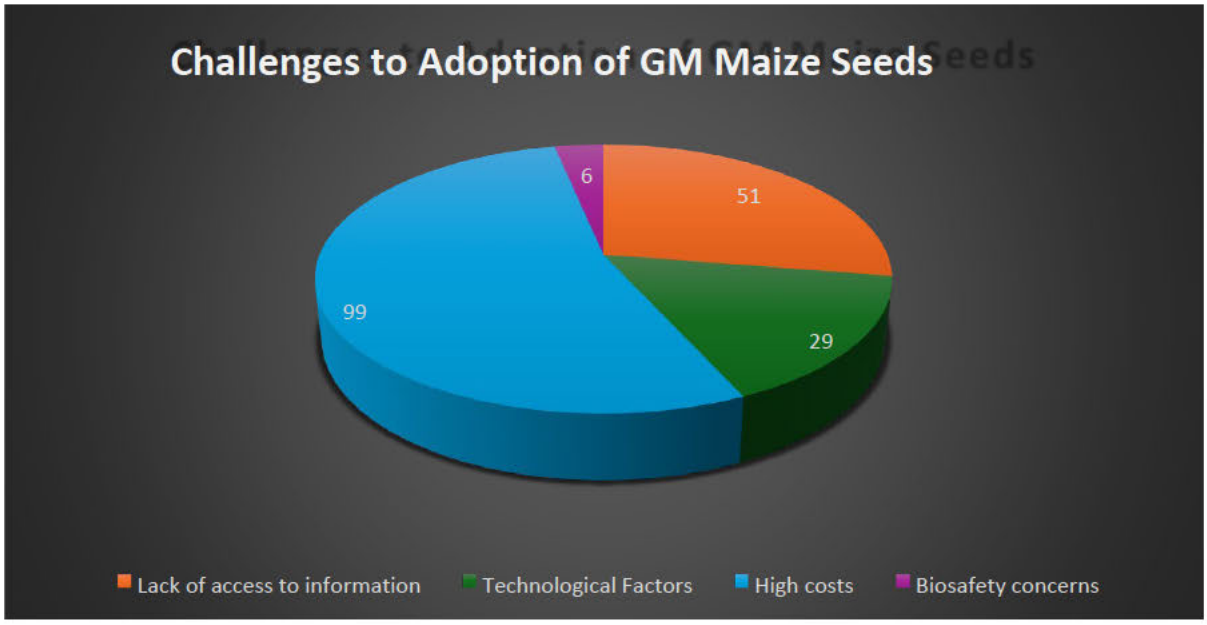


Figure 3.4: Challenges to the adoption of GM maize seeds

Source: Survey data were analysed using Stata version 30. (2025)

Note: these variables were coded as binary dummy variables (Yes = 1, No = 0)

3.4.6 Factors influencing the adoption decision of GM maize seeds by smallholder maize farmers in the Eastern Cape Province

Table 3.6 presents the factors affecting the decision to adopt genetically modified (GM) maize seeds among smallholder farmers in the Eastern Cape

Province. The Probit regression results indicate that the model is statistically significant, as confirmed by the likelihood ratio chi-square statistic (LR χ^2 (12) = 151.47, $p < 0.01$). This finding suggests that the explanatory variables jointly have a significant effect on farmers' adoption decisions. The model was estimated using 306 observations and produced a pseudo-R-squared value of 0.3849. This implies that approximately 38% of the variation in the probability of adopting GM maize is explained by the variables included in the model, indicating a good overall model fit.

Table 3.6: Factors influencing the adoption decision of GM maize seeds by smallholder maize farmers

Variables	**Co-efficient**	**Std Error**	**z-statistics**	**p-value**
Gender	-.3264505	.1931066	-1.69	0.091*
Age	.0084035	.0098894	0.85	0.395
Years spent in school	.0747567	.0349387	2.14	0.032**
Marital Status	.5618868	.1900757	2.96	0.003***
Household Size	.0910867	.0314046	2.90	0.004***
Household Monthly Income	.0001034	.0000374	2.76	0.006***
Land Size	.0870218	.0419224	2.08	0.038**
Member of an organization	.3496174	.2130661	1.64	0.101
Received extension services	1.006562	.2014604	5.00	0.000 ***
Years of farming maize	-.0167929	.0134992	-1.24	0.214
Amount of credits	.0001852	.0000562	3.30	0.001***
Distance to markets	-.0355219	.0122477	-2.90	0.004***
Constant	-2.991994	.7483314	-4.00	0.000***

Number of Observations	306			
Log likelihood	-121.05036			
LR chi^2 (12)	151.47			
Prob> chi^2	0.0000			
Pseudo R^2	0.3849			

Note: *, **, & *** show statistical significance at the 10%, 5% and 1% levels.

Source: Survey data were analysed using Stata version 30 (2026)

The gender of the household head was marginally significant and showed a negative effect on the adoption of GM maize seeds in the study area at the 10% significance level (Table 3.6). A negative relationship was found between gender and the adoption of GM technology, suggesting that female-headed households are less likely to adopt GM crops than male-headed households in the study area. Similar findings were found in the study of Namonje-Kapembwa and Thelma (2016), who revealed a negative effect on the likelihood of adopting improved seeds, fertilizer, and draft power by female farmers. The number of years of schooling was positively and statistically significant at the 5% level (p = 0.032), with a coefficient of 0.0747567. This implies that more educated farmers are most likely to adopt GM maize seeds as they have the capabilities of processing technical information provided by extension officers. Furthermore, these farmers can understand and evaluate GM technologies more effectively than their counterparts. These findings are consistent with the results of Achukwu et al. (2023), who noted that education makes it easier for farmers to access helpful knowledge that will guide them in making decisions regarding new agricultural technologies.

Marital status also showed a marginal influence on the adoption of GM seeds and was significant at 1% level. Married couples can make join decision making, which may lead to taking sound-decisions regarding their production practices. These results are consistent with the findings of Ojo et al. (2023), who found that married couples are more likely to adopt climate-smart technologies, as joint decision-making within households improves the quality and likelihood of adoption. Household size had a strong influence on the adoption of GM maize

seeds and was significantly positive at 1% (p=0.004) with a coefficient of .0910867. This means that an additional member per household increases adoption of GM maize seeds by 0.004 units. This was consistent with the results of Fadeyi et al. (2022), who pointed out that larger households are more likely to adopt new technologies, as larger households indicate the availability of labour.

Household monthly income was found to be positive and significant at 1% level with a p-value of 0.006 and a coefficient of .0001034. This suggests that households with higher monthly income are most likely to adopt GM maize seeds due to their financial capacity and ability to take risks. Comparable results were reported by Miine et al. (2023), who revealed that households with higher income are most likely to adopt improved technologies due to the affordability of the charges associated with the uptake of digital solutions. Land size was positively associated with the adoption of GM maize seeds at 5% level with a positive coefficient (.0870218) and p=0.038. This suggests that households with bigger lands are more likely to adopt GM technologies as they have enough land to allocate new technologies without compromising overall production. These results are in line with the findings of Mularumbwa and Taruvinga (2023), who noted that farmers with greater arable land can adopt new cultivars without disturbing existing cultivars.

Farmers ' access to extension services showed a strong and significant relationship with the adoption of GM maize seeds and was significant at the level of 1%. This suggest that farmers with access to extension services can receive information about GM maize, which will enhance adoption. These findings are consistent with the findings of (Mogashane et al., 2025), who revealed that farmers with extension contact can receive up-to-date information regarding new technologies. The amount of credits received by a farmer was significant at 1% level with a positive coefficient of .0001852. GM seeds are expensive, especially for smallholder farmers. Having access to production credits allows smallholder farmers to be able to purchase and invest in more capital-intensive technologies like GM maize seeds. These results are supported by the findings of Girma (2022), who found that access to credits increased adoption of agricultural production by 1.23 units when compared with farmers with no credits in the study

area. Distance to markets was found to be negatively associated with GM maize seeds adoption and was statistically significant at 10% level with a coefficient of -.0355219, respectively. Most smallholder farmers, especially in the Eastern Cape Province, are located in rural areas far from input markets, which results in higher transportation costs and delays, and this reduces their likelihood of adopting new agricultural technologies like GM maize seeds. These findings are consistent with the results of Manzoor (2025), who found that distance from farms to markets has a detrimental effect on whether the farmer adopts agricultural technologies due to higher costs.

3.4.6 Factors influencing the intensity of GM maize seeds by smallholder farmers in the Eastern Cape Province.

The empirical findings from the truncated regression model, which was used to identify the factors influencing the intensity of GM maize seeds by smallholder farmers who have already adopted them in the Eastern Cape Province, are presented in Table 3.7 below. The likelihood test depicts that the truncated regression model is highly significant (Wald $\chi^2 = 50.19$, $p = 0.0000$), which implies that the variables that were included in the model collectively influence the adoption and extent of GM maize seeds.

Table 3.7: Factors affecting the intensity of GM maize seed use by smallholder farmers in the Eastern Cape Province.

Variables	**Co-efficient**	**Std-Error**	**t-value**	**p-value**
Gender	1.751233	4.270703	0.41	0.682
Age	.281296	.2525969	1.11	0.265
Years spent in school	.8149117	.6582162	1.24	0.216
Marital Status	3.965601	4.775441	0.83	0.406
Household size	1.501825	.5074578	2.96	0.003***
household monthly	.0014601	.0003096	4.72	0.000***
Land size	.2448243	.0699054	3.50	0.000***

Member of an organization	-.1471355	6.140193	-0.02	0.981
Received extension services	-6.277019	5.246522	-1.20	0.232
Years of farming maize	.4309374	.3568957	1.21	0.227
Amount of credits	.0018815	.000495	3.80	0.000 ***
Distance to markets	-.2317839	.1264106	-1.83	0.0678**
_Cons	-99.04978	26.82131	-3.69	0.000***
Number of obs.	200			
Log likelihood	-309.78907			
Wald chi² (10)	50.19			
Prob > chi²	0.0000			

Note *, ** & *** show statistical significance at the 10%, 5%, and 1% levels

The size of the household was positively correlated with the extent of adoption of GM maize seeds, with a coefficient of 1.501825, and was significant at 1% level. This suggests that a 1% addition to the household size will increase the number of adopted seeds by 1.5 units while keeping other factors constant. This implies that larger households usually have more labour available to carry on maize activities such as seed sowing, weeding, and harvesting. These findings are supported by the findings of Katya (2025), who indicated that households with many members were positively associated with the adoption of activities that require more labour, such as minimum tillage, rainwater harvesting, and timely harvesting. Household average income was found to be statistically significant at 1% level. This shows that among farmers who adopted GM maize seeds, every 1% increase in the household income will increase the intensity of adoption of GM maize seeds by .0015 units. This implies that higher income in the household reduces financial challenges, which allows farmers to invest in more inputs such as GM maize seeds. These findings align with those of Miine et al. (2023), who reported that farmers with higher incomes are better able to afford the costs associated with adopting agricultural technologies.

Access to credit showed a positive relationship with the intensity of GM maize seed use among maize farmers, with a positive coefficient and statistical significance at the 1% level. This means that a 1% increase in the amount of credits received by a farmer will increase intensity by .0019 units. Farmers who receive credits have the financial power to purchase more seeds than their counterparts. Similar findings were revealed by Kule et al. (2020), who noted that access to production credits by farmers is very critical as it can allow farmers to purchase all needed inputs for long-term investments in their respective farms. Distance to markets was negatively associated with the intensity of use of GM maize seeds and statistically significant at 10% level. This means that every increase in the distance to the market reduces the intensity of adoption by 0.23 units. Therefore, this means that farmers who reside far from markets adopt GM maize seeds less intensively than farmers located near markets due to transportation costs. These results are supported by the study of Fadeyi et al. (2022), who noted that farmers close to markets and research institutes tend to access new technologies earlier and adopt them more quickly, whereas those residing in rural settings experience delayed access, which results in slower adoption.

3.5 Conclusion and Recommendations

This study assessed factors influencing the adoption intensity of genetically modified (GM) maize seeds among smallholder farmers in the Eastern Cape Province. The study employed a multistage sampling approach to select 306 maize farmers in the area. The data were collected using a structured questionnaire. Both descriptive and econometric models using a Probit and truncated regression were employed. The data were analyzed using STATA version 30. The findings indicate that different maize varieties were adopted by the farmers, such as GM maize (BT), GM (BT/HT), and traditional seeds. Farmers adopted GM maize primarily due to its pest resistance, herbicide tolerance, drought tolerance, and potential to improve maize yields. In addition to these agronomic advantages, access to reliable and timely information emerged as a critical factor in shaping farmers' awareness and understanding of GM maize technologies. Information on GM maize varieties was disseminated

through multiple channels, including local radio programmes, newspapers, mobile phones, and field visits, highlighting the importance of diverse communication pathways in technology diffusion. Despite the advantages of GM maize in the study area, farmers reported several constraints that limit the acceptance and wider uptake of GM maize seeds. These include high seed costs, limited access to information, technological barriers, and biosafety concerns, which continue to shape farmers' perceptions and adoption behaviour. These findings suggest that the successful adoption of GM maize depends not only on the technological benefits of the innovation but also on the institutional and socioeconomic environment that enables farmers to access information, financial resources, and extension support. Consequently, improving these enabling conditions is essential for accelerating the diffusion of GM maize technologies among smallholder farmers.

While the descriptive statistics provided initial insights into farmers' motivations, information sources, and constraints, they do not fully capture the simultaneous and sequential factors influencing the adoption intensity of GM maize seeds. To address this limitation, the study employed a double-hurdle regression model. The results from the first hurdle (Probit model) indicate that the decision to adopt GM maize seeds is positively and significantly influenced by gender, years of schooling, marital status, household size, monthly household income, farm size, access to extension services, credit availability, and proximity to markets. The second hurdle (Truncated regression model), which examined the intensity of adoption, revealed that household size, household monthly income, land size and amount of credits have positive and statistically significant effects on the extent of GM maize seed use. In contrast, the distance to markets was found to have a negative and statistically significant effect on adoption intensity. The distinction between the determinants of adoption and those influencing adoption intensity demonstrates that technology adoption is a sequential process rather than a single decision. This finding has important policy implications, as interventions aimed at encouraging first-time adoption may differ from those required to promote sustained and intensified use of GM maize technologies. While extension services, education, and market access are crucial for

encouraging initial adoption, continued use depends largely on farmers' access to productive resources and financial capacity.

Based on these findings, the study offers several recommendations to improve the adoption and intensity of GM maize seeds in the Eastern Cape Province:

- The study found positive effects of variables such as gender, years of schooling, and access to extension services on farmers' decision to adopt GM maize, and this suggests that knowledge and information dissemination are key to the adoption of technologies. The study recommends that extension practitioners should expand and adequately fund agricultural extension services, with a specific focus on GM crop management and biosafety. This can be achieved through initiatives such as farmer field schools and method demonstrations to improve awareness and practical understanding of GM maize by farmers in the study area.
- Furthermore, the government can also improve access to production credits and financial resources for farmers through the facilitation of many affordable agricultural credit schemes that are tailored to smallholder farmers. For instance, government departments, in collaboration with development finance institutions such as the Land Bank and commercial banks, could introduce low-interest seasonal production loans or input credit programmes that enable farmers to purchase certified GM maize seeds, fertilisers, and other essential inputs at the beginning of the planting season, with repayment scheduled after harvest.
- There is also a need for the government to invest in building rural roads and infrastructure, as this will help reduce transportation costs while also improving market connectivity among farmers.

References

Achukwu, G.A., Sennuga, S.O., Bamidele, J., Alabuja, F.O., Bankole, O.L. and Barnabas, T.M., 2023. Factors affecting the rate of adoption of agricultural technology among small-scale rice farmers in Gwagwalada Area Council of FCT, Nigeria. *Journal of Agricultural Science and Practice*, *8*(2), pp.30-37.

Azadi, H., Samiee, A., Mahmoudi, H., Jouzi, Z., Rafiaani Khachak, P., De Maeyer, P. and Witlox, F., 2016. Genetically modified crops and small-scale farmers: main opportunities and challenges. *Critical reviews in biotechnology*, *36*(3), pp.434-446.

Benjamin, J., Idowu, O., Babalola, O.K., Oziegbe, E.V., Oyedokun, D.O., Akinyemi, A.M. and Adebayo, A., 2024. Cereal production in Africa: the threat of certain pests and weeds in a changing climate: a review. *Agriculture & Food Security*, *13*(1), p.18.

Beshir, M., Tadesse, M., Yimer, F. and Brüggemann, N., 2022. Factors affecting adoption and intensity of use of tef-Acacia decurrens-charcoal production agroforestry system in Northwestern Ethiopia. *Sustainability*, *14*(8), p.4751.

Department of Agriculture, Land Reform and Rural Development. 2021. A profile of the South African Maize market chain. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://webapps1.daff.gov.za/AmisAdmi n/upload/Maize%20profile%202021.pdf. Accessed online: [08 November 2025]

Department of Rural Development and Agrarian Reform, 2021. Eastern Cape Agricultural Economic Transformation Strategy. chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/https://ecagriculture.gov.za/wp -content/uploads/2018/03/EASTERN-CAPE-AGRICULTURAL-ECONOMICTRANSFORMATION-STRATEGY.pdf [accessed online: 13 January 2026].

Department of Rural Development and Agrarian Reform, 2023. *Cropping production inputs support program*, Eastern Cape Province.

DiCaglio, J., 2021. *Scale theory: A nondisciplinary inquiry*. U of Minnesota Press.

Dimo, J.C., Maina, S.W. and Ndiema, A.C., 2022. Access to credit and its relationship with information and communication technology tools' adoption in agricultural extension among peasants in Rangwe sub-county, Kenya. *Asian J. Agric. Ext. Econ. Sociol*, *40*, pp.97-105.

Dragomir, V., Ioan Sebastian, B., Alina, B., Victor, P., Tanasă, L. and Horhocea, D.,
2022. An overview of global maize market compared to Romanian production. *Romanian Agriculture Research*, *39*, pp.535-544.

egene, T., Wims, P., Gebeyehu, D. and Abo, T., 2023. Analysis of communication approaches used in agricultural extension: Case of Wolaita Zone, Southern Ethiopia. *Local Development & Society*, *4*(2), pp.348-369.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. *Food security*, *14*(5), pp.1295-1319.

Erick, S.B., Mbwambo, J.S. and Salanga, R.J., 2025. Determinants of adoption and intensity of use of climate-smart agriculture (CSA) practices among smallholder leafy vegetable agripreneurs in semi-arid central Tanzania. *International Journal of Development and Management Review*, *20*(1), pp.56-78.

Fadeyi, O.A., Ariyawardana, A. and Aziz, A.A., 2022. Factors influencing technology adoption among smallholder farmers: a systematic review in Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *123*(1), pp.13-30.

Fadeyi, O.A., Ariyawardana, A. and Aziz, A.A., 2022. Factors influencing technology adoption among smallholder farmers: a systematic review in Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *123*(1), pp.13-30.

Fanteso, B., 2020. *Unlocking alternative water conservation technologies: the case study of the rural Eastern Cape Province, South Africa*. University of Johannesburg (South Africa).

Gadu, S.E., Adom, R.K. and Simatele, M.D., 2025. The Complex Task of Evaluating the Institutional Adaptive Capacity to Climate Change at Local Government Level: A Study of the Eastern Cape Province of South Africa. *Climate Resilience and Sustainability*, *4*(1), p.e70003.

Gebru, M., Holden, S.T. and Alfnes, F., 2021. Adoption analysis of agricultural technologies in the semiarid northern Ethiopia: a panel data analysis. *Agricultural and Food Economics*, *9*(1), pp.12.

Geyser, J.M., Pretorius, A. and Fourie, A., 2024. Trends in and determinants of South African maize exports in the post-deregulation era. *Journal of Economic and Financial Sciences*, *17*(1), p.862.

Girma, Y., 2022. Credit access and agricultural technology adoption nexus in Ethiopia: A systematic review and meta-analysis. *Journal of Agriculture and Food Research*, *10*, p.100362. https://doi.org/10.17159/2413-3221/2024/v52n5a18770

Jiba, P., Obi, A., Mdoda, L. and Mzuyanda, C., 2024. The Impact of Smallholder Irrigation Scheme on Household Welfare in Farm-Managed Irrigation Scheme Communities in the Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, *52*(1), pp.48-72.

Jose, A., Philip, M., Prasanna, L.T. and Manjula, M., 2020. Comparison of probit and logistic regression models in the analysis of dichotomous outcomes. *Current Research in Biostatistics*, *10*(1), pp.1-19.

Keba, A., Gobena, A.G. and Tesso, A., 2020. Factor affecting adoption and intensity of use of improved maize varieties: The case of Kiremu District, Oromia Regional State, Ethiopia. *Agricultural Science Research Journal, 10*(2), pp. 41 – 54.

Kiprotich, S., Mogaka, H., Ndirangu, S.N. and Onyari, C.N., 2024. Determinants of adoption and adoption intensity of integrated soil fertility management technologies among sorghum farmers in Upper Eastern Kenya. *Soil Use and Management*, *40*(1), pp. e12958.

Kirui, E.C., Kidoido, M.M., Akutse, K.S., Wanyama, R., Boni, S.B., Dubois, T., Dinssa, F.F. and Mutyambai, D.M., 2025. Factors Influencing the Adoption of Agroecological Vegetable Cropping Systems by Smallholder Farmers in Tanzania. *Sustainability (2071-1050)*, *17*(3).

Kule, E., Kyohangirwe, A., Midamba, D.C. and Byakatonda, J., 2025. Determinants of adoption of climate-smart agricultural technologies among smallholder coffee farmers in Western Uganda. *Cogent Social Sciences*, *11*(1), p.2588856.

Lesala, M.E., Mujuru, N., Mdoda, L. and Obi, A., 2025. Evaluating the Economic Impact of Market Participation on the Well-Being of Smallholder Irrigators: Evidence from the Eastern Cape Province, South Africa. *Sustainability*, *17*(8), p.3390.

Mailula, L.P., Mushunje, A. and Nhundu, K., 2023. Impact assessment of Genetically
Modified TELA® Bt. maize variety adoption on yield and household income in South Africa.

Makamane, A., Swanepoel, J.W. and Loki, O., 2024. Communication Channels and
Information Sources Utilised By Agricultural Extension Practitioners to Communicate Agricultural-Related Information to Farmers in the Eastern Cape Province. *South African Journal of Agricultural Extension*, *52*(5), pp.151-169.

Manzoor, F., Wei, L. and Siraj, M., 2025. Digital Agriculture Technology Adoption in Low and Middle-Income Countries-A Review of Contemporary Literature. *Frontiers in Sustainable Food Systems*, *9*, p.1621851.

Marikyan, D. and Papagiannidis, S., 2024. Technology acceptance model: A review. *TheoryHub book*.

Mdiya, l., Shiba, w.t., Mdoda, l. and Van Niekerk, J., 2025. Assessing the Role of Smallholder Livestock Farmers on Rural Household Food Security: Experiences from Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, 53(3), pp.96-110. DOI: https://doi.org/10.17159/2413- 3221/2025/v53n3a18491

Mdoda, L., 2025. Impact of Livestock Theft on the Welfare of Smallholder Livestock Farmers in Nyandeni Local Municipality, Eastern Cape Province. *South African Journal of Agricultural Extension*, *53*(2), pp.61-81.

Mdoda, L., Mdletshe, S.T.C., Dyiki, M.C. and Gidi, L., 2022. The impact of agricultural mechanization on smallholder agricultural productivity: Evidence from Mnquma Local Municipality in the Eastern Cape Province. *South African Journal of Agricultural Extension*, *50*(1), pp.76-101.

Mdoda, L., Mvelase, L.M. and Maziya, M., 2024. Determinants of Marketing Channels Choices: Evidence from Vegetable Farmers in the Eastern Cape Province of South Africa. *South African Journal of Agricultural Extension*, *52*(2), pp.1-20.

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D., 2025. Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis. *GM Crops & Food*, *16*(1), pp.272-304.

Medani, K.R., Neill, A., Garrod, G., Ojo, M. and Hubbard, C., 2024. Societal perceptions and attitudes towards genetically modified (GM) crops, feed, and food products in the Middle East, North Africa, and Turkey (MENAT) region: A systematic literature review. *Food Quality and Preference*, *117*, p.105148.

Miine, L.K., Akorsu, A.D., Boampong, O. and Bukari, S., 2023. Drivers and intensity of adoption of digital agricultural services by smallholder farmers in Ghana. *Heliyon*, *9*(12).

Milling Middle East & Africa. 2023. Top 10 maize producers in Africa - 2023/2024 marketing year. *Milling Middle East & Africa Magazine.*

https://millingmea.com/top-10maize-producers-in-africa-2023-2024-marketing-year/ [assed online: 16 January 2026].

Mogashane, C., Loki, O. and Mazwane, S., 2025. Farmer's Perception and Adoption of Digital Technologies as Information Sources for Farming Activities in the City of Tshwane, Gauteng. *South African Journal of Agricultural Extension*, *53*(3), pp.137159.

Mokhele, K., 2022. *Challenges of small-scale black women farmers in Maubane, Hammanskraal*. University of Johannesburg (South Africa).

Mpiira, S., Kipsat, M., Mose, P.B., Kalyango, F.X. and Staver, C., 2024. The Influence of Gender Specific Decision on Household Technology Choice Within the Farming Households in Central Uganda. *African Journal of Food, Agriculture, Nutrition and Development*, *24*(3), pp.25796-25824.

Msomi, L. and Zenda, M., 2024. An Analysis of Challenges Facing Smallholder Crop Farmers and Informal Food Traders in the Agri-Food Value Chain in Gauteng Province, South Africa. *South African Journal of Agricultural Extension*, *52*(2), pp.120-144.

Mukarumbwa, P. and Taruvinga, A., 2023. Landrace and GM maize cultivars' selection choices among rural farming households in the Eastern Cape Province, South Africa. *GM Crops & Food*, *14*(1), pp.1-15.

Mukhtar, F.B., 2021. Exploring the potentials of genetically modified organisms for achieving food security and sustainable agriculture: The dilemma of African countries. *Nigerian Journal of Botany*, *34*(2), pp.163-178.

Muleta, G. and Getahun, A., 2022. Impact of Technology Adoption on Household Income: The Case of Tef in Dendi District, Ethiopia. *Economics*, *11*(2), pp.69-75.

Muzhinji, N. and Ntuli, V., 2021. Genetically modified organisms and food security in Southern Africa: conundrum and discourse. *GM Crops & Food*, *12*(1), pp.25-35.

Mwaipungu, A., Philipo, F. and Nzali, A., 2023. Demographic Factors Influencing

Adoption of Modern Technologies among Tomato Smallholder Farmers: A Case of Mboga Na Matunda Project in Iringa District. *Asian J. Educ. Soc. Stud*, *49*(3), pp.80-
91.

Namonje-Kapembwa, T. and Thelma, A., 2016. Improved agricultural technology adoption in Zambia: Are women farmers being left behind?.

Ngcinela, S., Mushunje, A., Taruvinga, A., Ngarava, S. and Mutengwa, C.S., 2019. Determinants of genetically modified (GM) maize adoption and the intensity of adoption in OR Tambo District Municipality, Eastern Cape Province, South Africa. *GM Crops & Food*, *10*(1), pp.1-11.

Ngongolo, K. and Mmbando, G.S., 2025. Adoption of genetically modified crops in Sub-Saharan Africa: challenges, opportunities, and regulatory considerations for sustainable agricultural development. *Discover Sustainability*, *6*(1), pp.1-12.

Ngqulana, A., Oladele, O.I., Mdoda, L., Nontu, Y. and Mdiya, L., A Systematic Review on Enhancing the Technical Efficiency of Genetically Modified Maize Adoption in SubSaharan Africa: The Role of Agricultural Extension Services and Barriers to Success. *Frontiers in Sustainable Food Systems*, *9*, p.1609417.

Obi-Egbedi, O., Oluwatayo, I.B. and Ogungbite, O., 2020. Genetically modified crops' technology and its awareness among smallholder farmers in Nigeria. *Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie. Problemy Rolnictwa Światowego*, *20*(4), pp.58-67.

Ojo, T.O., Kassem, H.S., Ismail, H. and Adebayo, D.S., 2023. Level of adoption of climate smart agriculture among smallholder rice farmers in Osun State: does financing matter?. *Scientific African*, *21*, p.e01859.

Onumah, E.E., Dey, A.E., Kodua, T.T., Odame, D.C.A., Nyagsi, M.H. and Otokunor, P.B., 2025. Adoption of Genetically Modified Maize Technology in Ghana. *Research on World Agricultural Economy*, pp.926-940.

Owetu, Z., 2022. *Perceptions and determinants of genetically modified (GM) maize production among rural households: The case of Ngqushwa Local Municipality, South Africa* (Doctoral dissertation, University of Fort Hare).

Pongco, A., 2023. *An analysis of financial administration of municipal infrastructure grant in OR Tambo District Municipality with reference to water and sanitation* (Doctoral dissertation).

Ramokgopa, T.C., 2021. *Adoption of drought-tolerant maize varieties among smallholder farmers in Lepelle-Nkumpi Municipality, South Africa* (Doctoral dissertation).

Schut, M., Leeuwis, C. and Thiele, G., 2020. Science of Scaling: Understanding and guiding the scaling of innovation for societal outcomes. *Agricultural Systems*, *184*, p.102908.

Seti, T. and Madini, A., 2025. How cooperatives can build the economic muscle of smallholder farmers: A case study of maize farmers in the Eastern Cape.

Sharma, C. and AS Jadhav, A.S, 2024. Herbicide tolerance in economically important agricultural crops: Accomplishments and prospects. *International Journal of Research in Agronomy,* 7(7): 433-441.

Sihlobo, W. 2024. *South Africa's primary agricultural employment lifted in the first*

quarter of 2024. Grain Business Research, 14 May. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://agbiz.co.za/content/open/south -africas-primary-agricultural-employment-lifted-in-the-first-quarter-of-202 [accessed online: 16 January 2026].

Sotenjwa, F.P., 2021. An assessment of the performance management system for senior managers at Chris Hani district municipality.

Statistics South Africa,2025. *South Africa: maize production by province 2022/2023.*

https://www.statista.com/statistics/1135488/maize-production-in-south-africa-byprovince/ [accessed online: 16 January 2026].

Sturgis, P. and Luff, R., 2021. The demise of the survey? A research note on trends in the use of survey data in the social sciences, 1939 to 2015. *International Journal of Social Research Methodology*, *24*(6), pp.691-696.

Tse, T. and Reaney, M.J., 2025. Introductory Chapter: Cereal Crops. *Exploring the World of Cereal Crops*, *5*, p.1.

Wani, T.A. and Ali, S.W., 2015. Innovation diffusion theory. *Journal of general management research*, *3*(2), pp.101-118.

Yamini, V., Singh, K., Antar, M. and El Sabagh, A., 2025. Sustainable cereal production through integrated crop management: a global review of current practices and prospects. *Frontiers in Sustainable Food Systems*, *9*, p.1428687.

Zamisa, O. and Taruvinga, A., 2022. Drivers of genetically modified maize production among rural farming households in Ngqushwa local municipality, South Africa: a triple hurdle approach. *Journal of Agribusiness and Rural Development*, *65*(3), pp.229-241.

Zondo, B.S., 2020. Determinants of the adoption and use intensity of organic fertiliser. *SA-TIED Working Paper No*, *135*.

CHAPTER 4

Assessing the Productivity Effects of Agricultural Extension on Smallholder Maize Efficiency through a Meta-Frontier and Endogenous Switching Framework in the Eastern Cape Province, South Africa

Abstract

Maize remains central to food security and rural livelihoods among smallholder farmers in South Africa, particularly in the Eastern Cape Province. However, persistent yield gaps indicate that improved input use alone is insufficient without effective knowledge intermediation. This study moves beyond conventional impact assessments by examining how agricultural extension services influence technical efficiency under heterogeneous production environments. Using cross-sectional data from 306 smallholder maize farmers in the Chris Hani and OR Tambo District Municipalities, the study applies stochastic frontier analysis, endogenous switching regression, and a stochastic meta-frontier framework to control for selection bias and technological heterogeneity. Descriptive results indicate that 57% of farmers were female, with an average age of 60 years and a landholding of 8 hectares. The findings reveal that agricultural extension services significantly enhance maize productivity, with an average yield gain of 0.81 tonnes per hectare. Farmers with access to extension services operated at 93% technical efficiency, placing them closer to the production frontier and indicating superior production performance compared to non-participants, while the overall mean efficiency level was 77%, indicating room for improvement. Extension participation is influenced by education, income, credit access, market participation, and farmer organization membership. Farmers with access to extension services recorded a Technology Gap Ratio (TGR) of 0.95, indicating that they operated very close to the meta-frontier technology, whereas non-participants recorded a TGR of 0.70, reflecting a substantial technology gap. In conclusion, agricultural extension acts as both a productivity enhancer and a technology equalizer. Based on the study results, the study suggests a paradigm shift from conventional agricultural extension delivery to adaptive, digitally enabled, and market-oriented advisory systems. Strengthening agricultural

extension systems through mobile-based platforms, tailored knowledge dissemination, and inclusive targeting of resource-constrained farmers can significantly narrow efficiency gaps and promote sustainable intensification. These may include creating WhatsApp groups, SMS and voice records.

Keywords: Agricultural Extension Services, Meta-Frontier, Endogenous Switching, Technical Efficiency, Maize Farmers, Eastern Cape Province

4.1 Introduction

Agriculture is a significant sector in South Africa, with an estimated 70% of rural households depending on agricultural activities for their livelihoods, particularly through smallholder subsistence farming (Hlatshwayo et al., 2023). In South Africa, the agricultural sector contributes approximately 2-3% to national GDP and accounts for about 4-6% of total employment, while its share in total export earnings varies between 8% and 12%, depending on seasonal production conditions and commodity performance (Thaba, 2025). The agricultural sector has gone through different transformation phases ever since the year 1994, and smallholder agriculture has been the main focus, with 13.8%, which is around 2.33 million households, are agricultural holdings, with many of them living in rural communities in the year 2024 (Thaba, 2025). Currently, the South African agricultural sector is characterized by a dualistic structure, with a well-established commercial sector on one side and an underdeveloped small-scale sector (National Agricultural Marketing Council [NAMC], 2024). The small-scale agricultural sector is made up of approximately 250,000 smallholder farmers and around 1.5 million subsistence farmers (NAMC, 2024). This study will focus on the smallholder farmers.

Various studies, Nazia (2024); Carelsen et al. (2021); Machete (2024; and Ngqulana (2025) define smallholder farmers based on the basic characteristics of their production system, which include the use of indigenous and old technologies with low inputs, mostly dependence on a local and seasonal labour force. For this study, smallholder farming is defined as a small-scale agricultural system where farmers cultivate limited land and mainly rely on family labour and

simple tools to produce crops and livestock, primarily for household consumption and local markets. Smallholder production in regions such as the Eastern Cape is often constrained by insecure or limited land tenure, inadequate access to formal credit, and weak integration into input and output markets (Chimonyo et al., 2020). The constraints are further compounded by limited access to extension services and production technologies (Agbugba et al., 2020). Despite this, smallholder farming remains a long-standing practice most rural communities of South Africa (Kapari et al., 2023). It plays a key role in improving the food security status of several households and provides various benefits, with almost 80% of smallholder farmers worldwide producing food for local income generation and household consumption, thereby assisting in alleviating poverty in rural communities (Mdiya et al., 2025).

One of the major crops grown by smallholder farmers in South Africa is the maize crop. According to Ogujiuba et al. (2021), over the past 10 years, South Africa has been the main maize producer in Southern Africa, with an average production of around 10 to 12 million tons per year. According to Makwela et al. (2022), over 9000 commercial maize farmers produce a major part of the country's maize crop, with the rest produced by thousands of smallholder farmers. The industry contributes approximately ZAR9.5 billion to the South African economy per year (Mangani et al., 2025). Most of the maize grown in South Africa (about 63%) is produced in the Free State (39%), North-West (23%), and Mpumalanga (21%), while Eastern fall under the lowest producers at 1% of the total national production (Mangani et al., 2025; Mdoda et al., 2025). The South African agriculture industry contributed 2.5% of the country's Gross Domestic Product (GDP), while the maize industry accounted for about 0,4% of this contribution. Therefore, this makes maize play a key role in the manufacturing industry, which contributes around 13% of the total GDP of South Africa (Makwela et al., 2022).

Despite the huge role played by the South African maize industry, South African farmers, especially smallholder farmers, continue to face several challenges that affect their productivity and technical efficiency level. The post-apartheid government has even shifted its focus to promoting smallholder agriculture to

transform it into a commercially viable sector by improving productivity through enhanced access to inputs and extension services, increasing participation in formal and informal markets, and strengthening integration into agricultural value chains (Hlatshwayo et al, 2021). Though the realization of this has yet to be achieved in the South African smallholder system. For instance, a study conducted by Hlatshwayo et al. (2021) pointed out challenges such as limited access to modern technologies, institutional difficulties, inappropriate policies, poor infrastructure, and poor links to markets, which result in smallholder farmers being unable to participate in formal markets. Therefore, a review study conducted by Cairns et al. (2021) and Benjamin et al. (2024) reported a sharp decrease in maize yields at the country level in seven countries in Eastern and Southern Africa over the past 15 years, with weeds, pests, and diseases as the major causes of decline in production. For instance, maize yields in Africa are less than 3000kg/ha compared with those in developed countries (Machete, 2024; Leitner et al., 2020; Prah et al., 2023; Odinaka et al., 2025; Madamombe et al., 2024).

As a result, this has raised serious concerns among the government, policymakers, and other rural development stakeholders about how to effectively address the challenge of low maize production and poor technical efficiency levels. As the global population is expected to grow to 9 billion by 20250, and sub-Saharan Africa has the fastest-growing population rate worldwide, agricultural productivity will need to increase significantly to meet growing food demand (Ngqulana, 2025). Consequently, the government has introduced various strategies to improve production levels due to the increasing demand for maize. One strategy implemented by the government is the introduction of Agricultural Extension Services [AES] (Oluwole, 2021). AES refers to a chain of fixed communicative facilitations, essential for improving farming systems and aiding in solving the challenges of farmers (Mbatha, 2024). In the South African context, agricultural extension refers to the service provided to communal farmers to increase knowledge, skills, and production practices that will help improve their productivity (Ngomane, 2021). These services are key to the adoption of new, improved agricultural technologies, improving management practices to enhance production, farm returns and food security (Kauky, 2024).

Despite the significant role of agricultural extension services in supporting rural agriculture in South Africa, productivity among smallholder farmers' maize remains relatively low. The majority of smallholder maize farmers continue to experience suboptimal yields, not only because of poor access to production inputs but also because of inefficiencies in how they use the available resources on their farms. For instance, a study conducted by Mncube et al. (2024) noted that maize productivity of smallholder farmers ranges between 0.5 tonnes and 1.5 tonnes in South Africa. While another study conducted by Ono-Raphel reported that smallholder farmers produced a total average of 13,352 tonnes of maize, while commercial farmers received 861.00 tonnes in the year 2023/2024. Empirical evidence reveals very low to moderate technical efficiency levels among maize farmers, indicating that most output is lost due to poor allocation and utilization of resources and technologies rather than availability (Baloi, 2011; Bakhsh, 2024; Mtyobile, 2021). Thus, efficiency is one of the key concepts underpinning the current study, as it provides a crucial basis for evaluating how effectively resources are utilized in the production process. Muzeza et al. (2023) define efficiency as the farmer's ability to produce maximum output using a set of given inputs and avoid wastage. It remains below optimal levels in many farming systems in South Africa.

The impacts of agricultural extension services on farmers' technical efficiency are mixed, as reported by several authors (Mamashila and Antwi, 2025; Muzekenyi et al., 2021; Gebrehiwot et al., 2017; Biswas et al., 2021; Liu et al., 2023; Jolex, 2022; Lemba et al., 2012). Studies from Ethiopia, Bangladesh, China, and Malawi generally report a positive association between extension services and technical efficiency. However, the magnitude of these effects varies considerably across contexts. While farmers receiving extension services in Bangladesh achieved 95% efficiency (Biswas et al., 2021), considerably lower efficiency was reported in South Africa and Ethiopia (Mamashila and Antwi, 2025; Gebrehiwot et al., 2017). Furthermore, evidence from China suggests that the effectiveness of extension services depends on the source and type of extension support provided (Liu et al., 2023). These variations suggest that extension services alone may not guarantee improvements in technical efficiency, as outcomes are likely influenced by contextual factors such as farmer

characteristics, institutional arrangements, access to complementary resources, and the quality of extension delivery. Consequently, despite the growing body of literature, there remains no clear consensus regarding the extent to which agricultural extension services improve technical efficiency among smallholder maize farmers. This gap is particularly evident in the Eastern Cape Province of South Africa, where empirical evidence remains limited.

Therefore, assessing the technical efficiency is crucial as it allows for identifying the performance gaps between farmers and determining how far they are from the maximum potential (Gebrie, 2018). The agricultural extension services are expected to increase farmer efficiency by not only enhancing the adoption of improved practices but also by improving input allocation and utilization by smallholder farmers. However, despite the existing body of literature on agricultural extension services and farm efficiency, there remains a lack of evidence specific to the Eastern Cape Province, especially studies employing this methodological approach to assess the impact of extension services on the technical efficiency of maize farmers. This gap in the literature makes it difficult to establish whether extension services effectively enhance productivity and improve the efficiency of the farmers, as inefficiencies continue in their presence. It is therefore significant to assess the productivity effects of agricultural extension on smallholder maize farmers' efficiency in the Eastern Cape Province.

4.2 Conceptual Framework

Figure 1 below presents the determinants of technical efficiency among smallholder maize farmers in the Eastern Cape Province of South Africa. Though literature establishes the general determinants of efficiency among farmers, their effects are not uniform and not context-free. Therefore, the Eastern Cape Province mostly comprises smallholder systems that are operating on mixed subsistence farming with various agro-ecological conditions, uneven land holdings and sizes, and limited institutional support such as extension services, market access and credits (Chimonyo et al., 2020). Hence, such conditions of the province not only shape the technical efficiency levels of the farmers in the

province but also how the socio-economic, institutional, and technological factors interact with one another. The study grounds the framework in the assumption that farmers' technical efficiency not only depends on the available resources, such as seeds, fertilizers, pesticides, and labour, but also on how farmers effectively coordinate and integrate the available resources, knowledge, and the institutional support, such as extension services, under the local constraints. Unlike the commercial farmers with greater inputs, the Eastern Cape Province's smallholder maize production is further faced with several challenges that delay access to inputs, weak coordination of production services, including poor and inconsistent extension coverage (Khapayi and Celliers, 2016). Hence, the efficiency outcomes among smallholder farmers in the province are not merely determined by individual factors alone but by more complementary effects among them.

This study advances this framework by putting a key emphasis on the interaction between effects and binding constraints. For instance, access to production credits by maize farmers does not guarantee an improvement of the farmers' efficiency levels unless it is linked to timely extension support services, including well-functioning input markets. Similarly, agricultural extension service, they will only improve the farmers' efficiency when farmers have financial muscle and physical access to implement the recommendations from extension practitioners. This further shows a constraint-complementarity structure in which the effectiveness of one factor depends on the availability of others. Based on this context, socio-economic characteristics, which include farmers' educational level, age and years of farming maize, are not direct drivers of productivity, but these factors can determine the ability of the farmer to understand and respond to institutional support and innovative technologies better. In the Province, agricultural extension services are sometimes inconsistent, and generic ones do not consider the farmers' local conditions (Loki et al., 2021). Therefore, educational level and farming experience assist farmers in interpreting the agronomic advice to the local conditions. This further suggests that human capital (education and experience) goes hand in hand with institutional quality rather than operating in isolation.

Furthermore, production inputs such as land, seed, fertiliser, and mechanization are also impacted by uncertain availability and timing challenges, particularly in the smallholder farming systems, which mostly depend on seasonal income. As a result, inefficiency among farmers is not only caused by the absence of inputs alone, but also by further delays in accessing them, poor combinations, and the misalignment with rainfall within the rainfall-dependent production cycles. With regard to institutional factors, the province is characterised by diverse access to agricultural extension services, with varying quality of advice offered and uneven market integration (Loki et al., 2021). As a result, Figure 1 views agricultural extension services as a support structure whose impact differs among farming communities and depends on how farmers interact with the extension practitioners, the relevance of the advice offered, and how farmers access inputs and production credits. This further provides an explanation why empirical findings in a similar context mostly report mixed results on extension services and farmers' efficiency. The framework significantly introduces a context-based insight into the Eastern Cape Province maize system, and the technical efficiency of smallholder farmers is largely influenced by poor systematic coordination among extension services, credit providers, and suppliers. Hence, these failures result in efficiency losses even among farmers who have adequate knowledge and resources. Thus, the study does not look at inefficiency only at the farm-level factor but as a result of institutional problems within the local agricultural support system in the province.

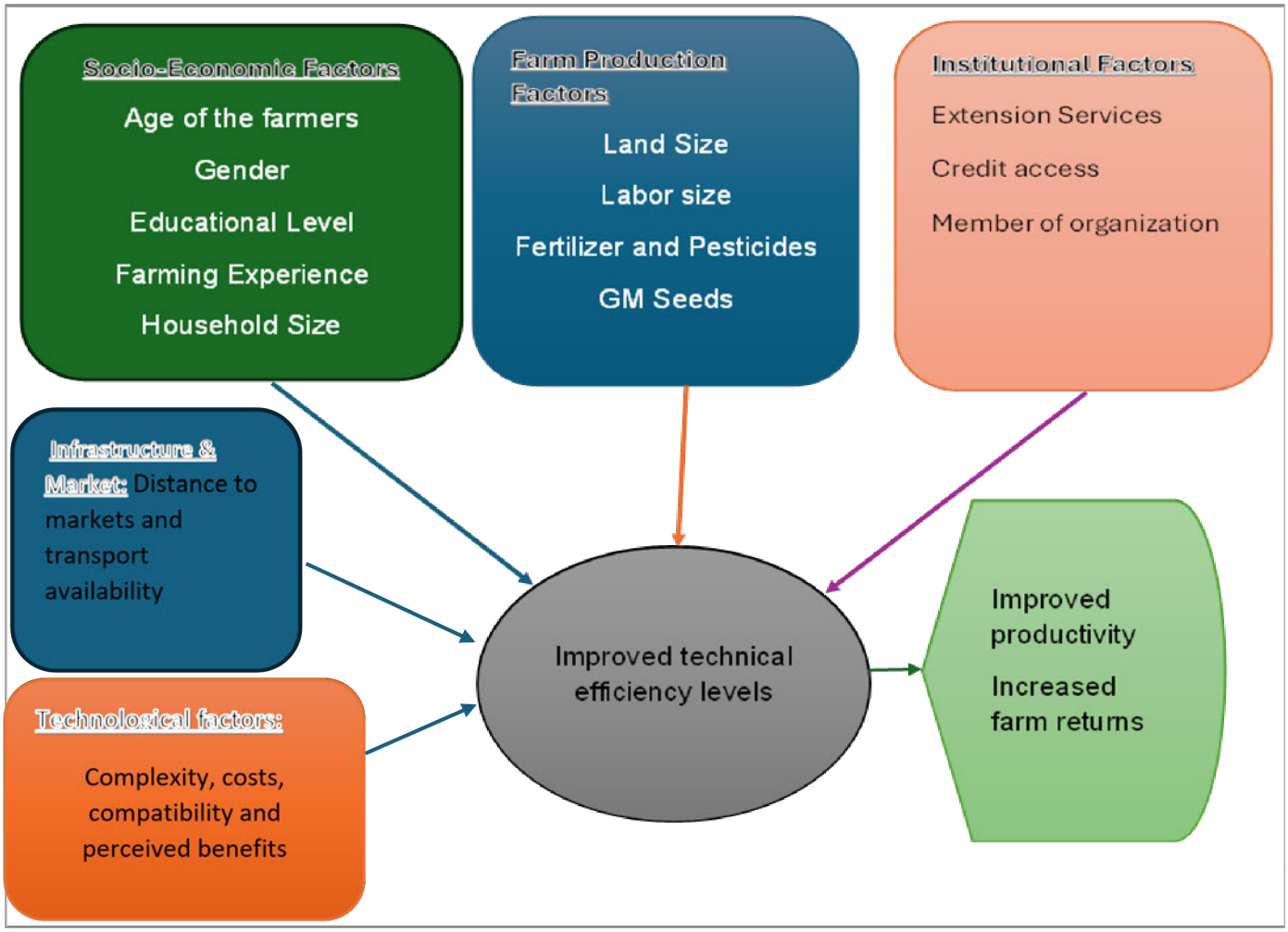


Figure 4.1: Conceptual Framework Showing factors affecting technical efficiency of maize farmers

Source: Author's Own Computerisation

4.3 Research Methodology

This section presents the methodological framework underpinning the study, detailing the research design, data sources, sampling methods, and analytical techniques employed. It provides a clear justification for the selection of tools and materials used to ensure robustness, reliability, and validity of the findings. Furthermore, the section explains how the chosen methods are aligned with the study objectives to generate rigorous and policy-relevant insights.

4.3.1 Description of the study Area

The study was carried out in the Eastern Cape Province of South Africa, specifically under the OR Tambo and Chris Hani District Municipalities. The province was chosen because it is mostly dominated by smallholder farmers who operate under poor resources, which makes it ideal for conducting a study on the technical efficiency of farmers. Literature shows that the province often produces maize that is below the national averages, with an average of less than 1 tonne per hectare, which clearly reflects poor allocation and utilisation of production resources (Agbugba et al., 2020; Chimonyo et al, 2020). The Eastern Province has a population of 7.23 million people, which makes it the fourth largest province in South Africa (National Council of Provinces, 2025). It covers an area of 168,966 km² and is the second-largest province of the country in terms of area (National Council of Provinces, 2025). The climatic conditions of the province are suitable for agricultural activities, with hot summers (26 degrees Celsius and winters (13 degrees Celsius) (Gidi et al., 2024). The province has an average rainfall of 1000mm in summer, while 400 mm during the winter season (Gidi et al., 2024). The Eastern Cape Province comprises diverse agricultural enterprises, such as crops, vegetables, and livestock production.



Figure 4.2: Showing the Eastern Cape Province

Source: Google Maps

4.3.2 Sampling Procedure and Size

This study was quantitative in nature, as this approach allows the systematic measurement and analysis of the relationships between the examined variables of interest. A cross-sectional research design was employed, as the study was conducted at once. Furthermore, this design saves time and cost, particularly when working with smallholder farmers with limited resources. It allowed the researcher to capture a snapshot of the current conditions in the study area, including farmers' demographic characteristics, input application and utilization, access to agricultural extension services, and farmers' technical efficiency levels. The study used a multi-stratified sampling method with three stages. The first stage was to select the district, local municipalities, and wards purposefully. This stage was important as it enhances the representativeness of the sample by ensuring that the researcher captures data from different agro-ecological zones. The second stage was to stratify the smallholder maize farmers into strata: A crop farmer (maize), B livestock farmers, and C mixed farmers, with strata being selected. The last stage was to randomly select the smallholder maize farmers in the areas. For a representative sample size, the researcher employed the Yamani formula, described as follows:

$$n = \ /((1 + Ne\text{^}2))$$

$$n = \ 921/((1 + 921\ (\ 〚0.05〛\ \text{^}2))$$

$$n = \ 921/((1 + 921\ (0.00250)))$$

$$n = 279$$

Where n is the required sample size of the study, N represents the total population size in the area, e^2 denotes the square of the level of precision and 1 is the constant included in the formula.

Therefore, the researcher utilized the above formula to calculate the sample size and received 279 maize farmers who adopted GM maize seeds. The researcher included 40% of the sample size, which represented the non-adopters of GM maize seeds, resulting in 391. Due to the availability of the farmers, limited

budget, and time constraints, the researcher managed to collect data from 306 maize farmers. This sample was still adequate and statistically reliable for the intended analysis of the study. Therefore, data were collected from 306 smallholder maize farmers in the study area.

4.3.3 Data Collection

The study utilized primary data collected through face-to-face interviews using a structured questionnaire. The use of a questionnaire allowed for the collection of standardised, reliable, and quantifiable data from a huge number of respondents. The questionnaires were translated into IsiXhosa, which is the local language in the study area, which assisted the participants in easily comprehending the questions. Well-trained enumerators were used to collect the data from the farmers. The questionnaire covered information on farmers' demographic characteristics, access to extension services, and maize output, as well as the inputs used in their maize production. For reliability, the questionnaires were pre-tested on 31 farmers, representing 10% of the sample size, and these farmers were then excluded from participating in the study. After the pre-testing was conducted, ambiguous questions were rephrased, redundant information was removed, response options were refined, and the sequence of questions was improved for clarity. The data was gathered from both adopters and non-adopters of GM maize seeds to be able to trace differences in terms of farm performance.

4.3.4 Data analysis

To analyse the study objectives, the primary data were captured and cleaned in a Microsoft Excel spreadsheet using predefined numerical codes for each variable. This was followed by checking if there were any missing values or inconsistencies, and all variables were coded in preparation for statistical analysis. After checking the data, it was then exported into STATA version 19 for quantitative analysis. The demographics of the maize farmers were analysed using descriptive statistics through means, frequencies, percentages, and standard deviations. To analyse the productivity effects of agricultural extension

services on the technical efficiency of smallholder maize farmers in the Eastern Cape Province, this study adopted a four-stage econometric approach.

In the first stage, the study examined access to agricultural extension services among smallholder maize farmers and the outcomes of these services, using a logit selection model. The logit was used to examine the determinants of access to extension services and to generate the selection correction term. The subsequent stage is the estimation of group-specific stochastic production frontiers. Followed by the estimation of the stochastic meta-frontier model, which allowed for the accounting of technological heterogeneity among farmers who participated in agricultural extension services and the non-participants. The last stage was to estimate the Endogenous Switching Regression (ESR) model to estimate the impact of agricultural extension services on technical efficiency, while also controlling for the selection bias, including the endogeneity.

The stochastic meta-frontier framework has been previously used by several studies to measure the technical efficiency of farmers (Das et al., 2023; Olasehinde et al., 2022). The reason this study adopts this framework is that it allows the researchers to compare the technical efficiency levels across groups that are operating under different technologies, and it further allows the estimation of the technology gaps attributed to differences in access to agricultural extension services in the Eastern Cape Province.

Access to agricultural extension services

The logit model is employed to analyse AES, which is represented as a binary variable. The use of the logit model to analyse a binary independent variable draws on the studies by Ikoyo-Eweto et al. (2023), Zagre et al. (2024), and Fanta et al. (2024). The reason the study opted to use a logit regression model over other binary regression models, such as the logistic and probit regression, is that the logit may offer odds ratios that are very significant in understanding the results in terms of access to extension services (Ambaye et al., 2021). Furthermore, the logit regression model can also handle non-linear relationships among the predictors and the outcome variable (Ambaye et al., 2021). When looking at robustness, this model is robust to outliers and the normality of the predictors.

The binary variable whether the farmer has access to agricultural extension services is modelled with a logit (latent utility representation and explicit probability):

$$D_{i*} = Z_i\gamma + \epsilon_i,\ D_i = \begin{cases} 1 \\ 0 \ \ 0 if herwise D_{i*} > 0,, \end{cases}$$

Where $_i$ has a logistic distribution. Equivalently, the probability of participation is

$$P(D_i = 1 \mid Z_i) = p_i = \Lambda(Z_{i\gamma}) = \frac{\exp(Z_{i\gamma})}{1 + \exp(Z_{i\gamma})}.$$

Where:

D_i^* is an **unobserved (latent)** measure of the farmer's underlying *propensity* or motivation to access agricultural extension services.

Z represents the **observable factors** (e.g., age, education, farm size, distance to extension office, membership in groups) that influence a farmer's decision to access agricultural extension services.

is the **random error term**, capturing unobservable factors (e.g., farmer motivation and personal preferences.

Therefore, the actual variable that is observed is D_i, which takes the value:
1 if the farmer accessed agricultural extension services,

0 if the farmer did not.

Stage 2: Stochastic Frontier Analysis for agricultural extension participants and non-participants.

Maize farmers who participate in agricultural extension services produce under different technologies compared to farmers who do not participate. Therefore, the stochastic frontier production function for participants and non-participants is specified as:

$$ln\, Y_i = \beta_0 + \sum_{k=1}^{K} \beta_k ln\, X_{ki} + V_i - U_i$$

where Y_i represent maize production in kg, X_{ki} shows the quantity of production input used by a smallholder maize farmer, i, β_k denotes the parameters that are going to be estimated in the study. In contrast, V_i represents a two-sided random error term that captures statistical noise and measurement errors, and U_i is a non-negative error term that represents the technical inefficiency.

The random error term, V_i is assumed to be independently and identically distributed as a normal random variable with mean zero and variance σ_v^2:

$$V_i \sim N(0, \sigma_v^2)$$

Where V_i captures random shocks, measurement errors, and other factors beyond the farmer's control that may affect maize production in the area.

The technical inefficiency term, U_i, is assumed to follow a truncated normal distribution:

$$U_i \sim N^+(\mu_i, \sigma_v^2)$$

where N^+ represents the truncated normal distribution, μ_i is the mean inefficiency effect, and σ_u^2 is the variance of the inefficiency term. The inefficiency component captures farm-specific factors that cause observed output to fall below the stochastic production frontier.

The inefficiency effects model is specified as:

$$U_i = \gamma_0 + \gamma_0 EXT_i + \gamma_2 GR_i + \sum_{j=1}^{m} \gamma_j W_{ji} + \omega_i$$

Where EXT_i represents access to agricultural extension services by maize farmers, GR_i denotes the generalized residual obtained from the Logit model, W_{ji} represents a vector of farmer-specific characteristics affecting inefficiency, γ_j are parameters to be estimated, and ω_i is the disturbance term.

The technical efficiency of each farmer is computed as:

$$TE_i = \exp(-U_i)$$

Where TE_i ranges between 0 and 1. A value closer to unity indicates that the farmer is operating closer to the production frontier and is therefore more technically efficient.

Stage 3: Stochastic Meta-Frontier Analysis

While estimating group-specific stochastic frontiers allows the researcher to be able to measure the technical efficiency within participants and non-participants, comparing the efficiency scores between the two groups might be misleading, as both the participants and non-participants may operate under different production technologies. Hence, the observed differences in technical efficiency may reflect variations in terms of technology rather than differences in managerial performance. To account for technological heterogeneity and be able to establish a common benchmark for comparisons, this study adopted a stochastic meta-frontier approach. Therefore, the meta-frontier represents the potential maximum output attainable under the best available technology and envelops all group-specific frontiers. Furthermore, this framework allows the estimation of Technology GAP Ratios [TGRs] and Meta-Frontier Technical Efficiency (MFTE) scores, thereby allowing for a meaningful comparison of technical efficiency across farmers operating under different technological conditions. The relationship between the group frontier and meta-frontier is expressed as:

$$f^g(X_i) = f^M(X_i)\ exp\ (-U_i^M)$$

where $f^g(X_i)$ is the group-specific frontiers, $f^M(X_i)$ represents the meta-frontier, U_i^M is the technology gap.

The Technology Gap Ratio (TGR) is estimated as:

$$TGR_i = \frac{f^g(X_i)}{f^M(X_i)} = exp(-U_i^M) \leq 1$$

The Meta-Frontier Technical Efficiency (MFTE) is computed as:

$$MFT\ E_i = TE_i \times TGR_i$$

Where TE_i measures efficiency relative to the group frontier, TGR_i measures the technology gap, $MFT\ E_i$ measures efficiency relative to the common meta-frontier. The MFTE measures technical efficiency relative to the common meta-

frontier and facilitates meaningful comparisons between extension participants and non-participants operating under different technologies.

Stage 4: Endogenous Switching Regression Model (ESR)

Following the estimation of Meta-Frontier Technical Efficiency scores, an Endogenous Switching Regression (ESR) model is employed to assess the causal effect of agricultural extension services on farmers' technical efficiency.

The ESR model specifies two separate outcome equations corresponding to farmers who accessed agricultural extension services and those who did not.

For farmers who accessed agricultural extension services:

$$MFT\ E_{1i} = X_{1i}\beta_1 + \rho_0\lambda_{1i} + \varepsilon_{0i}$$

For farmers who did not access agricultural extension services:

$$MFT\ E_{0i} = X_{0i}\beta_0 + \rho_0\lambda_{0i} + \varepsilon_{0i}$$

Where $MFT\ E_{1i}$ and $MFT\ E_{0i}$ denote the meta-frontier technical efficiency outcomes for participants and non-participants, while X_{1i} and X_{0i} are vectors of explanatory variables influencing technical efficiency under the participant and non-participant regimes, respectively. β_1 and β_0 are vectors of parameters to be estimated λ_{1i} and λ_{0i} derived from the Logit selection model, ρ_1 and ρ_0 measure the correlation between unobserved factors affecting participation in agricultural extension services and Meta-Frontier Technical Efficiency outcomes under each regime ε_{1i} and $\varepsilon_{0i}$are stochastic error terms assumed to be independent and normally distributed.

The Average Treatment Effect on the Treated (ATT) is:

$$ATT = E\ (MFT\ E_1|E = 1) - E(MFT\ E_0|E = 1)$$

The Average Treatment Effect on the Untreated (ATU) is:

$$ATT = E(MFT\ E_1|E = 0) - E(MFT\ E_0|E = 0)$$

Explanatory variables used in the logit regression, Stochastic Frontier Analysis, and the Endogeneity Switching Regression model

Table 1 below presents the variables used for the logit regression, Stochastic Frontier Analysis, and the ESR model. The described variables are gender, age,

education, marital status, household size, household income, access to land, access to credits, access to extension services, farming experience, membership of organization, maize seeds, fertilizer, pesticides and herbicides, labour, oxen, drought plough, and tractor.

Table 4.1: Description of Study Variables and Expected Outcomes of Explanatory variables used in the logit regression, Stochastic Frontier Analysis, and Endogeneity Switching Regression [ESR] model

A. Selection Equation (Access to Extension Services – Logit Model)

Variable	**Description and Measurement (Type)**	**Expected Effect**
Gender	Whether household head is married or not (0=Yes; 1= No)	+/-
Household Age	Actual household head age in years (continuous)	+/-
Marital Status	Whether married or not (0=Yes; 1=otherwise)	+/-
Household size	Actual size (continuous)	+
School Years	Actual years spent at school (continuous)	+
Average Household Income	Actual amount in Rands (continuous)	+
Land Size	Actual land size in hectares (continuous)	+
Credit access	Access to production credits (1=Yes; 0=No)	+
Years of farming Maize	Actual years of farming maize (continuous)	+
Membership of Organization	Part of farm Organization (1=Yes; 0=No)	+
Access to Markets	Whether a farmer's access markets or not (1=Yes; 0=No)	+

B. Stochastic Frontier Production Function

Variable	Description and Measurement (Type)	Expected Effect on Output
Land size	Actual size in hectares (continuous)	+
Fertilizer	Actual amount in kg (continuous)	+
Labour	Actual number (continuous)	+
Seeds	Actual size in Kg (continuous)	+
Pesticides	Actual number in litres (continuous)	+
Tractor	Amount paid in Rands (continuous)	+
Animal draft	Amount paid in Rands (continuous)	+/-

C. Inefficiency Model

Variable	Description and Measurement (Type)	Expected Effect on Inefficiency
Age	Actual age of the household head in years (continuous)	+
Gender	Maize farmer gender (0=male; 1=female)	+/-
Household Size	The actual size (continuous)	-
School Years	The actual years spent at school (continuous)	-
Marital Status	Whether the farmers is married or not (0=married; 1=otherwise)	-

Average Household Income	Actual amount in Rands (continuous)	-
Distance to Markets	Actual number (continuous)	+
Years of Farming Maize	Actual years (continuous)	-
Credit Access	Whether the farmers have access to credit (1=Yes; 0=No)	-
Extension access	Whether the farmer has access to extension services (1=Yes; 0=No)	-
Membership of Organization	Part of a farm Organization (1=Yes; 0=No)	-

Note: +/− Depicts the direction of influence (positive/negative)

4.4 Results and Discussion

This section discusses the results from 306 maize farmers in the study area. The section covers the demographic characteristics of the farmers and provides an analysis of the impact of extension services on the technical efficiency of maize farmers. The objective of this study was to assess the productivity effects of agricultural extension on smallholder maize farmers' efficiency in the Eastern Cape Province. This objective was achieved using the logit regression model, Stochastic Frontier Analysis, and the Endogenous Switching model.

4.4.1 The Demographic characteristics of maize farmers in the Eastern Cape Province.

The study area was mostly dominated by females at 57% (Figure 4.3). This shows that women are the main people who work on maize farming and sustain maize production, although men still have control over land and other major assets. These findings are consistent with Bakang et al. (2024), whose study also reported female dominance in the agricultural sector. However, these findings contradict Gebre et al. (2021), who indicated that maize production was mostly dominated by females in Ethiopia and males had greater productivity as

they had better access to production resources, which include land and production inputs. The farmers in the Eastern Cape Province were old, with an average age of 61 years. This was not surprising, as previous research showed that older people mostly practised agriculture, as youth usually relocate to work in cities (Borda et al., 2023). The majority (69%) of maize farmers were married, with an average household size of 9 members. Married households can make joint decisions, which enhances the chances of making sound decisions regarding their farming activities, while a larger household size is a proxy for family labour, which will assist in conducting farm operations. Similar findings were reported by Loki et al. (2021) and Jiba et al. (2024), who reported that being married has several advantages, such as joint decision-making and access to labour, both of which help facilitate maize planting. According to Figure 4.3, about 75.8% of respondents reported being affiliated with an agricultural organization. Being affiliated with an organization enhances the chances of farmers accessing information, training, inputs, market opportunities, and adoption of improved agricultural technologies. A similar pattern was observed in the study conducted by Oleh-Petani and di Negara (2021), who reported that joining a farm organization is one of the important institutional factors, as it increases the chances of adopting agricultural innovations. About 73.5% of the farmers agreed to apply herbicides and pesticides on their farms, and 99.3% indicated having access to labour on their farms. There was a noticeable 21.6% decrease in the use of animal-drawn ploughs, as 88.6% of farmers preferred to use tractors. This shows that most farmers are shifting from old farming methods to new practices that save time and increase production. These findings are contrary to the expectation of persistent reliance on animal draft power in smallholder systems.

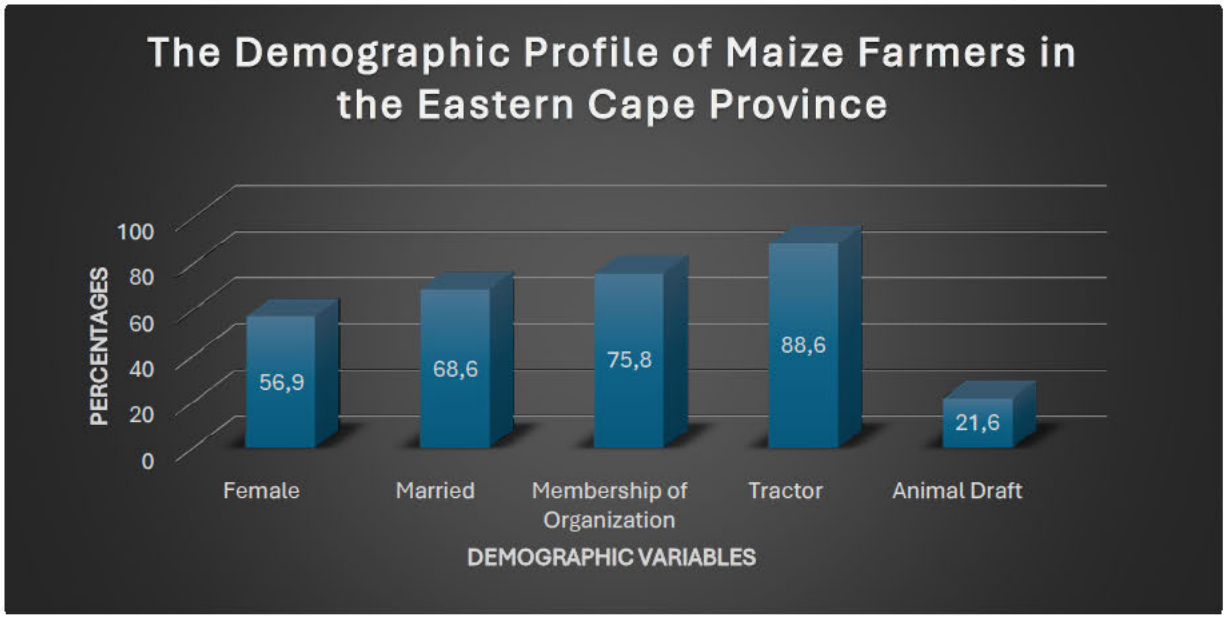


Figure 4.3: Showing the demographic characteristics of maize farmers in Eastern Cape Province

Farmers were highly educated, with an average of 7 years spent at school. Educated farmers are more likely to adopt new technologies, as these farmers have the capabilities to assess the potential risks associated with new technologies (Table 4.2). Similar findings were obtained from a study of Lesala et al. (2025), who reported that highly educated farmers stand a better chance of accessing and interpreting agricultural information. The farmers reported an average household monthly income of ZAR 6637.52; although this income is above the national upper-bound poverty line, it remains relatively low compared to the average income of formal-sector households in South Africa. However, it may still enhance farmers' ability to purchase essential production inputs such as quality seed, fertilizers, and pesticides, thereby supporting agricultural production. Farmers had access to bigger farmland of 8 hectares; larger land sizes allow more flexibility among farmers in diversifying crops optimization of input allocation, which leads to higher maize outputs. These results are in line with the findings of Bakang et al. (2024), who found that farmers with larger land may have the potential to increase their production without disturbing other farm operations. However, contrary findings have been reported in the literature. For instance, a study conducted by Oumer et al. (2022) in Ethiopia reports that the

size of the farm does not automatically lead to improved efficiency by smallholder farmers, suggesting that bigger lands may lead to management and supervision issues. Therefore, these contrary findings indicate that larger landholdings' benefits may depend on the capability of farmers to manage additional land efficiently, including access to complementary inputs such as labour, seeds, pesticides, and extension support.

The farmers received an average credit amount of ZAR 5149.26 from agricultural cooperatives. Farmers who receive credits have the financial muscle to obtain production inputs such as GM seeds, fertilizers, and pesticides recommended by agricultural extension officers promptly to support their production practices. In the absence of credit, farmers may delay or reduce input use, resulting in poor crop establishment, lower yields, and reduced productivity. These results are consistent with Midamba et al. (2022), who noted that farmers who received credit had a 13.40% probability of receiving agricultural extension services compared to their counterparts in the study area. Farmers were highly experienced, with an average of 17 years in farming. This implies that farmers were quite knowledgeable about maize farming, which allows them to apply effective crop management strategies on their farms. These findings were consistent with the findings of Bakang et al. (2024), who reported an average of 19.88 years of farming experience in their study area. The farmers allocated an average of 23.61 kg of maize seeds and 335.25 kg of fertilizer.

Table 4.2: Descriptive statistics of continuous socio-economic characteristics of maize farmers

Variables	**Mean**
Age	56.9
Education	7.38
Household Size	9.14
Average Income	6637.52
Land Size	8.42
Credit Amount	5149.26

Year of Farming	17.15
Quantity of Seeds	23.61
Quantity of Fertilizer	335.25
Pesticides	3.97
Labour	6.73

4.4.2 Types of Agricultural Extension Services Provided in the Study Area

Table 4.3 reveals that farmers received different types of agricultural extension services in the study area. 91.5% of the farmers indicated that they received agricultural extension services on technical advice on maize production, 83.5% indicated that they received services regarding improved maize seeds, while 71.5% indicated that they received services on training and workshops on modern farming techniques, and only 61.5% indicated that they received services on farm management. Therefore, the observed difference among farmers receiving a wide range of services shows that agricultural extension is not homogeneous in its impact on maize production. Similar findings were revealed by Maake and Antwi (2022) that farmers received different types of agricultural extension advice in the study area.

Table 4.3: The Types of Services Provided in the Study Area

TYPES OF AGRICULTURAL EXTENSION SERVICES	**PERCENTAGES%**	
	NO	**YES**
Technical advice on soil preparation, seed sowing and row spacing	8.5	91.5
Training on Integrated Pest Management	28.5	71.5
Access to GM maize seeds	16.5	83.5
Records keeping	38.5	61.5

Note: All variables included in the table were binary (Yes/No)

4.4.3 Methods of Communication Used by Agricultural Extension Services

Figure 4.4 reveals a clear hierarchy in the information dissemination channels utilized by agricultural extension officers in the Eastern Cape Province, with field visits emerging as the dominant and most trusted medium. An overwhelming 96% of farmers identified face-to-face interactions as their primary source of agricultural information, underscoring the enduring relevance of personalized, context-specific advisory services in smallholder farming systems. This finding highlights that extension delivery in rural settings remains deeply relational, where trust, demonstration, and real-time feedback are critical for effective knowledge transfer. Field visits not only facilitate practical learning through on-site demonstrations but also enable extension officers to tailor recommendations to farm-specific conditions, thereby enhancing the likelihood of adoption and improved farm performance. This aligns with existing literature, including Makamane et al. (2024), which similarly emphasizes the centrality of in-person engagement in strengthening farmer-extension linkages.

In contrast, the growing yet uneven role of digital and mass communication channels is evident. Smart mobile phone usage, reported by 58% of farmers, indicates a gradual shift toward more flexible and time-efficient communication methods used for SMS, calls and WhatsApp groups. This level of smartphone adoption suggests that a considerable proportion of farmers can access agricultural information, extension advisories, weather updates, and market-related information more rapidly than through traditional communication channels. Therefore, this might improve information dissemination and decision-making regarding production inputs. However, its limited reach suggests persistent structural barriers such as poor network connectivity, affordability constraints, and varying levels of digital literacy, particularly among older farmers. Meanwhile, about 30% of the respondents have radio access, and this appears to play a marginal role, potentially due to its generalized content and lack of interactivity, which may not adequately address the localized and dynamic needs of farmers. Collectively, these findings point to a hybrid extension

landscape, where traditional methods remain dominant, while digital tools offer complementary potential. This underscores the need for a more integrated and inclusive extension approach that combines the strengths of interpersonal engagement with scalable digital solutions to enhance outreach, efficiency, and impact.

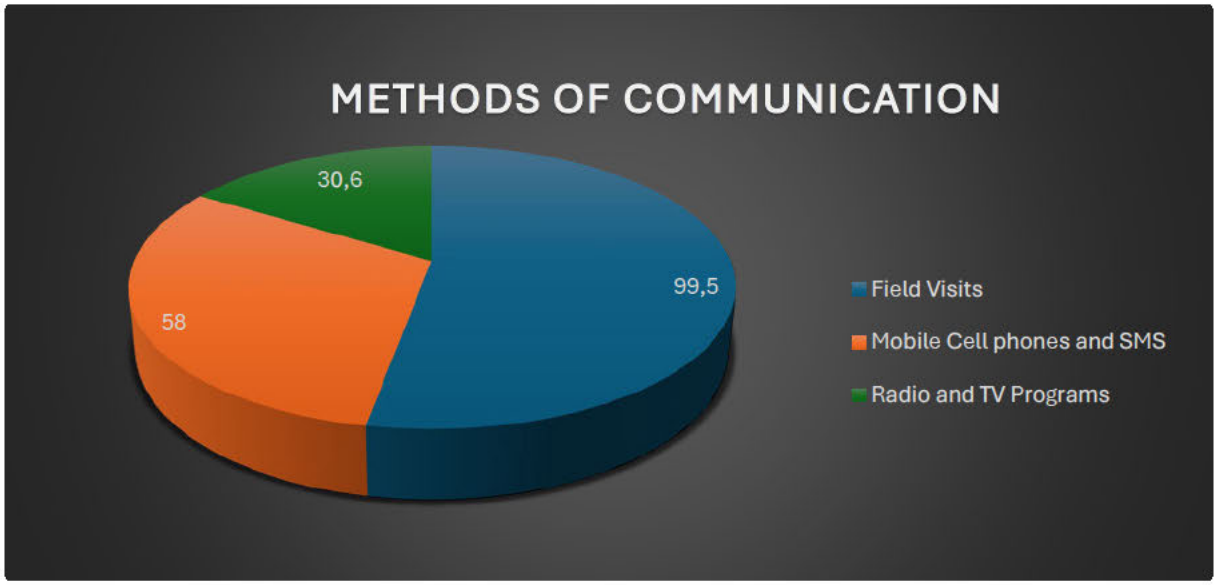


Figure 4.4: Showing agricultural extension sources of Information

Note: Multiple communication methods could be selected; each slice shows the percentage of the communication method selected.

4.4.4 Practices adopted by Maize Farmers due to Agricultural Extension Services in the Eastern Cape Province.

Table 4.4 depicts the different practices adopted by farmers as a result of agricultural services in the Eastern Cape Province. These practices include improved crop varieties, better soil management, enhanced pest and disease control, and improved water management practices. Based on Table 4.4, a substantial number of farmers (96%) reported adopting improved crop varieties. Followed by 82% of farmers reporting the adoption of better soil management, and 80% reported enhanced weed, pest, and disease control. Therefore, access to extension services appears to be associated with the adoption of improved farming practices, which may have positive implications for farm productivity and efficiency among maize farmers in the study area. This emphasizes the key role of agricultural extension services in facilitating the process of access to

agricultural and other agronomic practices. Farmers, by adopting these practices, show that extension support enhances the capacity of smallholder farmers, which leads to more efficient allocation of resources and improved output levels. These results are supported by the findings of Amrullah and Tokuda (2025), who noted that agricultural extension services are a significant mechanism in disseminating and encouraging the adoption of innovations and agricultural practices that enhance their productivity and efficiency. However, recent studies indicate that extension services' effects are not always constant. For instance, studies by Maake and Antwi (2023); Bontsa et al. (2023) revealed that the effectiveness of agricultural extension services chiefly relies on the quality, including the relevance of services offered to the farmers. This implies that these interventions tend to be effective when they are context-specific and address the real needs of the farmers.

Table 4.4: Practices Adopted by Maize farmers because of Agricultural Extension Services

PRACTICES ADOPTED	**PERCENTAGES%**	
	No	**Yes**
GM Crop Varieties	3.6	96.4
Better Soil Management	18.1	81.9
Weed, Pest and Disease Control	19.7	80.3

Note: All variables included in the pie chart were binary (Yes/No)

4.4.5 Agricultural extension services Providers in the Study Area

Based on Figure 4.5, the extension services were offered by both the government and the private sector. 86.5% of the farmers indicated to received extension services from the government, while 5.3% indicated private, and 8.2% of the farmers indicated that they received the services from both the government and the private sector. This indicates that in South Africa, extension services for smallholder farmers are largely provided by the government as part of rural welfare support, while the private sector primarily focuses on servicing

commercial farmers. These results are similar to the findings of Cloete et al. (2019), who noted that in South Africa, extension services utilize mostly the public extension model.

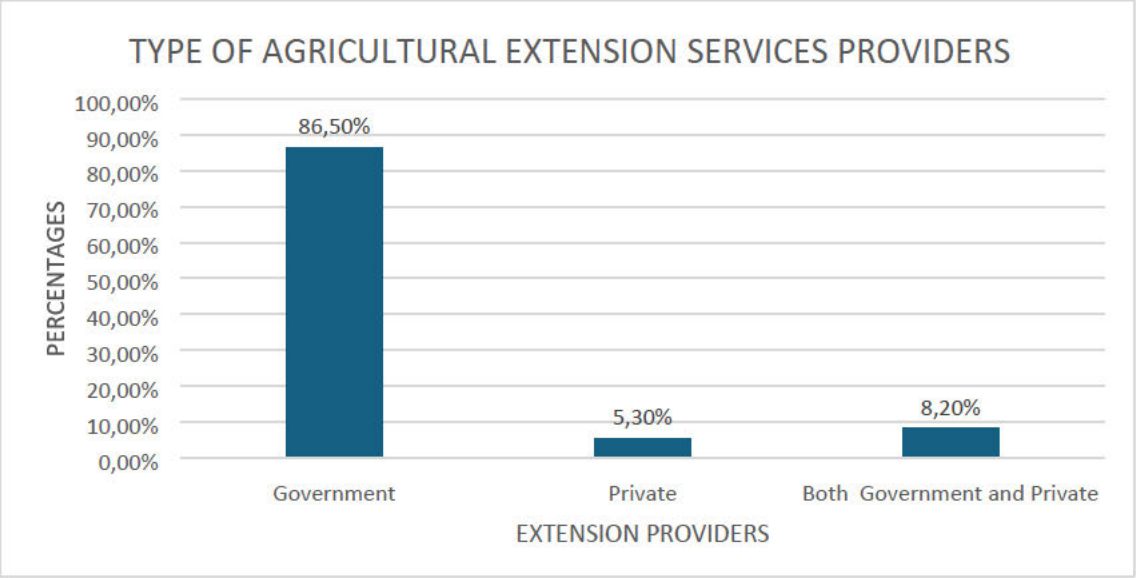


Figure 4.5: Agricultural Extension Services Providers in the Study

4.4.6 Perceived Quality of Agricultural Extension Services Received by Farmers

Figure 4.6 presents the perceived quality of AES by maize farmers. The perceived quality was ranked into 5 categories: very poor, poor, neutral, good, Good and excellent. The majority (44.6%) indicated the agricultural extension services were good, while 35.4% of the farmers indicated that the services were neutral, 12.4% indicated poor, and only 7.6% indicated excellent. Different perceptions on the quality of extension services may be due to differences in terms of productivity and efficiency, including the socio-economic background of the maize farmers. These results were similar to the findings of Al-Zahrani et al. (2019), who revealed that farmers' education level, age, and farm size significantly influenced perceptions of farmers in the study area.

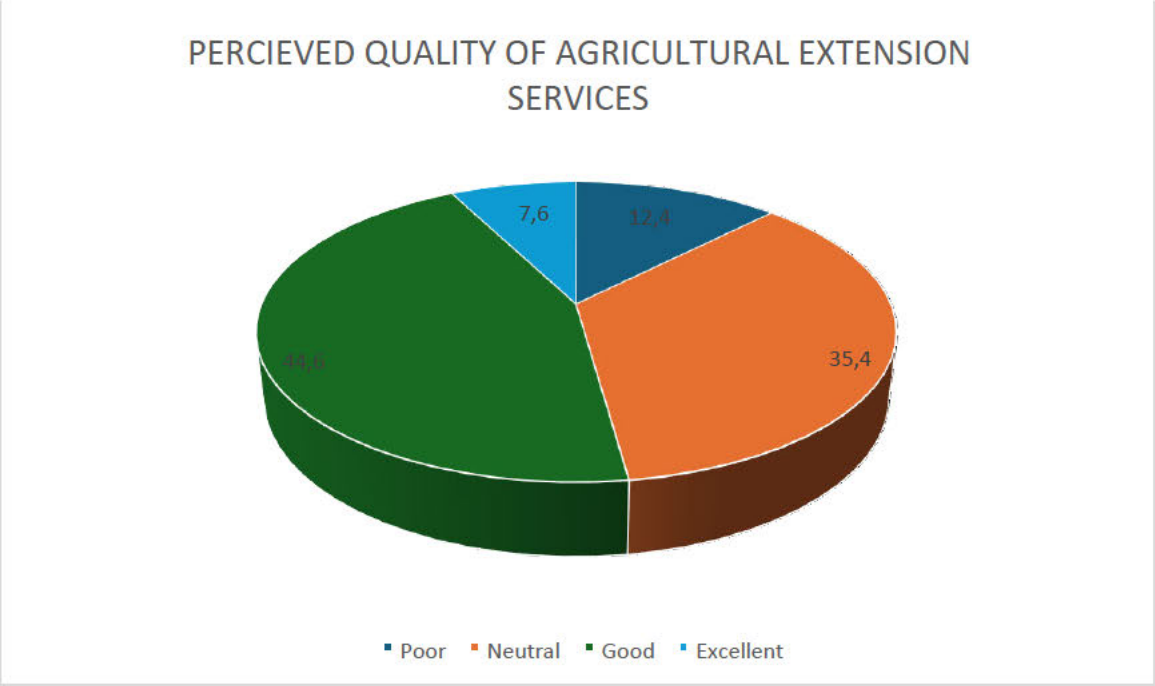


Figure 4.6: Quality of Agricultural Extension Services Received by Farmers

4.4.7 Diagnostic Tests and Model Validation

The diagnostic evaluation of the logit model was conducted to check multicollinearity among covariates (Table 4.5). The diagnostic statistics indicate that the estimated logit model is statistically robust and suitable for analysing factors influencing farmers' access to agricultural extension services. The mean Variance Inflation Factor (VIF) of 2.45 and maximum VIF of 4.18 were well below the critical threshold of 10, suggesting the absence of serious multicollinearity among explanatory variables. The model achieved an overall classification accuracy of 79.4%, correctly distinguishing between farmers with and without access to extension services. Furthermore, the Area Under the Receiver Operating Characteristic Curve (ROC-AUC) of 0.83 indicates strong discriminatory power and satisfactory predictive performance. These results confirm the reliability of the estimated logit model.

Table 4.5: Diagnostic Evaluation of the Logit Model

Diagnostic Test	**Value**

Mean VIF	2.45
Maximum VIF	4.18
Classification Accuracy	79.4%
Sensitivity	81.2%
Specificity	76.8%
ROC-AUC	0.83
Pseudo R^2	0.287

4.4.8 Stage 1: Factors Influencing Access to Agricultural Extension Services by Maize Farmers in the Eastern Cape Province.

Table 4.6 below shows the factors influencing access to agricultural extension services by maize farmers in the study area. The logit regression model was estimated using 306 observations. The likelihood ratio test shows that the regression model is statistically significant LR $chi^2(11) = 98.61$; $p < 0.001$). Therefore, this shows that the estimated variables jointly influence the probability of the outcome variable (access to/no access to extension services). Hence, the model exhibits a good fit, as reflected in the log likelihood with a value of -152.21607 and a pseudo-R-squared of 0.245. This indicates that the regression model estimated substantially improves over the null hypothesis.

Table 4.6: Factors Influencing Access to Agricultural Extension Services in the Study Area.

Variables	**Odds Ratio**	**Std. Error**	**z-value**	**p-value**
Gender	0.884	0.257	-0.42	0.672
Household Age	1.021	0.018	1.18	0.237
Marital Status	1.058	0.136	0.44	0.658
Household size	1.179	0.062	3.12	0.002***
School Years	1.145	0.051	3.01	0.003***

Average household income	1.000	0.001	2.32	0.020**
Land Size	1.004	0.010	0.48	0.635
Credit Access	1.740	0.530	1.82	0.069*
Years of Farming maize	0.939	0.019	-2.93	0.003***
Membership of organization	2.919	0.831	3.76	0.001***
Access to markets	2.222	0.730	2.43	0.015**
_cons	0.014	0.017	-3.40	0.001***
Number of obs.	306			
Log likelihood	-152.21607			
LR $chi^2(11)$	98.61			
Prob > chi2	0.001			
Pseudo R^2	0.245			

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively

Household Size was statistically and positively significant with access to agricultural extension services by farmers (OR=1.17; p=0.002). These results suggest that farmers with larger households have a higher possibility of accessing agricultural extension services, as household size was used as a proxy for labour availability. Therefore, families with more family members have more labour to apply new practices suggested by agricultural extension officers. The findings are consistent with Sahu et al. (2024), who noted that more household members sometimes encourage participation in collective action and

are willing to adopt different production practices that will improve productivity. Again, more manpower enhances interest in enquiring more resources and information from the farmer organization, which enhances production. Contrary to the study findings, Loki et. (2021) found that the size of the household had not significantly influenced the farmers' access to extension services in the Eastern Cape Province. This might suggest that access may sometimes be driven by the characteristics and production systems of the farmers rather than just labour availability.

School Years was found to be statistically significant and had a strong influence on access to extension services by maize farmers in the study area (OR=1.14; p=0.003). This implies educated farmers are most likely to receive agricultural extension services because educated farmers have the ability to seek information, which puts them in a better position to be able to communicate with agricultural extension officers. These findings agree with Mamba et al. (2022), who noted that farmers who have spent several years at school stand a better chance of receiving extension services.

Household Income was statistically significant with access to extension services by maize farmers in the study area (OR=1.00; *p*=0.020). This is because farmers with higher household income have the financial power to be able to purchase inputs and implement new practices and technologies recommended by agricultural extension officers. The results concur with Sumo et al. (2022), who found that farm households that have more income can increase their production, which in turn increases their interest in seeking extension services.

Credit Access was significant with a positive effect on the probability of receiving extension services by the maize farmers (OR=1.74; *p*=0.069). This is because farmers who receive credit are more motivated to seek extension advice and support, as this helps to ensure the effective usage of the borrowed funds and minimize production risks. Again, farmers mostly get credits through cooperatives, which are programs aimed at developing smallholder farmers, and these also serve as important channels for extension information. These results are consistent with Wossen et al. (2017), who reported that smallholder farmers

who receive production credits are more willing to seek agricultural extension services.

The number of years farming maize was statistically significant and had a strong negative effect on the probability of accessing extension services by maize farmers in the study area (OR=0.94; *p*=0.003), which is different from the expected sign. This might be because farmers with a number of years in maize farming often feel they already have enough information on how to plant maize, and they may feel less need for extension advice compared with farmers with less experience and who seek guidance. Furthermore, years of farming correlate with older age, and older farmers tend to be more conservative and less willing to take risks, thus choosing to stick with old ways of farming. These results were similar to Abdallah et al. (2016), who revealed that households that have huge experience can take longer to assess the potential before taking final decisions based on the previous experiences with the services.

Membership of the organization was statistically significant with a strong influence on the probability of accessing extension services by the farmers (OR=2.92; p=0.001). This emphasises the key role played by social networks and access to agricultural information. Farmers affiliated with a farm organization can receive information on new opportunities that would be beneficial to their farm operations. Similar findings were reported by Masanja et al. (2023), who revealed that the majority of agricultural opportunities are delivered via farmer groups due to fewer numbers of agricultural extension officers compared to farmers; therefore, in most cases, contact with the farmers is mostly done through farmer groups.

Access to markets was statistically significant at 5% and influenced the farmers' probability of accessing extension services (OR=2.22; 0.015). This implies that market-oriented farmers are most likely to seek technical support from agricultural extension officers to improve their productivity and competitiveness in the market. These results are similar to findings of Shitaye et al. (2025), who noted that farmers with better access and who live closer to markets are likely to interact with traders, input suppliers, extension officers, and farm organizations that are found next to market centres.

4.4.9 Analysing the technical efficiency of maize farmers in the Study Area

Table 4.7 shows findings of the technical efficiency from a Stochastic Frontier Analysis (SFA), which was estimated using data from 306 maize farmers. The findings reveal that the model was highly significant with a Wald $\chi^2 = 1045.62$, $p < 0.001$, and a loglikelihood of -232.98, which indicates that the included variables explain the technical efficiency of maize farmers in the study area.

Table 4.7: Technical efficiency of maize farmers in the Study Area

Variables	**Coefficient**	**Std. Err.**	**z-statistics**
Cons_	5.745***	0.252	22.83
Land Size (ln)	0.184***	0.053	3.48
Quantity of fertilizer (ln)	0.035**	0.015	2.32
Total labour (ln)	0.523***	0.079	6.63
Quantity of pesticides (ln)	0.115***	0.017	6.91
Quantity of seeds (ln)	0.298***	0.073	4.08
Tractor (rands) (ln)	0.014**	0.006	2.15
Animal draft (rands) (ln)	-0.027**	0.013	-2.17

Note: Values reported in parentheses represent standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The coefficient for Ln Land Size (β_1), valued at 0.184 and significant at the 1% level, indicates a positive relationship between maize output and land size in the study area. This shows that land plays a huge role in maize production, as the farmers have enough land to allocate to maize. These results were supported by the findings of Muzekeny et al. (2021), who indicated that land size or farm size is directly related to bigger output, as the farmers can cultivate different types of crops. However, these findings contrast with Asefa and Muluken (2024), whose study revealed that farmers with smaller land holdings were more technically efficient than farmers with larger land holdings in Ethiopia. This is

because smallholder farmers have closer supervision and there may be effective utilization of family labour.

Ln Quantity of fertilizer (β_2) had a positive coefficient of 0.015, which was significant at 5% level. This implies that fertilizer plays a key role in maize output as it is one of the significant inputs that enhance productivity. Maize is one of the crops that requires high nutrients, particularly nitrogen, phosphorus, and potassium for optimal growth, formation of grain, and yield. The application of fertilizer by farmers improves maize production by enhancing nutrients in the soil, promoting vegetative growth, and improving grain filling. However, poor and inconsistent application of fertilizer may lead to diminishing returns and result in higher production costs. The results are in line with those of Mdoda et al. (2021), who found that an increase in fertilizer application will enhance maize output because fertilizer offers maize crops with essential nutrients required for proper growth, which subsequently improve maize production.

Ln total of labour (β_3) had a positive coefficient of 0.52 and was significant at 1% level. This suggests that an increase in labour improves maize production in the study area. This implies that the timely allocation of enough labour ensures that activities such as planting, weeding, and harvesting are conducted effectively to enhance maize productivity. These results are similar to the results of Bedasa and Tekalign (2023), who revealed a positive relationship between labour amount and production output. Farmers with more labour can cultivate larger areas of land than those with limited labour. Ln Quantity of pesticides (β_4) had a positive and highly significant effect on maize output in the study area. A 1% increase in the amount of pesticides applied by the farmers increases the output of maize by 0.11%. This suggests that the application of pesticides by farmers plays a significant role, as they are likely to reduce maize loss due to pests and diseases. These results were supported by the findings of Mdoda et al. (2021), who noted that every increase in fertilizer usage will increase maize output as fertilizers provide the required nutrients for crop germination, which subsequently improves production.

Ln Quantity of seeds (β_5) was found to be positive and highly significant at 1% level, making seeds one of the key inputs in maize production. This implies that

a 1% increase in the quantity of seeds used will increase maize output by 0.29%. This implies that farmers who apply more seeds in their farms are likely to increase the maize production output than those applying smaller quantities. These findings are consistent with the findings of Matthew et al (2024), who found that an increase in the number of maize seeds leads to increased maize production, as seeds are an important input that can improve yields. Ln Tractor (rands) (β_6) was positive with a moderate effect on maize output at 5% level. This suggests that a 5% increase in tractor usage by a farmer increases the output of maize by 0.01%. The use of tractors for mechanization allows the timely preparation of land and plant much bigger fields than using manual labour or animal draft power, which subsequently increases the total maize output. For instance, previous findings have reported that in Ghana, mechanization of maize, particularly with the use of a tractor, was linked to greater returns to scale (Othieno, 2021).

Ln Animal draft (rands) (β_7) was negatively associated with the output of maize at 5% level. This suggests that the use of animal draft reduces maize output by -0.02%. Animal power is a proxy for traditional agricultural practices, and these practices can take time, require too much labour, and can be less effective due to poor coordination between labour and animal power, which causes inefficiencies. These findings contradict the previous findings of Belete (2020), who reported a positive impact of oxen on maize output. This may be a result of differences in agro-ecological conditions and farm sizes. Another study by Madzivanzira et al. (2024) indicated that animal draught plough improved productivity as it facilitated timely land preparation for smallholder farmers. These contrasting findings may indicate that the impact of animal-drawn plough may be context-specific and may depend on factors which include the size of the farm, labour availability, and having access to mechanized alternatives.

4.4.10 Analysis of Technical Inefficiency Model Parameters

Table 4.8 below depicts the MLE findings of the technical inefficiency model for maize farmers in the Eastern Cape Province. Therefore, hypothesis testing confirmed the presence of technical inefficiency effects in the SFA model. The tested inefficiency variables were gender, household age and size, school years,

marital status, average household income, distance to markets, and years of farming maize, credit access, extension services, and membership in an organisation. Therefore, negative coefficients translate to a reduction in inefficiency.

Table 4.8: Maximum likelihood estimation results of the technical inefficiency model variables.

Variables	**Parameter**	**Coefficient**	**Std. Err.**	**z-statistics**
Constant	α_0	-1.329	0.744	-1.79
Gender	α_1	0.175	0.301	0.58
Household Age	α_2	0.022*	0.012	1.87
Household size	α_3	0.128	0.095	1.34
School years	α_4	-0.256***	0.078	-3.28
Marital status	α_5	0.039	0.466	0.08
Average Household Income	α_6	-0.001***	0.001	-3.66
Distance to markets	α_7	-0.121	0.075	-1.61
Years of farming maize	α_8	0.328***	.097	3.39
Credit access	α_9	0.173	.303	0.567
Received extension services	α_{10}	-1.696**	0.815	-2.08
Membership of organization	α_{11}	-0.014	0.375	-0.04
Number of Obs.	306			
Wald chi-square	1045.62			
Log Likelihood	-232.98249			
Prob > Chi^2	0.001			
Sigma-squared (σ^2)	0.701			
Gamma (γ)	0.712			
LR Test Statistic	3.59**			

Note: Values in parentheses are standard errors. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Household Age had a positive coefficient and was statistically significant at the 10% level (α_2=0.022). Since the coefficient was estimated in the inefficiency model, the positive sign indicates that increasing age is associated with higher technical inefficiency and therefore lower technical efficiency. This suggests that older farmers may face challenges related to declining physical capacity, slower adaptation to modern farming technologies, and greater reliance on traditional production practices. Consequently, older farmers are less likely to operate close to the production frontier compared to younger farmers. These results are consistent with the findings of Mujuru et al. (2022), who revealed that an increase in age is associated with less physical ability in performing manual work efficiently. Years spent at school had a negative coefficient and were significant at 1% level (α_4= -0.256). This indicates that being educated reduces the farmers' technical inefficiency, as educated farmers can better understand and process information from agricultural extension officers that would help in enhancing farm management capabilities to improve their production levels. Similar findings were revealed by Aman (2024), who revealed a negative relationship between education and farmer technical inefficiency. Average household income had a negative coefficient and was highly significant at 1% level (α_6 =-0.001), indicating that household with higher income exhibits lower technical inefficiency levels than households with lower income. This is because households with higher income have the financial muscle to invest in technologies that will improve their productivity. This is supported by the findings of Belete (2020), who noted that farmers need more money for them to be able to purchase sufficient inputs and be able to afford hired labor.

Years of farming maize had a positive coefficient and were highly significant at 1% level (α_8 = 0.328). Years of farming maize had a positive and highly significant coefficient (α_8 = 0.328; $p < 0.01$). This result is contrary to the a priori expectation of a negative coefficient. Given that the coefficient originates from the inefficiency model, the positive sign indicates that additional years of farming are associated with increased technical inefficiency. Although farming experience is generally expected to improve performance, the result suggests that highly experienced farmers may be less willing to adopt improved

technologies and modern management practices, thereby reducing their ability to achieve maximum technical efficiency. This finding may also indicate a tendency among more experienced farmers to continue relying on indigenous farming practices and traditional production methods that they have used for many years. While such practices may be valuable in certain contexts, they may limit the adoption of more productive technologies and innovations, ultimately contributing to lower technical efficiency levels. These results are consistent with Biswas et al. (2021), who reported a positive relationship between years of farming and technical inefficiency in Bangladesh. Access to extension services had a negative coefficient and was statistically significant at 5% (α_{10} = -1.696). This implies that maize farmers who had contact with extension officers exhibit lower technical inefficiencies than farmers without extension contact. This is because extension services offer farmers new and timely information on new ways of farming and offer farmers the necessary production inputs like fertilizer, seeds, and pesticides. These results are consistent with the findings of Ng'Atigwa et al. (2022), who noted that extension services reduce technical inefficiency by providing farmers with knowledge on new agronomic practices and marketing information to improve their efficiency.

4.4.11 The Technical Inefficiency Scores of Maize Farmers

Table 4.9 below shows the distribution of the efficiency scores among smallholder maize farmers in the study area. The findings provide a full overview of the maize farmers' operational performance. With a sample of 306 maize farmers, the technical efficiency ranges between 0.12 and 0.99, reflecting variations in farmers' technical efficiency. The mean technical efficiency of farmers was 0.772, which is moderate. This means that the maize farmers are producing below the production frontier and have a potential output gain of roughly 29% achievable using the same inputs. A few maize farmers (1.96%) were within the lowest efficiency range (≤0.20), which indicates extreme technical inefficiency is rare in the study area. However, targeted interventions are necessary for these farmers to improve their efficiency. While the largest group (25.49%) scored between 0.81 and 0.90. This implies that a relatively high proportion of near-efficient producers. The highest group (42.81%) was between

0.91 and 1.00; this shows that most farmers are highly efficient. Therefore, the findings show that despite best practices and technologies being available in the study area, not all farmers can allocate and use their resources effectively; there is room for improvement with proper interventions.

Table 4.9: Analysis of Technical Efficiency Distribution

Efficiency range	**Frequency**	**Percentage (%)**
≤0.20	6	1.96
0.21–0.30	12	3.92
0.31-0.40	16	5.23
0.41-.50	22	7.19
0.51-0.60	27	8.82
0.61-0.70	26	8.50
0.71-0.80	31	10.13
0.81-0.90	35	11.44
0.91-1.00	131	42.81
Total	**306**	
Efficiency Scores		
Mean	0.772	
Minimum	0.1213	
Maximum	0.99	

4.4.12 Impact of Agricultural Extension Services on Maize Productivity of Maize Farmers in Eastern Cape Province

Table 4.10 presents the estimated impact of agricultural extension services on maize productivity among smallholder farmers in the Eastern Cape Province, employing the Endogenous Switching Regression Model (ESRM) to account for potential selection bias and unobserved heterogeneity. This approach provides a robust framework for distinguishing between farmers who have access to agricultural extension services and those who do not, while also capturing the

counterfactual outcomes: what farmers' productivity levels would have been under alternative scenarios of access. By estimating the Average Treatment Effect on the Treated (ATT), the Average Treatment Effect on the Untreated (ATU), and the Heterogeneity Effect (HE), the model offers deeper insights into both the direct productivity gains associated with extension participation and the underlying differences across farmer groups. Consequently, this analysis moves beyond simple comparisons and provides a more rigorous evaluation of how extension services influence maize yields under real-world conditions.

Table 4.1 10: Average treatment effects using an endogenous switching regression model.

Outcome Variable	**Category**	**Decision stage**		**Treatment Effect**	**P-value**
		Access to Agricultural Extension Services (t/ha)	**Non-access to Agricultural Extension Services (t/ha)**		
Maize yields (metric tonnes/ha)	ATT	(a) 4.52	(c) 3.71_{cf}	0.81 (a-b)	0.038**
	ATU	(b) 2.08_{cf}	(d) 1.34	0.74 (c-d)	0.004***
				0.07 (a-d)	
Base Heterogeneity Effect	HE			3.18	

Note: ***, ** significance level at 1%, 5%, respectively, cf means counterfactual ATT = average treatment effect on the treated, ATU = average treatment effect on the untreated, HE = heterogeneity effect.

The results from the Endogenous Switching Regression (ESR) model reveal that access to agricultural extension services has a significant and positive effect on maize productivity among farmers. The Average Treatment Effect on the Treated (ATT) indicates that farmers who accessed agricultural extension services achieved an average maize yield of 4.52 tonnes per hectare, whereas their estimated counterfactual yield, had they not accessed extension services, would have been 3.71 tonnes per hectare. This results in a productivity gain of 0.81 tonnes per hectare, which is statistically significant ($p = 0.038$). This finding implies that agricultural extension services contribute meaningfully to improving maize yields among participating farmers. Access to agricultural extension services likely enhances farmers' knowledge of improved agronomic practices, including optimal fertilizer application, improved seed varieties (GM maize seeds), pest and disease management, and soil fertility management. Furthermore, agricultural extension officers often provide critical advisory support on crop management and climate-related risks, enabling farmers to make informed production decisions. Similar findings were found in a study conducted by Baylie and Pércsi (2025) in Ethiopia, which revealed that farmers who were receiving extension were producing an average of 0.6 quintal more per hectare than they would if they had never received the services, whereas farmers who did not receive the services would have received around 28% higher yields if they participated in agricultural extension services. Equally, the Average Treatment Effect on the Untreated (ATU). The ATT estimate indicates that farmers who received extension services produced 0.81 tonnes more maize per hectare than they would have produced without extension support. Similarly, the ATU estimate suggests that farmers currently excluded from extension programmes could increase their maize productivity by approximately 0.74 tonnes per hectare if they gained access to extension services. The positive transitional heterogeneity estimate (0.07) suggests that current extension participants derive slightly greater benefits from extension services than non-participants would obtain. This may reflect differences in farmer characteristics such as resource endowment, managerial ability, or readiness to adopt new technologies. These results are similar to the findings of Jolex (2022), who reported that extension services enhance the technical efficiency of the farmers

as they develop the capacity of the farmers through advice on new information, technologies, and improved farming practices.

4.4.13 Test of mean technical efficiency

The study initially assumed no significant difference in mean technical efficiency between maize farmers with and without access to Agricultural Extension Services [AES]. This assumption formed the null hypothesis (H_0) tested in the analysis. A test for a significant difference in mean technical efficiency among maize farmers was therefore conducted to compare the performance of the two groups. As shown in Table 4.11, the results indicate notable differences in mean technical efficiency between farmers with access to agricultural extension services and those without the services.

Table 4.11: Test of the significant difference in mean technical efficiencies between access to agricultural extension services and non-access to AES for maize farmers.

Category	**Number of farmers**	**Mean Technical Efficiency**	**Standard Deviation**
Access to Extension Services	183	0.9329	0.084
No Access to Extension Services	123	0.5239	0.163
Total/Average	**306**	**0.7720**	**0.197**
Mann–Whitney U Test			
Statistic	**Value**		
Mean difference	0.4090		
Mann-Whitney U Statistic	4,215.0		
Z-value	-13.284		

Effect Size (r)	0.52
95% Confidence Interval	0.347 – 0.471
p-value	<0.001
Decision	Reject H_0

Table 4.11 presents the comparison of technical efficiency scores between maize farmers who had access to agricultural extension services and those who did not. Out of the 306 sampled farmers, 183 (60.8%) reported having access to extension services, while 123 (39.2%) did not receive extension support. The results reveal substantial differences in technical efficiency between the two groups. Farmers with access to extension services achieved a substantially higher mean technical efficiency score (0.9329) compared to those without extension access (0.5239), resulting in a mean difference of 0.4090. This indicates that extension-supported farmers operated considerably closer to the production frontier and were more efficient in utilizing available production resources. The lower standard deviation among extension beneficiaries (SD = 0.084) further suggests relatively consistent performance within this group, whereas farmers without extension access exhibited greater variability in efficiency levels (SD = 0.163).

The technical efficiency scores are bounded between 0 and 1 and may violate the assumptions of normality required for parametric tests; a Mann-Whitney U test was employed to compare the two groups. The results revealed a statistically significant difference in technical efficiency between extension beneficiaries and non-beneficiaries ($U = 4{,}086.0$; $Z = -13.284$; $p < 0.001$). The findings suggest that agricultural extension services play a critical role in enhancing farmers' managerial capabilities, facilitating the adoption of improved production practices, and promoting more efficient allocation of production inputs. Extension officers provide technical guidance, timely production information, and advisory support that enable farmers to make informed production decisions, thereby improving farm-level efficiency. The estimated

effect size (r = 0.52) indicates a large practical effect, suggesting that access to extension services is strongly associated with improved technical efficiency. The findings imply that extension services enhance farmers' managerial capacity, facilitate the adoption of improved production practices, and promote more efficient allocation and utilization of production inputs. Consequently, farmers receiving extension support operate significantly closer to the production frontier than those without access to extension services. These results provide empirical evidence that strengthening agricultural extension systems can contribute substantially to improving farm-level productivity and efficiency among maize producers.

Table 4.12: Technology Gap Ratio (TGR) and Meta-Frontier Technical Efficiency (MFTE) by Farmer Group

Group	**Number of Farmers**	**Technology Gap Ratio (TGR)**	**Meta-Frontier Technical Efficiency (MFTE)**
Access to Extension Services	183	0.95	0.89
Non-Access to Extension Services	123	0.70	0.37
Overall	**306**	**0.85**	**0.68**

The findings of the Technology Gap Ratio (TGR) illustrate differences in access to production technologies among extension participants and non-participants (Table 4.12). Participants had a mean TGR of 0.95, while non-participants had a mean TGR of 0.70; this represents a technology gap of 0.25. Therefore, a TGR of 0.95 indicates that the maize farmers with extension contact operate under technologies that are very close to the best available technology, which is represented by the meta-frontier. On the other side, a mean TGR of 0.70 indicates that maize farmers without extension contact were constrained by a significant technology gap, and these farmers were unable to make the best use of the available technology within the farming system.

The Technical efficiency and technology differences were considered simultaneously through the Meta-Frontier Technical Efficiency (MFTE) measure (Table 4.12). Maize farmers with extension contact had an MFTE score of 0.89 compared to only 0.37 for farmers without extension contact, with a difference of 0.52. These findings suggest that farmers with extension contact achieved approximately 89% of the maize output under the best available technology, while farmers without extension contact achieved only 37%. These findings underscore the critical role of agricultural extension services in enhancing farmers' productivity and efficiency, supporting existing empirical evidence that extension access improves resource utilization, facilitates technology adoption, and strengthens overall farm performance (Oluwole et al., 2021; Biswas et al., 2021; Gebrehiwot et al., 2017; Tsegaye et al., 2025; Bayan et al., 2025).

4.5 Conclusion and Recommendations

The study assessed the productivity effects of agricultural extension services on smallholder maize efficiency in Eastern Cape Province. The descriptive findings revealed female dominance in the study area, with an average age of 61 years and 7 years spent at school. Farmers received various extension services, including training on soil preparation, fertilizer application, and row spacing on maize production, training on access to GM seeds, and record keeping, with services provided by the government, private, and both the government and private sectors. Agricultural Extension Officers used different sources of information in disseminating agricultural technologies and information, such as field visits, mobile cell phones, and radios. While maize farmers adopted several practices because of extension services, such as improved crop varieties, better soil management, enhanced pest and disease control, and improved water management practices.

The Stochastic Frontier Production model revealed that the mean technical efficiency of farmers was 0.772, which was moderate. This means that the maize farmers are producing below the production frontier. The logit regression model revealed that access to extension services was positively influenced by factors such as household size, school years, average household income, credit

access, years of farming maize, membership of organizations, and access to markets. The results from the Endogenous Switching Regression (ESR) model revealed that access to agricultural extension services had a significant and positive effect on maize productivity among farmers. Consequently, the results demonstrate that farmers who participated in extension programs benefited from improved technical knowledge and management capacity, which translates into higher maize productivity. Furthermore, the mean test was conducted between the farmers who received extension services and the farmers who did not. The results from the mean test revealed that farmers who received extension services exhibited higher technical efficiency, Technology Gap Ratio and Meta-Frontier Technical Efficiency than farmers who did not, indicating that they were very close to achieving the maximum possible output from the available resources.

The study recommends that the government, in collaboration with agricultural institutions, should prioritize investing in employing more extension practitioners, offering training, and logistical support to improve service coverage, particularly in remote rural areas. The expansion of mobile-based advisory platforms using SMS based services, WhatsApp groups, farmer field schools, and demonstration plots should be promoted to enhance farmers' access to timely agricultural information and improve technology adoption in the study area. This can be initiated using voice-based and local language mobile extension platforms, such as interactive voice response (IVR) systems and audio messages delivered in local languages. In addition, a district-level digital extension system should be developed to link SMS and WhatsApp platforms with public extension services, so that messages are checked for local relevance and aligned with the seasonal crop production calendar. Furthermore, special attention should be provided to resource-constrained and women farmers through targeted extension programmes that address their unique challenges. Also, strengthening farmer cooperatives and other producer organizations can help facilitate collective learning, improve information dissemination among farmers, and increase participation in extension services and access to inputs from extension officers.

Policies should further be designed to support broader productivity and technical efficiency goals of the farmers instead of focusing on merely the adoption of improved technologies and practices. For example, beyond just promoting the use of improved seed varieties, governments and agricultural institutions should ensure that farmers have access to complementary resources such as affordable credit, timely input supply, irrigation infrastructure, market information, and extension support. Though the adoption of improved technologies is the first significant step, it does not automatically improve farm performance unless farmers can utilize production resources efficiently and manage their farms in an effective manner. Hence, targeted extension services should be developed in a way that goes beyond technology promotion and emphasizes ways in which farmers can maximize their maize using the available resources. Therefore, this will ensure that farmers receive training and guidance in applying inputs such as seeds, fertilizers, and pesticides using the recommended quantities and combinations, as this will help reduce wastage. In practical terms, this includes the introduction of input-use calibration training sessions, such as fertilizer micro-dosing demonstrations and seed density trials) delivered through demonstration plots within each extension ward.

Ethical Considerations

Ethical clearance for this study was granted by the Humanities and Social Sciences Research Ethics Committee (HSSREC) from the University of KwaZulu-Natal with the protocol number HSSREC/00007889/2024. Approval was formally issued on 18 October 2024. The research was conducted in full compliance with the approved protocol from the University. Any alterations to the study design, including adjustments to the questionnaire, interview schedule, informed consent procedures, study site, or methodological approach, were required to undergo prior review and approval by the ethics committee. Participation in the study was entirely voluntary, and informed consent was obtained from all respondents before data collection commenced. Throughout the study, strict measures were implemented to ensure the confidentiality and anonymity of all participants

Study Limitations

The current study encountered several limitations during the data collection process. Firstly, the study was based on cross-sectional data, which were collected at a single point in time. This type of data limits the researcher in capturing causal relationships and changes in farmer productivity and technical efficiency over time. Furthermore, data collection was conducted under financial and logistical constraints, such as booking the vehicle for a longer duration. Some of the maize farmers who had initially agreed to partake in the study were later unavailable during the survey period due to the harvesting and threshing period. Despite the provided limitations, the study was able to provide useful insights into the role played by agricultural extension services in improving the productivity and technical efficiency of maize farmers in the Eastern Cape Province.

Future Research

Future studies can consider focusing on using a longitudinal this will help in capturing long-term effects of extension services in influencing the production decisions and efficiency of the farmers. Furthermore, future research can also cover the whole province, as the current study focused on a few district municipalities.

Acknowledgement

The study is very thankful to the smallholder maize farmers from OR Tambo and Chris Hani District Municipalities in the Eastern Cape Province for availing themselves and sharing with us their knowledge. The study is further grateful to agricultural extension agents who assisted during data collection and organizing the meetings.

Author contributions

All authors contributed equally to the conception, methodological development, analysis, interpretation of results, and writing of the manuscript. All authors read and approved the final version of the paper.

Funding

The study received funding provided by the University of KwaZulu-Natal within the Fee Remission Agreement

Data Availability

The data used in this study are only available on substantial request from the corresponding author

Conflict of interest

The authors declare no competing interests.

Reference

Abdallah, A.H. and Abdul-Rahaman, A., 2016. Determinants of access to agricultural extension services: evidence from smallholder rural women in Northern Ghana. *Asian Journal of Agricultural Extension, Economics & Sociology*, *9*(3), pp.1-8.

Abdulai, S., Nkegbe, P.K. and Donkoh, S.A., 2018. Assessing the technical efficiency of maize production in northern Ghana: The data envelopment analysis approach. *Cogent Food & Agriculture*, *4*(1), p.1512390.

Abebe, M.B. and Endale, K., 2023. *The Impact of Improved Seed Adoption on Nutrition Outcome: A Panel Endogenous Switching Regression Analysis* (No. 23-1).
Environment for Development, University of Gothenburg.

Agbugba, I.K., Christian, M. and Obi, A., 2020. Economic analysis of smallholder maize farmers: Implications for public extension services in Eastern Cape. *South African Journal of Agricultural Extension*, *48*(2), pp.50-63.

Ahmed, A.M., 2024. *The role of agriculture on the Ethiopian economy with special emphases on livestock production in case of the Fentale District.* College of business and economics department of economics, Oda Bultum University.

Ajzen, I., 1991. The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), pp.179-211.

Aman, R., 2024. Stochastic Frontier Analysis of Technical Efficiency of Smallholder Maize Farmers in Morogoro Municipality: A Reflection from RIPAT Program. *Available at SSRN 5030244*.

Ambaye, T.K., Tsehay, A.S. and Hailu, A.G., 2021. Analysis of the status and determinants of rural households' access to agricultural extension services: The case ff Jimma Geneti Woreda, Oromia Regional State, Ethiopia. *International Journal of Agricultural Extension and Rural Development Studies*, *8*(1), pp.52-99.

Bakang, J.E.A., Wongnaa, C.A., Tham-Agyekum, E.K., Fatimatu, S., Obeng, J.A., Nsafoah, E.B. and Antwi, M.A., 2024. Determinants of maize farmers willingness to pay for private extension services in Ejisu municipality, Ghana. *Heliyon*, *10*(17).

Bakang, J.E.A., Wongnaa, C.A., Tham-Agyekum, E.K., Fatimatu, S., Obeng, J.A., Nsafoah, E.B. and Antwi, M.A., 2024. Determinants of maize farmers willingness to pay for private extension services in Ejisu municipality, Ghana. *Heliyon*, *10*(17).

Bakhsh, S., 2024. Analyzing Smallholder Farmers Performance-Farmer Typology, Technical Efficiency, Market participation, Policies and Management Practices Evidence from Limpopo Region of South Africa.

Baloi, R.T., 2011. *Technical efficiency in maize production by small-scale farmers in Ga-Mothiba, Limpopo Province, South Africa* (Doctoral dissertation, University of Limpopo).

Bayan, B., Sahu, P.P. and Dutta, M.K., 2025. Technical Efficiency of Smallholder Dairy Farms in Rural Assam: A Double Bootstrap Data Envelopment Analysis Approach. *International Journal of Rural Management*, *21*(1), pp.121-140.

Baylie, M.M. and Pércsi, K.N., 2025. Examining access and impact of agricultural extension services on crop yield in Farta Woreda, Ethiopia, using

endogenous switching regression model. *Agriculture & Food Security*, *14*(1), p.32.

Bedasa, Y. and Tekalign, T., 2023. Technical efficiency of smallholder farmers in Sesame production (Ethiopia). *SN Business & Economics*, *4*(1), p.3.

Belete, A.S., 2020. Analysis of technical efficiency in maize production in Guji Zone:
stochastic frontier model. *Agriculture & Food Security*, *9*(1), p.15.

Belete, A.S., 2020. Analysis of technical efficiency in maize production in Guji Zone: stochastic frontier model. *Agriculture & Food Security*, *9*(1), p.15.

Benjamin, J., Idowu, O., Babalola, O.K., Oziegbe, E.V., Oyedokun, D.O., Akinyemi, A.M. and Adebayo, A., 2024. Cereal production in Africa: the threat of certain pests and weeds in a changing climate—a review. *Agriculture & Food Security*, *13*(1), p.18.

Biswas, B., Mallick, B., Roy, A. and Sultana, Z., 2021. Impact of agriculture extension services on technical efficiency of rural paddy farmers in southwest Bangladesh. *Environmental Challenges*, *5*, p.100261.

Borda, Á.J., Sárvári, B. and Balogh, J.M., 2023. *Generation change in agriculture: A systematic review of the literature. Economies, 11 (5), 129* [online]

Cairns, J.E., Chamberlin, J., Rutsaert, P., Voss, R.C., Ndhlela, T. and Magorokosho,
C., 2021. Challenges for sustainable maize production of smallholder farmers in subSaharan Africa. *Journal of Cereal Science*, *101*, p.103274.

Chimonyo, V.G.P., Mutengwa, C.S., Chiduza, C. and Tandzi, L.N., 2020. Characteristics of maize growing farmers, varietal use and constraints to increase productivity in selected villages in the Eastern Cape province of South Africa. *South African Journal of Agricultural Extension*, *48*(2), pp.64-82.

Cloete, P., Bahta, Y.T., Marunga, M. and Lombard, W.A., 2019. Perception and understanding of agricultural extension: perspective of farmers and public agricultural extension in Taba Nchu. *South African Journal of Agricultural Extension*, *47*(3), pp.14-31.

Das, A., Kumar, S. and Ganga Rao, N.V.P.R., 2023. Potential for increasing groundnut production in Tanzania by enhancing technical efficiency: A stochastic meta-frontier analysis. *Frontiers in Sustainable Food Systems*, *7*, p.1027270.

Department of Cooperative Governance and Traditional Affairs, 2021. Profile and analysis of the district development model. OR Tambo District Municipality. chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cogta.gov.za/ddm/wpcontent/uploads/2020/11/ORTamnco-September-2020.pdf [accessed online: 14 November 2025].

Department of Cooperative Governance and Traditional Affairs, 2020. Chris Hani District Municipality in Eastern Cape Province. Profile and analysis of the district development model. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cogta.gov.za/ddm/wpcontent/uploads/2020/08/Take3_DistrictProfile_CHRISHANI03072020.pdf [accessed online: 14 November 2025].

Fitawek, W. and Hendriks, S.L., 2021. Evaluating the impact of large-scale agricultural investments on household food security using an endogenous switching regression model. *Land*, *10*(3), p.323.

Gebrehiwot, K.G., 2017. The impact of agricultural extension on farmers' technical efficiencies in Ethiopia: A stochastic production frontier approach. *South African Journal of Economic and Management Sciences*, *20*(1), pp.1-8.

Gebrie, A., 2018. *Technical Efficiency of Smallholder Wheat Producers in Simada Distric of Amhara Region, Ethiopia* (Doctoral dissertation, ARBA MINCH, ETHIOPIA).

Gidi, L.S., Mdoda, L., Ncoyini-Manciya, Z. and Mdiya, L., 2024. Climate change and small-scale agriculture in the Eastern Cape Province: Investigating the nexus of awareness, adaptation, and food security. *Sustainability*, *16*(22), p.9986.

Girma Asefa, Y. and Ayalew Muluken, A., 2024. Land size and efficiency in agriculture: the case of Ethiopian smallholder farmers. A meta-analysis. *Frontiers in sustainable food systems*, *8*, p.1447186.

Hlatshwayo, S.I., Ngidi, M., Ojo, T., Modi, A.T., Mabhaudhi, T. and Slotow, R., 2021. A typology of the level of market participation among smallholder farmers in South Africa: Limpopo and Mpumalanga Provinces. *Sustainability*, *13*(14), p.7699.

Hlatshwayo, S.I., Ngidi, M.S.C., Ojo, T.O., Modi, A.T., Mabhaudhi, T. and Slotow, R., 2023. The determinants of crop productivity and its effect on food and nutrition security in rural communities of South Africa. *Frontiers in sustainable food systems*, *7*, p.1091333.

Jiba, P., Obi, A., Mdoda, L. and Mzuyanda, C., 2024. The impact of smallholder irrigation scheme on household welfare in farm-managed irrigation scheme communities in the Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, *52*(1), pp.48-72.

Jolex, A., 2022. Influence of agricultural extension services on technical efficiency of maize farmers in Malawi. *African Journal of Agricultural and Resource Economics*, *17*(1), pp.92-105.

Kapari, M., Hlophe-Ginindza, S., Nhamo, L. and Mpandeli, S., 2023. Contribution of smallholder farmers to food security and opportunities for resilient farming systems. *Frontiers in Sustainable Food Systems*, *7*, p.1149854.

Kauky, M.S., 2024. Role of Agricultural Extension Services (AES) on Farm Productivity and Household Food Security in Tanzania. *The African Review*, *1*(aop), pp.1-24.

Kehinde, A.D., Ojo, T.O. and Ogundeji, A.A., 2024. Impact of participation in social capital networks on the technical efficiency of maize producers in Southwest Nigeria. *Agriculture & Food Security*, *13*(1), p.12.

Khapayi, M. and Celliers, P.R., 2016. Factors limiting and preventing emerging farmers to progress to commercial agricultural farming in the King William's

Town area of the Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, *44*(1), pp.25-41.

Leitner, S., Pelster, D.E., Werner, C., Merbold, L., Baggs, E.M., Mapanda, F. and Butterbach-Bahl, K., 2020. Closing maize yield gaps in sub-Saharan Africa will boost soil N2O emissions. *Current Opinion in Environmental Sustainability*, *47*, pp.95-105.

Lemba, J., D'Haese, M., D'Haese, L., Frija, A. and Speelman, S., 2012. Comparing the technical efficiency of farms benefiting from different agricultural interventions in Kenya's drylands. *Development Southern Africa*, *29*(2), pp.287-301.

Lesala, M.E., Mujuru, N., Mdoda, L. and Obi, A., 2025. Evaluating the Economic Impact of Market Participation on the Well-Being of Smallholder Irrigators: Evidence from the Eastern Cape Province, South Africa. *Sustainability*, *17*(8), p.3390.

Liu, Q., Jiang, Y., Lagerkvist, C.J. and Huang, W., 2023. Extension services and the technical efficiency of crop-specific farms in China. *Applied Economic Perspectives and Policy*, *45*(1), pp.436-459.

Loki, O., Aliber, M. and Sikwela, M.M., 2021. Assessment of socio-economic characteristics that determine farmers' access to agricultural extension services in Eastern Cape, South Africa. *South African Journal of Agricultural Extension*, *49*(1), pp.198-209.

Maake, M.M.S. and Antwi, M.A., 2022. Farmer's perceptions of effectiveness of public agricultural extension services in South Africa: an exploratory analysis of associated factors. *Agriculture & Food Security*, *11*(1), p.34.

Machete, K.C., 2024. *Vulnerability assessment of smallholder maize farmers to climate change risks and willingness to adopt climate-smart agriculture in Limpopo Province South Africa* (Doctoral dissertation).

Madamombe, S.M., Ng'ang'a, S.K., Öborn, I., Nyamadzawo, G., Chirinda, N., Kihara, J. and Nkurunziza, L., 2024. Climate change awareness and adaptation

strategies by smallholder farmers in semi-arid areas of Zimbabwe. *International Journal of Agricultural Sustainability*, *22*(1), p.2293588.

Madzivanzira, T., Mvumi, B.M., Nazare, R.M., Nyakudya, E., Mtambanengwe, F. and Mapfumo, P., 2024. A review of appropriate mechanisation systems for sustainable traditional grain production by smallholder farmers in sub-Saharan Africa with particular reference to Zimbabwe. *Heliyon*, *10*(17).

Mahaboob, B., Ajmath, K.A., Venkateswarlu, B., Narayana, C. and Praveen, J.P., 2019, December. On Cobb-Douglas production function model. In *AIP Conference Proceedings* (Vol. 2177, No. 1, p. 020040). AIP Publishing LLC.

Makamane, A., Swanepoel, J.W. and Loki, O., 2024. Communication Channels and Information Sources Utilised By Agricultural Extension Practitioners to Communicate Agricultural-Related Information to Farmers in the Eastern Cape Province. *South African Journal of Agricultural Extension*, *52*(5), pp.151-169.

Makwela, M.A., Oluwatayo, I.B. and Gidi, L.S., 2022. *Determinants of smallholder maize farmer's varietal choice: a case study of Mogalakwena Local Municipality Limpopo Province, South Africa* (Doctoral dissertation, University of Limpopo).

Mamashila, M.J. and Antwi, M.A., 2025. Assessment of profit efficiency of smallholder maize farmers in Limpopo province, South Africa: A stochastic frontier approach. *Journal of Agribusiness and Rural Development*, (1 [75]).

Mangani, R., Mazarura, J., Matlou, S., Marquart, A., Archer, E. and Creux, N., 2025. The impact of past and current district-level climatic shifts on maize production and the implications for South African farmers. *Theoretical and Applied Climatology*, *156*(2), p.109.

Masanja, I., Shausi, G.L. and Kalungwizi, V.J., 2023. Factors Influencing Rural Farmers' Access to Agricultural Extension Services Provided by Private Organizations in Kibondo District, Tanzania. *European Journal of Agriculture and Food Sciences*, *5*(5), pp.115-122.

Matthew, M.D., Ajibefun, I. A. and Oduntan, O. 2024. Technical Efficiency Analysis of Small-Holder Maize Farmers in Ondo State, Nigeria. International journal of research and scientific innovations, 10(5), p 81-89

Mbatha, M.W., 2024. The provision of agricultural extension services to rural farmers as a strategy to improve agricultural practices in South Africa. *South African Journal of Agricultural Extension*, *52*(1), pp.1-19.

Mdiya, L., Shiba, W.T., Mdoda, L. and Van Niekerk, J., 2025. Assessing the Role of Smallholder Livestock Farmers on Rural Household Food Security: Experiences from Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, *53*(3), pp.96-110.

Mdoda, L., Obi, A., Christian, M. and Jiba, P., 2021. Technical efficiency of maize-based farm irrigators in the Eastern Cape province. *Journal of Agribusiness and Rural Development*, *62*(4), pp.371-381.

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D., 2025. Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis. *GM Crops & Food*, *16*(1), pp.272-304.

Midamba, D.C., Muteti, F.N., Mpofu, T.P., Ouko, K.O., Kwesiga, M., Ouya, F.O. and Chepkoech, B., 2022. Socio–economic factors influencing access to agricultural extension services among smallholder farmers in Western Uganda. *Asian J. Agric. Ext. Econ. Sociol*, *40*, pp.998-1008.

Mncube, T.L., Phiri, E.E., Mothapo, P.N., Rugare, J.T., Pieterse, P.J. and Mloza-Banda, H.R., 2024. Characterising productivity factors affecting maize (Zea mays) production in a smallholder crop-livestock system. *Agricultural Research*, *13*(1), pp.124-136.

Mtyobile, M., 2021. Evaluation of the yield performance of maize cultivars (Zea mays L.) in a Semi-Arid Region of the Eastern Cape Province, South Africa. *Int. J. Agric. Sci. Food Technol*, *7*, pp.327-330.

Mujuru, N.M., Obi, A., Mishi, S. and Mdoda, L., 2022. Profit efficiency in family-owned crop farms in Eastern Cape Province of South Africa: a translog profit function approach. Agriculture & Food Security, 11(1), p.20.

Muzekenyi, M., Zuwarimwe, J. and Kilonzo, B.M., 2021. Analysis of technical efficiency of small-scale commercial farmers in Vhembe district. *South African Journal of Agricultural Extension*, *49*(1), pp.91-104.

Muzeza, N.T., Taruvinga, A. and Mukarumbwa, P., 2023. Analysis of factors affecting technical efficiency of A1 smallholder maize farmers under command agriculture scheme in Zimbabwe: The case of Chegutu and Zvimba Districts. *Cogent Economics & Finance*, *11*(1), p.2163543.

Mwalupaso, G.E., Wang, S., Rahman, S., Alavo, E.J.P. and Tian, X., 2019. Agricultural informatization and technical efficiency in maize production in Zambia. *Sustainability*, *11*(8), p.2451.

National Agricultural Marketing Council, 2024. Improving market access for smallholder farmers in South Africa, Policy brief. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.namc.co.za/wp-content/uploads/2024/10/Policy-Brief-Improving-Market-Access-for-Smallholder-Farmers-in-South-Africa.pdf [accessed online: 11 November 2025].

National Council of Provinces, 2025. *Provincial Profiles: Eastern Cape Province. 2025 NCOP Provincial Week – Building Viable Municipalities for Enhanced Delivery of Basic Services to Communities*.

Nazia, H., 2024. Omission in Adoption: Whole of Systems Approach Applied to Case Study Analysis of Genetically Modified (GM) Maize Adoption in Eastern Cape Province South Africa. *MSD J Agric Sci Appl Econ*, *1*(1), pp.001-022.

Ng'Atigwa, A.A., Hepelwa, A., Manyong, V. and Feleke, S., 2022. Analysis of technical efficiency among youth involved in crop production in Njombe Region, Tanzania. *Cogent Economics & Finance*, *10*(1), p.2103923.

Ngomane, T.S., 2021. South African Women's Access to Agricultural Extension Services: An Analysis of Barriers and Constraints. International Conference on Public Administration and Development Alternatives (IPADA).

Ngqulana, A., Oladele, O.I., Mdoda, L., Nontu, Y. and Mdiya, L., A Systematic Review on Enhancing the Technical Efficiency of Genetically Modified Maize Adoption in Sub-Saharan Africa: The Role of Agricultural Extension Services and Barriers to Success. *Frontiers in Sustainable Food Systems*, *9*, p.1609417.

Odinaka, I.E., Ajadike, J.C. and Ogbu, S.O., Multivariate effects of climate variability on maize yield and implications for food security in Ejule, Kogi State, Nigeria. *Irish International Journal of Engineering and Scientific Studies*, *8*(5), 38–59.

Ogujiuba, K., Agholor, A.I. and Mabila, L., 2021. Socio economic factors affecting small scale maize producing farmers in Kamhlushwa, South Africa.

Olasehinde, T.S., Qiao, F. and Mao, S., 2022. Performance of Nigerian rice farms from 2010 to 2019: A stochastic metafrontier approach. *Agriculture*, *12*(7), p.1000.

Oleh-Petani, D.A.T.P. and di Negara, K., 2021. Determinants of Agricultural technology adoption by smallholder farmers in developing countries: Perspective and prospect for Indonesia. *Jurnal Penelitian dan Pengembangan Pertanian Vol*, *40*(1), pp.21-30.

Oluwole, A.J., Segun, A.O., Bayonle, R.S., Samuel, B.B. and Oladeji, O.I., 2021. Effect of extension training on technical efficiency of maize farmers in Ogbomoso agricultural zone of Oyo State, Nigeria. *Int J Res Rev*, *8*(9), pp.210-217.

Ono-Raphel, J.G., du Preez, L., Cherry, A.L. and Jacobson, M.G., 2025. Improving Smallholder Maize Production in KwaZulu-Natal, South Africa. *Food and Energy Security*, *14*(1), p.e70053.

Othieno, A., 2021. Impact of Mechanization on Maize Output in Kenya (Doctoral dissertation, University of Nairobi).

Oumer, A.M., Mugera, A., Burton, M. and Hailu, A., 2022. Technical efficiency and firm heterogeneity in stochastic frontier models: application to smallholder maize farms in Ethiopia. *Journal of Productivity Analysis*, 57(2), pp.213-241.

Phali, L., Mudhara, M., Ferrer, S. and Makombe, G., 2020. Determinants of Farmers' Participation in the Management of Smallholder Irrigation Schemes in Kwazulu-Natal Province, South Africa. *philosophy*, *12*(6), pp.21-32.

Prah, S., Asante, B.O., Aidoo, R., Mensah, J.O. and Nimoh, F., 2023. Impact of agricultural policy intervention on yield and profitability of maize farmers: The case of Planting for Food and Jobs (PFJ) programme in Ghana. *Cogent Food & Agriculture*, *9*(1), p.2249928.

Sahu, S., Bishnoi, S., Sharma, P.R., Satyapriya, Mahra, G.S., Burman, R.R., Barua, S., Misha Madhavan, M., Sangeetha, V., Sinha, S.K. and Singh, R., 2024. Exploring popular information sources and determinants of farmers' access to agricultural extension services in the Indo-Gangetic plains. *Frontiers in Sustainable Food Systems*, *8*, p.1339243.

Shitaye, Z., Tadesse, B. and Enkuahone, K., 2025. Intensity of agricultural information utilization among small holder farmers in East Gojjam Zone, Amhara Region, Ethiopia. *Heliyon*, *11*(4).

Sumo, T.V., Ritho, C. and Irungu, P., 2022. Effect of farmer socio-economic characteristics on extension services demand and its intensity of use in post-conflict Liberia. *Heliyon*, *8*(12).

Suresh, K., Khanal, U., Wilson, C., Managi, S., Quayle, A. and Santhirakumar, S., 2021. An economic analysis of agricultural adaptation to climate change impacts in Sri Lanka: An endogenous switching regression analysis. *Land Use Policy*, *109*, p.105601.

Thaba, T.K. and Molobe, J.R., 2025. Empirical investigation into the role of agriculture in employment generation in South Africa. *International Journal of Economics and Financial Issues*, *15*(3), p.383.

Tsegaye, T., Haji, J., Sileshi, M., Degefu, S. and Abaynew, H., 2025. Small-scale irrigation and its impact on technical efficiency and household income among smallholder potato farmers in Ethiopia. *Discover Food*, *5*(1), p.54.

Wossen, T., Abdoulaye, T., Alene, A., Haile, M.G., Feleke, S., Olanrewaju, A. and Manyong, V., 2017. Impacts of extension access and cooperative

membership on technology adoption and household welfare. *Journal of rural studies*, *54*, pp.223-233.

CHAPTER 5

Unpacking Smallholder Maize Farmers' Preferences for Genetically Modified Maize Seeds in the Eastern Cape Province, South Africa

Abstract

Maize is a staple food and a vital source of income for smallholder farmers in South Africa, particularly in the Eastern Cape Province, where agriculture underpins rural livelihoods. Despite its importance, maize productivity remains low due to poor seed quality, pest and disease susceptibility, climate variability, limited access to quality inputs, inadequate extension services, and suboptimal farm management. Genetically modified (GM) maize seeds have been developed to improve production, resilience, and overall farm performance; however, their adoption remains inconsistent. Understanding the factors that influence farmers' GM maize seed selection choice is therefore critical for effective policy and extension strategies. This study was conducted in Chris Hani and OR Tambo district municipalities, using a multistage random sampling approach to collect data from 306 smallholder maize farmers via structured questionnaires. Descriptive statistics and a multinomial logistic regression model were used for analysis. Results showed that 57% of respondents were female, averaging 61 years old, with 8 hectares of land and a household income of ZAR 6,637.52. Only 6.2% were formerly employed, 19.3% self-employed, 34.0% unemployed, and 40.5% retired, with an average household size of 9.14. Farmers' seed choices included GM (HT/BT) at 38.6%, GM (BT) at 26.8%, and traditional maize at 35.0%. MNL results revealed that household age, education, income, years of maize farming, and organizational membership positively influenced both GM (HT/BT) and GM (BT) selection. In contrast, extension services and credit access influenced GM (HT/BT) adoption only. The study recommends context and variety-specific policies, strengthening extension services, farm organizations, engaging experienced farmers as lead farmers, and developing subsidies and microcredit schemes to enhance the choice of GM maize seed selection by farmers.

Keywords: Eastern Cape Province, Smallholder farmers, GM Maize Choice of Selection, Multinomial Regression Model

5.1 Introduction

Poverty reduction is one of the central priorities within the framework of the Sustainable Development Goals (SDGs) globally (Magakwe et al., 2025). In 2022, it was reported that 9.2% of the global population experienced hunger, up from 7.9% in 2019 (United Cities and Local Governments [UCLG], 2024). Among them, about 11.3% were reported to have experienced severe food insecurity and lacked physical, social, and economic access to enough, safe, and nutritious food required for their dietary needs (UCLG, 2024). Therefore, to fight the issue of food security and achieve the Sustainable Development Goals demands transdisciplinary research and outreach in all role players (Herrera et al., 2025). This requires a holistic approach that includes practices, policies, and technologies that can efficiently fight food insecurity, advance environmental sustainability, and at the same time ensure the long-term sustainability of food production (Hiywotu, 2025).

According to Hlatshwayo et al. (2024), agriculture is widely recognised as a fundamental strategy for improving nutrition and combating hunger. Beyond food production, agricultural land underpins global food security and delivers critical ecosystem services, including the provision of food, fuel, and fibre. Globally, the agricultural sector remains a cornerstone of employment and rural development. A review by Islam (2025) indicates that over one billion people are employed in agriculture worldwide, making it the largest employer across sectors. In Africa, the agricultural sector contributes nearly 40% of the continent's Gross Domestic Product (GDP) and provides employment for approximately 70% of the labour force (Uyanga et al., 2024). These figures underscore the indispensable role of agriculture not only in sustaining human diets but also in supporting broader livelihood systems and ecological stability.

In South Africa, primary agriculture had a total value of R460 184 in the year 204, while it contributed about R182 181 million to the GDP of the country

(Department of Agriculture, Land Reform and Rural Development [DALRRD], 2024). Furthermore, the agricultural sector in South Africa has been growing by 8,8% per annum since 2013 (DALRRD, 2024). Among the major crops cultivated in South Africa, maize (Zea mays) stands out as the most important and the largest locally produced field crop (Akanbi et al., 2020). Its strategic importance extends beyond economic contribution, as maize serves as a staple food for the majority of households and as a critical input in the livestock and agro-processing industries. Within the Southern African Development Community (SADC), South Africa is recognised as one of the leading producers and exporters of maize (Akanbi et al., 2020). This strong production capacity is reflected in the 2018/2019 maize season, during which the country produced more than 11 million tonnes (Mt) of maize (Akanbi et al., 2020). Such output not only strengthens national food security but also reinforces South Africa's strategic role in regional grain markets and cross-border trade within the SADC bloc.

In the 2025 production season, the most maize-producing provinces were Free State, Mpumalanga, and North West (Department of Agriculture, Land Reform and Rural Development [DALRRD], 2025). The Free State province planted 1,195.000 hectares of maize, making it the largest producer, contributing about 46% of South Africa's maize area and 40.2% of the total maize production. While Mpumalanga was the second largest with 534.000 hectares, which is 20.2% of the national area, North West had around 540,000 hectares that were planted, which is 20.8% of the national area (DALRRD, 2025). Beyond its economic significance, maize plays a central role in national food systems. It is a staple food for most of the population and is a critical input in both human consumption and animal feed industries (Colbert et al., 2024). Estimates indicate that between 67% and 83% of South Africans consume maize and maize-based products daily, with per capita intake ranging from 476 g to 690 g (Colbert et al., 2024). The dominance of maize meal products (particularly in the form of pap) highlights the indispensable role of maize in household food security and the broader food industry in South Africa.

Despite South Africa's position as the largest maize producer in the region, a significant proportion of smallholder farmers continue to operate under resource-constrained conditions. Many rely on indigenous farming methods, limited mechanisation, and traditional seed systems, producing primarily for subsistence with minimal marketable surplus (Mamashila et al., 2025). This production structure restricts economies of scale, limits commercial integration, and ultimately constrains technical efficiency. Empirical evidence consistently reports low levels of technical efficiency among maize farmers in South Africa, attributing this to weak financial sustainability, inadequate governance and institutional support, limited access to improved production technologies, restricted access to formal markets, and insufficient extension services (Seti and Madini, 2025; Muzekenyi et al., 2021; Zewdie et al., 2021; Lutonja, 2023). Furthermore, Carelsen et al. (2021) contend that development stakeholders often struggle to deliver targeted and efficient support due to the absence of a clear and consistent classification framework for smallholder farmers. This institutional ambiguity undermines policy design, resource allocation, and the effective delivery of interventions aimed at improving productivity and competitiveness.

Historically, maize production in South Africa has been characterised by persistent productivity gaps, particularly among smallholder farmers. Mdoda et al. (2025) attribute this trend to ineffective farming practices, limited access to improved seed varieties, and exposure to unfavourable environmental conditions. In response, the introduction of genetically modified (GM) crop varieties has been promoted as a strategic intervention to improve maize production and resilience (Lovemore et al., 2020). GM crops are genetically modified to include desirable characteristics such as increased yield potential, resistance to pests and diseases, and improved tolerance to environmental stresses linked to climate variability (Mbando, 2024). When appropriately regulated and managed, these technologies hold substantial potential to strengthen food security and agricultural sustainability (Adenle et al., 2013). Evidence suggests that GM crop adoption yields both agronomic and economic benefits, including improved yield stability, reduced pesticide application, enhanced pest and disease resistance, and increased farm profitability (Cai,

2024). For example, Ngongolo and Mmbando (2025) report that between 1996 and 2016, GM crops contributed to a reduction of 671.2 million kilograms in pesticide use, lowered the environmental footprint by 18.4%, and reduced overall pesticide application by approximately 37%. Globally, producers accrued an estimated US$18.2 billion in direct income benefits from GM crops, with GM maize accounting for more than half of these gains (Ala-Kokko et al., 2021). These findings highlight the transformative potential of GM maize in enhancing both productivity and environmental sustainability.

Nevertheless, the adoption of GM maize seed varieties among South African farmers remains uneven and relatively low. This suggests that mere availability and physical access to GM maize seeds are insufficient to guarantee widespread uptake. Adoption decisions are embedded within broader socio-economic, institutional, and behavioural contexts that shape farmers' risk perceptions, resource endowments, and market orientation. Therefore, understanding the development of GM maize technologies alone is inadequate; equal attention must be given to the determinants influencing farmers' seed selection decisions. Identifying these factors is critical for designing context-specific policies and extension strategies that enhance adoption rates and maximise the returns from biotechnology investments. Against this backdrop, the present study seeks to assess the key factors influencing farmers' GM maize seed selection choices in the Eastern Cape Province of South Africa, to inform evidence-based interventions to enhance smallholder productivity and food security outcomes.

5.2 Theoretical Framework

The study adopted both the Theory of Planned Behaviour [TPB] and Diffusion Theory (Figure 5.1). These theories have been used by several studies to analyse the adoption of technologies in several countries (Chukwuma, 2023; Kulugomba et al, 2025; Jahangir et al., 2023; Hamilton and Terblanche-Smit, 2018). The TPB theory states that behaviour is influenced by the intentions of the person and determined by attitudes, subjective norms, and perceived control (Ajzen and Schmidt, 2020). According to this theory, intentions are regarded as

the significant predictor of the actual behaviour by the individual (Judge et al., 2019). In the context of farmers' GM maize seed selection choices, the farmers' intentions to select GM maize varieties are determined by high yielding and disease resistance, and these will determine whether the farmer will adopt GM maize or not. Therefore, this intention is then influenced by attitudes of the farmers towards GM technologies. This will be based on the farmers' evaluation of GM maize seeds, when the farmers believe that improved seeds will improve his/her yields, enhance farm income, resist pests and diseases, then the farmers are likely to have a favourable attitude towards GM seeds and adopt them. On the other hand, if the farmers perceived risks, which may include high input costs and market uncertainty, then the farmers' attitudes may be negative, thus reducing the adoption intentions.

The second will be the subjective norms, which focus on the social pressure that will influence farmers' behaviour. According to Ajzen and Schmidt (2020), subjective norms are the farmer's beliefs on whether significant others believe he/she should conduct a certain behaviour. In South Africa, smallholder farmers are mostly influenced by the opinions and the behaviour of agricultural extension officers, fellow farmers who serve as opinion leaders, farm organizations, families, and community leaders. These act as reference groups to the farmers, and if these reference groups already use GM seed varieties, then farmers are most likely to feel encouraged to adopt these technologies. Thirdly, there is the perceived behavioural control, which speaks to the farmers' perception of their ability to adopt the GM seeds. Therefore, these include access to certified seeds, production credits, fertilizers, and pesticides, knowledge, labour, and extension support services. However, a farmer may have a positive attitude and favourable social pressure, lack of access to production inputs or resources may impede their intention and thus lead to rejection of GM seeds.

The study employed the Diffusion Theory to complement the Theory of Planned Behaviour. Whereas TPB explains why a farmer intends to adopt GM seed varieties by looking at the attitudes, subjective norms, and behavioural control, the diffusion theory explains how and why the GM seed varieties spread across the social system over a period. The diffusion theory specifies the characteristics

of GM maize seeds, which include the relative advantage, compatibility with the current farming systems, complexity, ability of the farmer to try GM seeds, and observability, which shape the attitude in the TPB. For instance, if the GM maize seed variety is seen as more productive in terms of yields and suitable to the conditions of the Eastern Cape, and the farmers are most likely to have a positive attitude, which results in the intention of adoption. The theory further emphasizes the channels of communication and the social system, which helps to further strengthen the subjective norms in TPB. The maize farmers will first observe from the fellow farmers, neighbours, farmers groups, and demonstrations from extension agents before adopting GM maize seeds. With most of the farmers utilizing GM maize seeds, social pressure, which will lead to acceptance increases, and thus reinforces the influence of subjective norms on intention.

Lastly, diffusion of Innovation theory further speaks to different categories of adopters that you would find in a social system. They include innovators, who are the first to adopt, followed by early adopters, and the early majority, who usually want to see the results before they adopt an innovation; the late majority, laggards, and the role of agricultural extension services.

Therefore, all these factors help in providing an explanation for the differences in perceived behavioural control in TPB. For example, early adopters might have greater access to production resources, knowledge, and networks, which make them more capable of adopting GM maize seed varieties than later adopters. This study integrates the Technology Acceptance Model (TAM) and the Theory of Planned Behaviour (TPB) with the production economics framework, such as the Stochastic Production Frontier Analysis (SFA), to allow a more comprehensive understanding of technology understanding of GM seed technology adoption and its productivity outocomes of the maize farmers in the Eastern Cape Province. Therefore, TAM and TPB explained the behavioural and socio-psychological factors influencing the decisions of the farmers to adopt GM maize technologies, whereas the production economics, in the form of SFA, evaluated whether GM maize improves technical efficiency. This integration of these frameworks allowed the study to link farmers' adoption decisions with their production performance, and hence provide a holistic assessment of the role of

agricultural extension services and GM maize technologies in enhancing the efficiency and productivity of smallholder maize farmers.

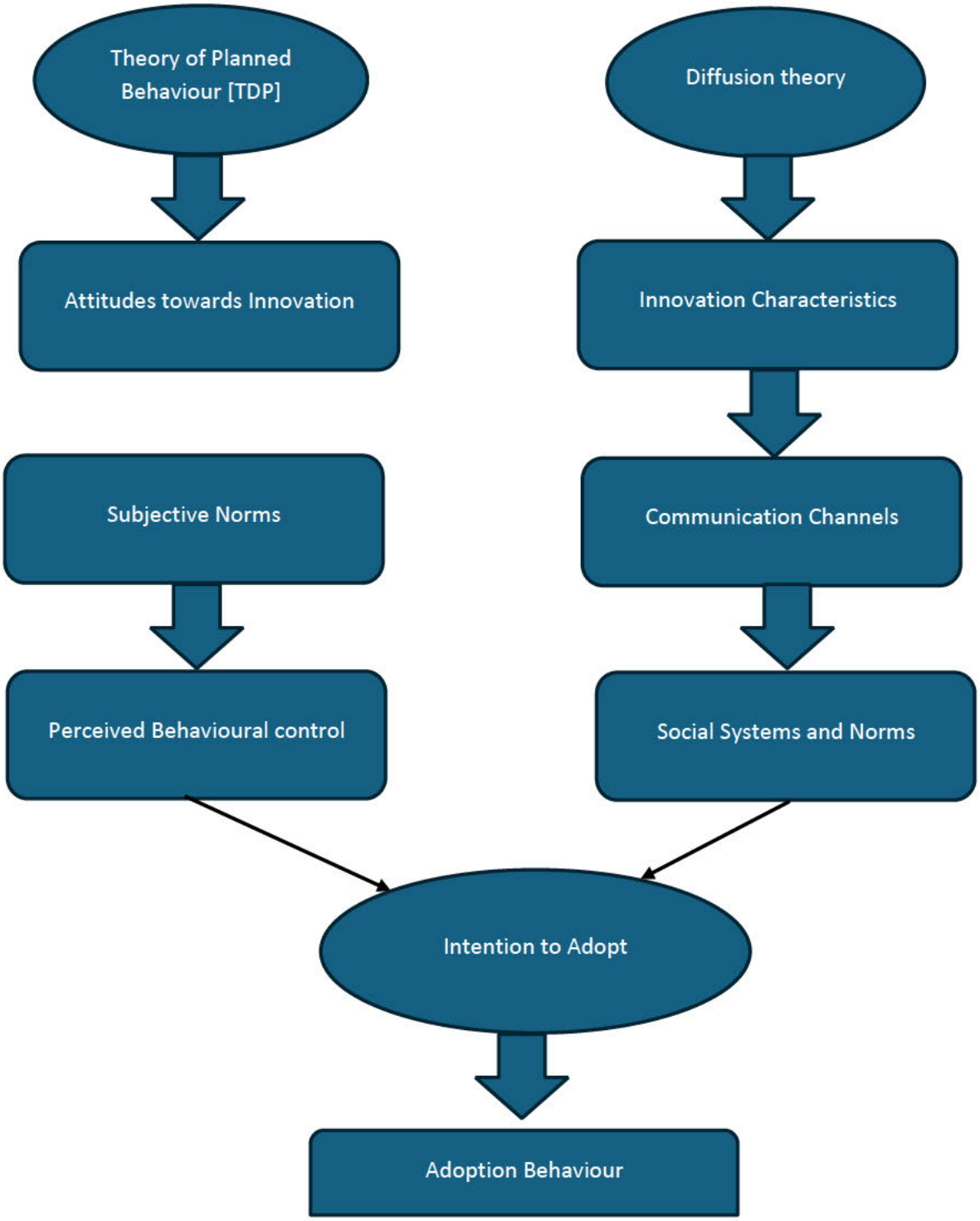


Figure 5.1: Theory of Planned Behaviour and Diffusion Theory

Source: Authors' own Computation

5.2 Research Methodology

5.2.1 Description of The Study Area

This study was carried out in the Eastern Cape Province of South Africa under two district municipalities, the OR Tambo and Chris Hani District Municipalities. The selection of the Eastern Cape Province was due to its high reliance on smallholder maize production as the primary source of livelihood, especially for rural districts where maize farming plays a critical role in both food security and household income. The province is characterised by considerable interannual rainfall, but sometimes with prolonged dry periods, which impact farmers' productivity. This has led traditional maize seed varieties to face significant challenges in relation to productivity and resilience to climatic shocks, which resulted in the promotion of GM maize seeds. Despite the availability of GM maize seed varieties that improve yields, resistance to diseases and pests, and better market value, their adoption and selection among smallholder farmers continues to be uneven across communities in the province.

Therefore, the province was selected in relation to the objective of assessing the farmers' selection choice of GM maize seeds. The province further offers a relevant context where farmers utilize both traditional and improved maize varieties, and this allows for analysis of the factors affecting the farmers' decision-making. Within the province, the OR Tambo [ORTDM] and Chris Hani Districts [CHDM] were purposively chosen because they are characterised by a high concentration of smallholder farmers, who are diverse in agro-ecological conditions, and significant variation in access to inputs, extension services, and markets.

According to the Chris Hani District Municipality [CHDM] (2024), Oliver Reginald Tambo District [ORTDM] is among the six districts in the Eastern Cape located in the eastern coastal part of the Province of South Africa. The district municipality covers an area of 15 947 km2, which is characterized by varied mountains and valleys (CHDM, 2024). The ORTDM is predominantly rural, and most of its population is dependent on agriculture for livelihoods. The total population of the ORTDM is 1 501 702 from the five local municipalities in the district (CHDM, 2024). Whereas, the CHDM is in the northern parts of the

province with a surface area of roughly 36.756 km2 (Chris Hani District Municipality [CHDM], 2024). About 35.2% of the district population resides in urban areas, with 63.8% residing in rural areas (CHDM, 2024). The district has a population size of 828,387, which is 11.9% of the total population in the Eastern Cape Province. Two main activities dominate the primary sector in the CHDM, which include mining and the agricultural sector (CHDM, 2024). Within the agricultural sector, maize is one of the staple crops for the district's population, while cabbage is the most consumed vegetable (Mujuru and Obi, 2020).

5.2.2 Sampling Procedure and Size

The study adopted a quantitative research approach using a cross-sectional design. This design was appropriate for this study as it allowed the collection and estimation of the technical efficiency data among farms, including the identification of factors, which included the socio-economic profile, farm management practices, and the institutional support that influences the technical efficiency of maize farmers. With a cross-sectional design, the investigator can measure the outcome and exposure of the farmers at the same time (Setia, 2016). Furthermore, this design can be versatile, which allows for studying multiple variables simultaneously, and it is good for establishing baselines and investigating population characteristics quickly. Due to the wide geographical coverage of the study area and the dispersed nature of smallholder farmers in the Province, a multistage sampling was employed.

Stage number one was to purposively select the OR Tambo and Chris Hani Districts. These districts were chosen because they are characterised by the high density of smallholder maize farmers who mainly depend on maize as their staple crop. The second stage involved the division of the study into strata: A maize, B vegetables and C livestock, of the two district municipalities from the six districts where these farmers resided. This allowed representation of all-important farming groups across the study areas. This stage allowed for the capture of variation in the farming conditions and access to agricultural services by farmers.

The Last stage was to randomly select 306 farmers in the study area. This stage was important as it allowed the researcher to select a manageable number of respondents while ensuring statistical reliability of the study.

5.2.3 Data Collection

Primary data for the study were collected through face-to-face interviews using a structured questionnaire administered to smallholder maize farmers. The questionnaire was designed to capture detailed information on farmers' sociodemographic characteristics, farm-level attributes, input use, and harvest output quantities, as well as institutional factors, which were measured both in continuous and dummy variables. To ensure inclusivity and comprehension, the questionnaire was translated into isiXhosa, the local language of the respondents, allowing enumerators to explain questions clearly and accurately. A team of five well-trained enumerators, fluent in the local language, assisted in administering the questionnaire and guiding respondents throughout the data collection process. Before the main survey, the questionnaire underwent a pre-testing process to ensure clarity, validity, and reliability. A pilot survey was conducted with 49 maize farmers in areas with characteristics similar to the main study sites. Farmers who participated in the pilot survey were excluded from the final sample. Feedback from the pre-test was used to refine the questionnaire, including improvements in question wording, sequencing, and overall relevance. The refinement process was guided by experts in technology adoption, agricultural economics, rural development, and seed producers within the University of KwaZulu-Natal (UKZN) and the Cape Peninsula University of Technology (CPUT), ensuring the instrument met high academic and methodological standards before the main data collection.

Several challenges arose during the data collection period, including late arrival of participants, poor road infrastructure, and unavailability of some respondents due to competing commitments. Late arrivals were addressed by adjusting interview schedules and engaging local leaders to mobilise participants and encourage punctuality. Access to remote and difficult-to-reach areas was facilitated by hiring a bakkie, ensuring enumerators could reach all targeted farmers. Ethical approval for the study was granted by the University of KwaZulu-

Natal (Protocol Number: HSSREC/00007889/2024), and written informed consent was obtained from all participants before data collection. These measures ensured the protection of participants' rights, promoted transparency, and maintained the ethical integrity of the study.

5.2.4 Data analysis

The collected data was recorded on Microsoft Excel. The Excel spreadsheet allowed a simple and flexible process for coding the raw data, which assisted in checking all errors, duplicates, and missing values before importing the data into Stata software. The coded data were transferred to STATA version 30 for further analysis. Descriptive statistics in the form of means and percentages were used to analyse the demographics of the farmers in the study area. To examine the farmers' GM maize seed selection choices among smallholder farmers, the multinomial regression model was employed.

5.2.5 Analytical framework

To assess the farmers' GM maize seed selection choices among smallholder farmers, the study adopted the Multinomial Regression Model [MRM]. This model has been adopted by several studies that seek to analyse factors influencing categorical variables in several countries such as Ethiopia, Kenya, and Uganda (Tesfahun et al., 2024; Zizinga et al., 2017; Mustapha et al., 2017). This model was adopted in this study as the dependent variable has categorical responses, which present the farmers' choice of GM maize seeds. The MNL regression analysis is different from binary regression models, such as the Probit or Logit model, as it allows the researcher to simultaneously estimate factors affecting the choice outcome compared to the base category. Furthermore, this model allows for interpretable coefficients that depict how predictors influence the odds of each category relative to the base, which allows inference over pure prediction. The MNL regression can also accommodate both categorical and continuous predictors without any strict linearity assumptions, broadening its applicability.

Model Specification

The Multinomial regression model is given by the following:

Let a farmer choose from J maize seed options available

$j = 0$ which is the traditional maize seed (used as a base category)

$j = 1$ which the GM (HT/BT) (Pests and Herbicide Tolerant)

$j = 2$ which is the GM (HT) (Herbicide Tolerant)

The gains obtained by a farmer from choosing alternative maize seed are as follows;

$$U_{ij} = V_{ij} + {}_{ij}$$

Where: U_{ij}: This represents the total maize gains

V_{ij}: The Observable (deterministic) component

${}_{ij}$: Represents the random error term

Therefore, the observable component is specified as:

$$V_{ij} = \beta_j X_i$$

Where:

V_{ij}: $\beta_{0j} + \beta_{1j}\mathrm{GENDER}_i + \beta_{2j}\mathrm{HHAGE}_i + \beta_{3j}\mathrm{SCHOLYRS}_i + \beta_{4j}\mathrm{MARST}_i +$

$\beta_{5j}\mathrm{HHSIZE}_i + \beta_{6j}\mathrm{LNDSIZE}_i + \beta_{7j}\mathrm{AVERGHHI}_j + \beta_{8j}\mathrm{YRSFRMMAZ}_i +$

$\beta_{9j}DISTMARK_j + \beta_{10j}RCVEXTSRV_i + \beta_{11j}MEMBORG_j +$

$\beta_{12J}\mathrm{AMNTCRED}_j$ where X_i represents a vector of socioeconomic, farm, and institutional characteristics influencing farmers' seed choice decisions.

Farmer i Choose maize seed option *j* if:

$$U_{ij} > U_{ik}, \quad \forall k \neq j$$

The assumption is that the error terms are independently and identically distributed (IID) and follow a Gumbel distribution, the probability that the farmer i chooses seed type j is given by:

$$P\ (Y_i = j) = \frac{\exp\ (\beta_j X_i)}{\sum_{k=0}^{J} \exp(\beta_k X_i)}$$

where $P\ (Y_i = j)$ is the probability of choosing an alternative j, and the denominator represents the sum of probabilities across all available alternatives.

For model identification, the traditional seeds are selected as the base category. Therefore, the parameters of the traditional seeds are normalized to zero.

The model is therefore expressed in log-odds form as:

$$ln\ \left(\frac{P(Y_i = j}{P = (Y_i = 0}\right) = \beta_j X_i, \qquad j = 1,2,3$$

5.2.6 Data

Table 5.1 presents the explanatory variables used in the Multinomial Logistic regression model [MNL] model, which were collected to analyse the choice of GM maize seed. The variables included for analysis were farmers' gender, age, educational level, and number of years, marital status, household size, and household monthly income, access to land and credits, access to extension services, maize seeds, fertiliser, herbicides and pesticides, labour, tractor, and oxen draught power. These variables are hypothesised to influence the technical efficiency levels of maize farmers in the study area.

Table 5.1: Summary of variables used in the Multinomial Regression Model

Variables	**Description and Measurement (Type)**	**Expected Outcome (+/-)**
Gender	Gender of smallholder maize farmer (Male=1; Female=0) (dummy)	+/-
Household Age	The actual age in years of the household head (continuous)	+/-
School Years	Number of years spent at school by a farmer (continuous)	+
Marital Status	Whether the farmer is married, single, divorced, or Widowed (Married=0; Single=1; Divorced=2; Widowed=3) (categorical)	(+/-)
Household Size	The actual number of household members (continuous)	+
Household Income	The monthly household income in Rands (continuous)	+
Years of farming maize	Number of years a farmer is involved in farming maize (continuous)	+/-
Land size	The actual number of land the farmers have access to (continuous)	+
Distance to Markets	Distance to market measured the physical distance between a farmer's residence and markets (continuous	-
Received Extension Services	Whether the farmer has access to agricultural extension services (Yes=1; No=0) (dummy)	+

The Amount of credits	The amount of credits the farmer has access to in Rands (continuous)	+
Membership of farm organization	Whether a farmer is affiliated with a farm organization.	+

Note: +/− Depicts the direction of influence (positive/negative)

5.3 Results and Discussion

This section presents the data from the smallholder maize farmers. These results include the demographic characteristics and the factors affecting the choice of GM maize seeds by maize farmers.

5.3.1 The Demographic Profile of Maize Farmers in the Eastern Cape Province

The demographic profile of the 306 smallholder maize farmers reveals a sector dominated by older female farmers, with 57% females and 43% male respondents. The average age of 60.8 years highlights the predominance of elderly farmers, suggesting limited youth participation as many migrate to urban areas in search of employment (Nyamazana et al., 2025; Agholor et al., 2024). Educational attainment among farmers averaged 7.38 years of schooling, which likely supports informed decision-making, resource allocation, and adoption of improved farming practices (Loki et al., 2025). About 6.2% of farmers were employed, 19.3% were self-employed, 34.0% were unemployed, and 40.5% were retired. These results reveal a low proportion of formally employed farmers, which indicates a few respondents who have regular salaries and income. Large household sizes, averaging 9.14 members, further provide a readily available source of family labour, enhancing operational capacity on farms (Mdoda et al., 2025). In addition, a reported average monthly household income of ZAR 6,637.52 indicates sufficient financial capacity to support basic household needs and invest in productivity-enhancing inputs such as GM maize seeds.

The distance from the farmer's homestead to the markets was found to be 24 km, which proxies market accessibility and transport-related constraints that may affect farmers' technical efficiency due to post-harvest losses and limited access

to price information and services. Farm-level characteristics suggest that farmers have moderate to large landholdings, averaging 8.42 hectares, which offer opportunities for crop diversification and higher production potential. Access to credit, averaging ZAR 5,249.26 per farmer, provides financial support that can enhance productivity, in line with previous studies indicating that credit access improves farm performance (Jonas and Christian, 2025). Labour availability, averaging 6.73 persons, enables the timely execution of critical farm operations, enhancing Mechanization efficiency. Mechanisation is widespread, with 89% of farmers using tractors for land preparation, while only 22% rely on oxen-drawn ploughs, suggesting that mechanised land preparation dominates and likely contributes to improved production efficiency. About 48.4% of the farmers reported being affected by drought in the study area.The results depict a farming community with considerable experience, access to resources, and moderate mechanisation, yet with variations in input use and labour practices that may influence productivity and the adoption of improved maize technologies.

5.3.2 Maize Seeds Grown by Smallholder Maize Farmers in the Eastern Cape Province

Figure 5.2 illustrates the distribution of GM maize seeds cultivated by farmers in the study area. The respondents reported growing genetically modified (GM) maize seeds, including GM (HT/BT), which is both herbicide-tolerant and pest-resistant, and GM (BT), which is primarily pest-resistant, alongside traditional maize varieties that are locally adapted to the environmental conditions. Among the total sample, 38.6% of farmers cultivated GM (HT/BT), 26.8% grew GM (BT), while 35% relied on traditional maize. These findings highlight the diversity of maize production strategies in the study area, reflecting farmers' varied preferences for improved traits, local adaptation, and management practices.

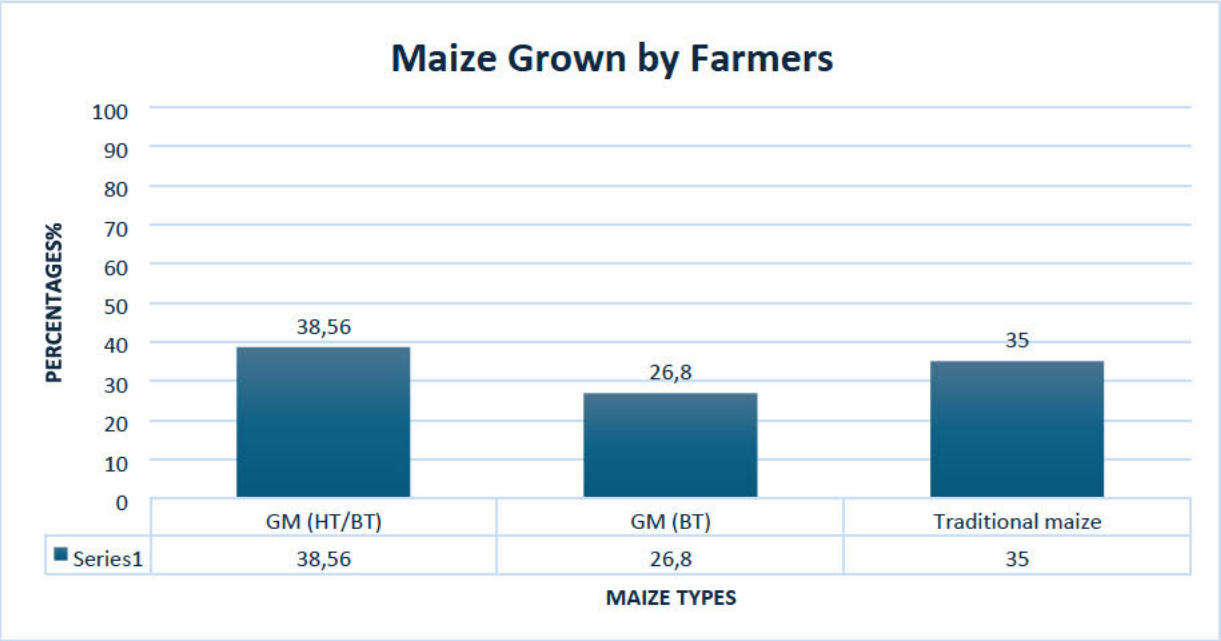


Figure 5.2: Maize varieties grown in the study area

5.3.3 Factors Affecting the Choice of GM Seeds in the Study Area

To examine the factors influencing farmers' choice of GM maize varieties, a multinomial logistic regression (MLR) model was employed using 306 observations from the study area (Table 5.2). The model provides a robust framework for analysing choices among more than two discrete alternatives in this case, GM (HT/BT), GM (BT), and traditional maize varieties, with traditional maize serving as the base category. The Likelihood Ratio Chi-square (LR χ^2 = 346.28, $p < 0.001$) indicates that the model is highly significant, demonstrating that the set of explanatory variables included in the analysis jointly has a strong influence on farmers' variety selection decisions. This confirms that the factors considered (such as socio-economic characteristics, farm size, access to information, and perceptions of GM maize traits) meaningfully contribute to explaining farmers' choice behaviour.

The Pseudo R^2 value of 0.63 further reinforces the model's explanatory power, indicating that almost 63% of the variation in farmers' maize variety choices is accounted for by the independent variables in the model. While Pseudo R^2 is not directly comparable to the traditional R^2 in linear regression, this relatively high value indicates a strong fit of the model to the observed data, highlighting its

suitability for capturing the decision-making dynamics of smallholder farmers in the Eastern Cape Province. The log likelihood value of -159.66156 provides a measure of model fit, with higher (less negative) values indicating a better-fitting model. Taken together, these results provide statistical evidence that the chosen model effectively identifies and quantifies the key determinants influencing farmers' selection of GM maize varieties, offering insights into both adoption patterns and the potential interventions needed to enhance the uptake of improved maize technologies.

Table 5.2: The factors influencing the GM maize seed selection choices in the study area

	GM (BT/HT)				GM maize (BT)			
Independent Variables	**β**	**Std. Error**	**zvalue**	**p-value**	**β**	**Std. Error**	**z-value**	**p-value**
Gender	-.6426	.7587	-0.85	0.397	-.5567	.7533	-0.74	0.460
Household Age	.1269	.0404	3.14	0.002***	.1534	.0409	3.75	0.001***
School Years	.7881	.2148	3.67	0.001***	.7454	.2142	3.48	0.001***
Marital Status	-.0810	.9852	-0.08	0.934	-.3354	.9828	-0.34	0.733
Household Size	-.3684	.5476	-0.67	0.501	-.4349	.5472	-0.79	0.427
Average Household Income	.0022	.0007	3.02	0.003***	.0022	.0007	3.06	0.002***
Year of Farming Maize	.1859	.0786	2.36	0.018**	.1812	.0793	2.28	0.022**
Land Size	-.8348	.5192	-1.61	0.108	-.8318	.5192	-1.60	0.109
Distance to Markets	.0479	.1558	0.31	0.758	.0616	.1555	0.40	0.692
Received Extension Services	8.1692	1.4350	5.69	0.001***	.6203	1.0255	0.60	0.545
Amount of Credits	.0005	.0002	1.94	0.052**	.0004	.0003	1.25	0.213
Membership of organization	3.2903	.9847	3.34	0.001***	2.4095	1.0159	2.37	0.018**

Constant	-10.1325	2.5558	-3.96	0.000				
Number of obs	306							
Log likelihood	-159.66156							
LR chi2(24)	346.28							
Prob > chi2	0.0000							
Pseudo R2	0.6302							

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively

The household age was found to have a positive and highly significant influence at the 1% level on the choice of GM maize seeds. The findings imply that older farmers are likely to select both GM (BT/HT) and GM maize (BT) relative to traditional maize seed. These results suggest that farming experience and accumulated knowledge in maize farming play a huge role in influencing the farmers' adoption decisions in the study area. Furthermore, these farmers might have been involved in farming for several years, which makes them known to local extension officers, and this increases exposure to new technologies and access to guidance. Similar findings were reported by Ateka et al. (2021), who reported a positive relationship between older farmers and adoption of farm technologies in Kenya, possibly due to accumulated experience, which allows them to better understand farming risks.

School Years was found to be positively associated with the selection of GM maize seed varieties, with a strong effect on both the selection of GM (BT/HT) and GM maize (BT) compared to the traditional maize varieties, and this was significant at the level of 1% level. This implies that education influences the choice of GM maize seeds in the study area, as education improves the farmers' capability in accessing and understanding technical information, which directly influences the decision-making of the farmer. Furthermore, these farmers have a higher ability to assess the costs and benefits of selecting improved technologies than less educated farmers. The findings are in line with those of Mukarumbwa and Taruvinga (2023), who reported that more educated farmers are most likely to access, analyse, and interpret new information on GM maize

better than less educated farmers, which then enhances their decision-making ability on the choice of adoption (Mukarumbwa and Taruvinga, 2023).

Average Household Income showed a positive relation and was highly significant in the choice of GM seed varieties. These findings reveal that maize farmers who have high household income are more likely to select GM (BT/HT) and GM maize (BT) relative to traditional maize varieties in the study area. This is because farmers with higher income levels are more likely to choose improved and certified maize varieties rather than traditional ones. The reason is that higher levels of income improve the ability of the farmer to afford improved seeds and other complementary inputs, such as fertilizers, including their capability to bear risks from the selection of new technologies. These findings are similar to those of Zamisa and Taruvinga (2022), who noted that household income increases the likelihood of farmers choosing GM maize, which is quite expensive, as these farmers have a greater ability to afford and can bear the associated risks of selecting GM maize seeds.

Years of farming maize were positive and significant at the 5% level on the choice of GM maize seeds. This means that farmers with a number of years of farming experience are more experienced and are most likely to select certified maize over traditional ones. This might be because of the accumulated knowledge, including a better understanding of productivity benefits and higher confidence in selecting new technologies. The findings are consistent with Sennuga et al. (2020), who revealed that farmers with many years of farming have accumulated knowledge and technical skills that improve their decision-making based on previous experience and contribute to new technology adoption.

Access to Extension Services had a positive influence and was highly significant with the selection of GM (BT/HT) at the level of 1%. This suggests that farmers with extension contact were more likely to select improved and certified maize varieties compared to traditional varieties. This underscores the huge role that agricultural extension services play in disseminating agricultural information, improving knowledge, and subsequently enhancing the selection of technologies that enhance productivity. Similar findings were reported by w

Fadeyi et al. (2022), who pointed out that agricultural extension services provide farmers with the necessary information and the benefits of GM technologies, which increase the chances of adoption.

The amount of Credits received by maize farmers was positive and had a significant effect at the level of 5% with the selection of GM (BT/HT) relative to the adoption of traditional maize varieties. This implies that credit access improves the ability of a farmer to be able to afford expensive technologies that help improve their farming practices. These findings were supported by findings of Ndeko et al. (2025), who found that credit access increases the probability of farmers selecting improved maize, as receiving credits relaxes the financial challenges of the farmers to buy inputs and allows them to invest in capital-intensive technologies and equipment.

Membership of the organization was significant with the selection of GM (BT/HT) at the level of 1%, while significant with GM (BT) at the level of 5%. These emphasise the significant role of social networks in facilitating access to agricultural information, production inputs, and market access. These results are similar to the findings of Wongnaa et al. (2018), who reported that most agricultural technologies are disseminated through farm organisations in rural communities. Therefore, farmers affiliated with farm organisations are likely to have more access to information about GM technologies than farmers who are not.

5.4 Conclusion and Recommendations

The study investigated the farmers' GM maize seed selection choices among smallholder farmers in the Eastern Cape Province. The study findings highlight that the majority of farmers were females with an average age of 61 years. The farmers had 8 hectares of land and a household income of ZAR 6,637.52. Farmers' seed choices included GM (HT/BT) at 38.6%, GM (BT) at 26.8%, and traditional maize at 35.0%. The multinomial regression analysis revealed that the adoption of Genetically Modified maize seeds (BT/HT) was influenced by household age, education, income, years of maize farming, and organisational

membership, which positively influenced both GM (HT/BT) and GM (BT) selection. In contrast, extension services and credit access influenced GM (HT/BT) adoption only and this might be because it offers multiple agronomic benefits, including both herbicide tolerance and insect resistance, making it a more comprehensive technology for improving maize productivity. This implies that GM seeds (HT/BT) require more resources and knowledge than GM (BT). This suggests farmers may need more financial support in the form of production credits to afford seeds and the complementary inputs like herbicides and technical knowledge from agricultural extension officers for them to utilize the technology correctly. On the other hand, GM seeds (BT) might be simpler and more familiar to the farmers, which makes them need less external support. Therefore, the study recommends that policymakers improve and expand agricultural extension programs, which will focus on training farmers in agronomic practices that will help in the use of GM (BT/HT). Furthermore, extension advisors should target both experienced farmers and new farmers and make sure to emphasise the benefits of disease-resistant and herbicide-tolerant varieties. Furthermore, the study recommends that policies should be developed for improving farmers' access to affordable production credits through designing tailored credit schemes that will require low-interest or input financing programmes that will help farmers to afford GM seeds and other production inputs. Overall, the study recommends context and variety-specific policies, strengthening extension services, farm organisations, engaging experienced farmers as lead farmers, and developing subsidies and microcredit schemes to enhance the choice of GM maize seed selection by farmers.

References

Adenle, A.A., Morris, E.J. and Parayil, G., 2013. Status of development, regulation and adoption of GM agriculture in Africa: Views and positions of stakeholder groups. *Food policy*, *43*, pp.159-166.

Agholor, A.I., Nkambule, T.B., Olorunfemi, O.D. and Mcata, B., 2024. ICT education and determinants of acceptance amongst smallholder farmers in

Mbombela, South Africa. *South African Journal of Agricultural Extension*, *52*(1), pp.73-89.

Ajzen, I. and Schmidt, P., 2020. Changing behavior using the theory of planned behavior. *The handbook of behavior change*, *23*, pp.17-31.

Akanbi, R.T., Davis, N. and Ndarana, T., 2020. Climate change and maize production in the Vaal catchment of South Africa. *Climate Research*, *82*, pp.191-209.

Ala-Kokko, K., Nalley, L.L., Shew, A.M., Tack, J.B., Chaminuka, P., Matlock, M.D. and
D'Haese, M., 2021. Economic and ecosystem impacts of GM maize in South Africa. *Global Food Security*, *29*, p.100544.

Ateka, J.M., Mbeche, R.M. and Muendo, K.M., 2021. Determinants of protected tomato production technologies among smallholder peri-urban producers in Kiambu, Kenya. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *122*(1), pp.43-52.

Cai, R., 2024. The Use of Genetically Modified Maize in Sustainable Agriculture. *Field Crop*, *7*.

Chris Hani District Municipality, 2024. *Integrated Development Plan (IDP) Review 2024–2025*. Queenstown: Chris Hani District Municipality.

Chukwuma, P., 2023. Integrating diffusion of innovations and theory of planned behavior to predict intention to adopt electric vehicles in Rwanda. *European Journal of Business and Strategic Management*, *8*(1).

Colbert, T., Bothma, C., Pretorius, W. and du Toit, A., 2024. Developing an Acceptable Nixtamalised Maize Product for South African Consumers: Sensory, Survey and Nutrient Analysis. *Foods*, *13*(18), p.2896.

Department of Agriculture, Land Reform and Rural Development, 2025) *Crops and Markets: Second Quarter 2025, Volume 106, No. 1 004*. Pretoria: Directorate:
Statistics and Economic Analysis, Department of Agriculture.

Department of Agriculture, Land Reform and Rural Development. 2024. Economic Review of the South African Agriculture, Statistics and Economic Analysis, Pretoria.

Fadeyi, O.A., Ariyawardana, A. and Aziz, A.A., 2022. Factors influencing technology adoption among smallholder farmers: a systematic review in Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *123*(1), pp.13-30.

Herrera, J.P., Rabezara, J.Y., Ravelomanantsoa, N.A.F., Metz, M., France, C., Owens, A., Pender, M., Nunn, C.L. and Kramer, R.A., 2021. Food insecurity related to agricultural practices and household characteristics in rural communities of northeast Madagascar. *Food security*, *13*(6), pp.1393-1405.

Hiywotu, A.M., 2025. Advancing sustainable agriculture for goal 2: zero hunger-a comprehensive overview of practices, policies, and technologies. *Agroecology and Sustainable Food Systems*, pp.1-29.

Hlatshwayo, S.I., Slotow, R. and Ngidi, M.S.C., 2023. The role of smallholder farming on rural household dietary diversity. *Agriculture*, *13*(3), p.595.

Islam, S., 2025. Agriculture, food security, and sustainability: a review. *Exploration of Foods and Foodomics*, *3*, p.101082.

Jonas, N. and Christian, M., 2025. Transforming South African agriculture: The role of credit in supporting value chain sustainability. *Agriculture*, *15*(6), p.620.

Judge, M., Warren-Myers, G. and Paladino, A., 2019. Using the theory of planned behaviour to predict intentions to purchase sustainable housing. *Journal of cleaner production*, *215*, pp.259-267.

Kulugomba, R., Mapoma, H.W., Gamula, G., Mlatho, S. and Blanchard, R., 2025. Understanding people's intentions towards the adoption of biogas technology: applying the diffusion of innovation theory and the theory of planned behavior. *Energies*, *18*(9), p.2169.

Lovemore, T., Assefa, Y., Nyari, P. and Mnkeni, S., 2020. Effects of genetically modified

(GM) maize adoption in small scale farms on cropping systems of the Eastern Cape Province, South Africa. *International Journal of Biotechnology*, *9*(2), pp.67-80.

Magakwe, A., Olorunfemi, O. and Sithole, A., 2025. Factors influencing smallholder farmers' participation in collective marketing: micro-level evidence from Ehlanzeni, South Africa. *Frontiers in Sustainable Food Systems*, *9*, p.1567943.

Mamashila, M.J., Antwi, M.A. and OS, O., 2025. Technical and Allocative Efficiency Challenges Smallholder Maize Farmers Face in Limpopo Province, South Africa. *Afr. J. Food Agric. Nutr. Dev*, *25*(8), pp.27491-27508.

Mdoda, L., Obi, A., Christian, M. and Jiba, P., 2021. Technical efficiency of maizebased farm irrigators in the Eastern Cape Province. *Journal of Agribusiness and Rural Development*, *62*(4), pp.371-381.

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D., 2025. Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis. *GM Crops & Food*, *16*(1), pp.272-304.

Mmbando, G., 2024. The adoption of genetically modified crops in Africa: the public's current perception, the regulatory obstacles, and ethical challenges. *GM crops & food*, *15*(1), pp.185-199.

Mujuru, N.M. and Obi, A., 2020. Effects of cultivated area on smallholder farm profits and food security in rural communities of the Eastern Cape Province of South Africa. *Sustainability*, *12*(8), p.3272.

Mujuru, N.M., Obi, A., Mishi, S. and Mdoda, L., 2022. Profit efficiency in family-owned crop farms in Eastern Cape Province of South Africa: a translog profit function approach. *Agriculture & Food Security*, *11*(1), p.20.

Mukarumbwa, P. and Taruvinga, A., 2023. Landrace and GM maize cultivars' selection choices among rural farming households in the Eastern Cape Province, South Africa. *GM crops & food*, *14*(1), pp.1-15.

Mustapha, S., Mohammed, T. and Abukari, I., 2017. Application of multinomial logistic to smallholder farmers' market participation in Northern Ghana. *International Journal of Agricultural Economics*, *2*(3), pp.55-62.

Muzekenyi, M., Zuwarimwe, J. and Kilonzo, B.M., 2021. Analysis of technical efficiency of small-scale commercial farmers in Vhembe district. *South African Journal of Agricultural Extension*, *49*(1), pp.91-104.

Ndeko, A.B., Chuma, G.B., Mondo, J.M., Kazamwali, L.M., Civava, R., Bisimwa, E.B. and Mushagalusa, G.N., 2025. Farmers' preferred traits, production constraints, and adoption factors of improved maize varieties under South-Kivu rainfed agro-ecologies, eastern DR Congo: implications for maize breeding. *International Journal of Agricultural Sustainability*, *23*(1), p.2464524.

Ngongolo, K. and Mmbando, G.S., 2025. Adoption of genetically modified crops in Sub-Saharan Africa: challenges, opportunities, and regulatory considerations for sustainable agricultural development. *Discover Sustainability*, *6*(1), p.641.

Oliver Regional Tambo District Municipality, 2023. *Integrated Development Plan (IDP) 2023/2024*. Mthatha: O.R. Tambo District Municipality.

Pangapanga, P.I., Jumbe, C.B., Kanyanda, S. and Thangalimodzi, L., 2012. Unravelling strategic choices towards droughts and floods' adaptation in Southern Malawi. *International Journal of Disaster Risk Reduction*, *2*, pp.57-66.

Sennuga, S.O., Fadiji, T.O. and Thaddeus, H., 2020. Factors influencing adoption of improved agricultural technologies (IATs) among smallholder farmers in Kaduna State, Nigeria. *International Journal of Agricultural Education and Extension*, *6*(2), pp.382391.

Setia, M.S., 2016. Methodology series module 3: Cross-sectional studies. *Indian journal of dermatology*, *61*(3), pp.261-264.

Tesfahun, T., Abegaz, A. and Abate, E., 2024. A quantitative analysis on the adoption of soil, water, and forest conservation technologies in the upper Gelana watershed, Northeast Ethiopian highlands. *Heliyon*, *10*(17).

United Cities and Local Governments. 2024. Rising to the challenges of food insecurity. Initiative for local Governments. chrome-

extension://efaidnbmnnnibpcajpcglclefindmkaj/https://uclg.org/wpcontent/uploads/2024/05/ENG-Rising-to-the-Challenges-of-Food-InsecurityInitiatives-by-Local-and-Regional-Governments-2.pdf [Accessed online: 10 November 2025].

Uyanga, V.A., Bello, S.F., Bosco, N.J., Jimoh, S.O., Mbadianya, I.J., Kanu, U.C., Okoye, C.O., Afriyie, E., Mak-Mensah, E., Agyenim-Boateng, K.G. and Ogunyemi, S.O., 2024. Status of agriculture and food security in post-COVID-19 Africa: Impacts and lessons learned. *Food and Humanity*, *2*, p.100206.

Wongnaa, C.A., Awunyo-Vitor, D. and Bakang, J.E.A., 2018. Factors affecting adoption of maize production technologies: a study in Ghana. *Journal of Agricultural Sciences–Sri Lanka*, *13*(1).

Zamisa, O. and Taruvinga, A., 2022. Drivers of genetically modified maize production among rural farming households in Ngqushwa local municipality, South Africa: a triple hurdle approach. *Journal of Agribusiness and Rural Development*, *65*(3), pp.229-241.

Zewdie, M.C., Moretti, M., Tenessa, D.B., Ayele, Z.A., Nyssen, J., Tsegaye, E.A., Minale, A.S. and Van Passel, S., 2021. Agricultural technical efficiency of smallholder farmers in Ethiopia: A stochastic frontier approach. *Land*, *10*(3), p.246

Zizinga, A., Kangalawe, R.Y., Ainslie, A., Tenywa, M.M., Majaliwa, J., Saronga, N.J. and Amoako, E.E., 2017. Analysis of farmer's choices for climate change adaptation practices in South-Western Uganda, 1980–2009. *Climate*, *5*(4), p.89.

CHAPTER 6

Productivity-Profitability Trade-offs and the Welfare Effects of GM Maize Adoption: Evidence from Smallholder Systems in the Eastern Cape Province, South Africa

Abstract

Maize is among the most significant crops grown and consumed across the world and a major contributor to the economy of South Africa, as it creates employment and provides food to both humans and animals. Despite this, maize farmers, particularly smallholder farmers, continue to experience low productivity and unstable incomes due to several challenges, such as reliance on traditional varieties, which tend to perform poorly under harsh climatic conditions as they are susceptible to pests and diseases, thereby limiting productivity and income. Hence, this study evaluates the yield and economic effects of GM maize seed adoption in smallholder farming systems of the Eastern Cape Province of South Africa. Using a multi-stratified sampling method, data were collected from 306 smallholder maize farmers, which were analyzed using descriptive statistics, the probit regression model, and the propensity score matching. The study was dominated by females at 57%, with an average age of 61 years, and produced maize under 8 hectares of land. The respondents reported an average monthly income of ZAR 6637.52 and grew different maize varieties such as GM (Ht/Bt), GM (Bt), and traditional maize seeds. Across both matching approaches, adopters consistently achieved higher maize yields compared to non-adopters of GM technology, with increases of 2.1 tons/ha (Nearest Neighbor) and 2.25 tons/ha (Kernel). While adoption was influenced by factors such as gender, years spent in school, marital status, household size, household monthly income, land size, access to extension services, and amount of credits, distance to markets was negatively associated with the adoption of GM seeds. The study recommends improving the adoption of GM maize seeds through an integrated approach that strengthens, expands, and enhances access to GM maize seed varieties in the study area. Government and developmental agencies should ensure that they strengthen certified seed systems by supporting local seed

development and distribution networks through partnering with the existing private seed enterprises.

Key words: GM Maize Seeds, Smallholder Farming, Eastern Cape Province

6.1 Introduction

Maize is one of the major and widely grown cereals and is consumed worldwide (Ssemugenze et al., 2025). For instance, maize, rice, and wheat are the world's staple cereals, accounting for approximately 42% of the global food calorie intake (Ssemugenze et al., 2025). Around 197 million hectares account for the global maize area for dry grain, including substantial areas in sub-Saharan Africa (SSA), Asia, and Latin America (Erenstein et al., 2022). This crop is significant as it is one of the human food crops in various countries, where it is consumed as a human crop, and it contributes to over 20% food calories (Erenstein et al., 2022). This was supported by a study conducted by Gheith et al. (2022), who noted that maize is grown for various purposes, which include animal feed such as silage and grains, poultry and pigs feed, which include grains as well as human consumption, as grains, sweet maize, and grain maize.

In South Africa, maize is predominantly cultivated under rain-fed conditions for human consumption, animal feed, and income generation, accounting for about 90% of the total production area in the region (Ogujiuba et al. 2021). The crop is mostly produced by the poor in rural areas and is regarded as the primary food for most of the population in South Africa (Ogujiuba et al., 2021). As a result, maize contributes roughly R9.5 billion per year to the South African economy, which ranks South Africa ninth globally and second in sub-Saharan Africa in terms of maize production (Mangani et al. 2025). According to Mdoda et al. (2025a), maize production in South Africa is largely concentrated in a few provinces, with the Free State, Northwest, and Mpumalanga contributing the bulk of output. Table 6.1 shows the distribution of maize production by provinces from the period of 2014/15 to 2019/20 maize production season in South Africa (Department of Agriculture, Land Reform and Rural Development, 2021).

Table 6.1: Illustrating the distribution of Maize production by provinces from 2014/15 to 2019/20 production season (Tons)

Season	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
PROVINCE						
Western Cape	45 000	45 000	22 000	34 000	34 000	34 000
Eastern Cape	70 000	76 000	97 000	93 000	93 000	154 000
Northern Cape	712 000	710 000	712 000	668 000	670 000	674 000
Free State	2264 000	2214 000	7362 000	5 275 000	4 553 000	6 909 000
KwaZulu-Natal	454 000	522 000	740 000	660 000	670 000	733 000
Limpopo	248 000	310 000	492 000	232 000	200 000	231 000
Mpumalanga	2108 000	2319 000	3431 000	2 817 000	2 775 000	3 220 000
Gauteng	441 000	442 000	804 000	632 000	607 000	627 000
North-West	914 000	1141 000	3160 000	2 099 000	1 673 000	2 718 000

Source: DALRRD (2021)

Table 6.1 above reveals an important regional and year-to-year difference in maize from the year 2014/15 to 2019/20 production seasons. This indicates an unequal distribution in terms of maize across South Africa. The dominant provinces are the Free State, Mpumalanga, and NorthWest provinces, with the Free State reporting a large increase in terms of production from 2.26 million tons in 2014/15 to an increase of 7.36 million tons in the 2016/17 season (Table 6.1). This indicates that the province is sensitive to climate and market conditions. Furthermore, provinces like Mpumalanga and Northwest recorded similar trends, with a sharp increase in 2016/17 and again in 2019/2020 (Table 6.1). Provinces like the Western Cape, Eastern Cape, and Limpopo persist with a relatively low and stable production level. Hence, this indicates their more limited role in the South African maize supply. The Northern Cape province continues to have a steady but modest production, whereas provinces like Gauteng contribute slightly throughout the period. All in all, Table 6.1 indicates relevant trends in the maize industry that are heavily influenced by favourable weather cycles, use of improved technologies, and market conditions.

Despite these production trends and South Africa being one of the leading producers of maize in Sub-Saharan Africa, their productivity and income levels remain relatively very low (Mujuru et al., 2022; Chimonyo et al., 2020). Smallholder maize farmers continue to experience low productivity and unstable incomes despite the availability of improved maize varieties and production technologies. According to Mdoda et al. (2025), the major contribution to these challenges is that smallholder farmers continue to use traditional maize varieties, which are characterized by poor yields, prone to pests and diseases, and poorly adapted to climate variability. This was supported by Msomi and Zenda (2024), who mentioned that smallholder farmers have limited access to improved modern technologies, high input costs and they normally rely on manual labour and outdated traditional methods, which take time and result in low yields and income. A study conducted by Agbugba et al. (2020) in the Eastern Cape reported very low levels of maize production in the province, with most smallholder farmers producing less than 1 tonnes per hectare and attributed these challenges primarily to variable rainfall patterns. A study by Mdoda et al. (2022) reported inadequate extension services as the major contributor to low maize productivity among smallholder farmers in the Eastern Cape Province.

To address this, GM maize technologies have been introduced to improve the productivity of the farmers and help reduce production associated with climate variability, pests, and diseases, and subsequently improve farmers' income. According to Ngqulana et al. (2025), Genetically Modified (GM) maize is among innovations developed to fight climate change, land degradation, and the everincreasing population. This technology improves agricultural productivity, resistance to pests and drought, and helps to increase yields for maize farmers (Ngqulana et al., 2025). For instance, Zamisa (2020) reported that in many developing countries, millions of farmers plant GM maize, which offers several benefits such as a 37% decrease in pesticide use, a 22% improvement in yields, and a 68% rise in farm income. Another study by Ala-Kokko et al. (2021) estimated that producer income gains from GM crops in South Africa between 1998 and 2016 amounted to approximately US$2.3 billion, with about 97% of these benefits attributed to GM maize varieties. Another study conducted by Klümper and Qaim (2014) reported that GM crops reduced pesticide use by

37%, increased yields by 22%, and improved farm returns by 68% in the study area. Despite the potential of GM maize seeds to improve productivity and income, their adoption among smallholder farmers remains uneven, and concerns persist about their actual impact on these outcomes. While other studies indicate that the adoption of improved technologies like GM maize seeds may improve production, there is limited evidence on whether these productivity gains results into increase farm returns when the input costs are subtracted. Furthermore, there are limited location-specific studies that strictly examine the effects of GM maize adoption on the productivity and income of smallholder farmers in the Eastern Cape Province. This knowledge gap makes it difficult for researchers, practitioners, policy makers, and other development agencies to design interventions that are targeted and effective in promoting the adoption of technologies that will improve the standard of living for farmers. Hence, this study seeks to evaluate the effects of GM maize seed adoption on farm returns, input costs, and maize yields among smallholder farming systems of the Eastern Cape Province.

6.2 Conceptual Framework

This study evaluates the effects of GM maize seed adoption on farm returns, input costs, and maize yields of smallholder farmers. Therefore, the conceptual framework is built on the narrative that GM seeds are the key influence in enhancing the farm returns and productivity of maize farmers in the Eastern Cape Province (Figure 6.1). GM seeds do not just automatically improve the farm productivity and returns; their adoption is influenced by several factors, such as farm characteristics (gender, age, household income, and educational level. These go hand in hand with the farm characteristics (land and production inputs), including institutional factors (extension services, credits, and access to markets). In the middle, the framework depicts the relationship between GM maize seed adoption and farm returns. According to AlaKokko (2021), GM maize seeds improve farm income through enhanced productivity due to their resistance to environmental impacts such as drought, pests, and disease.

Another important aspect of the framework is the mediating factors, which explain that GM maize seeds do improve farm income through resistance to environmental stresses such as drought, weeds, pests, and diseases. Though GM maize seed influences farm income, it does not happen automatically, but it improves production processes and thus reduces the challenges that are faced by farmers. The framework also brings in the technological factors such as compatibility, complexity, costs, and relative advantages. These factors may improve the likelihood of the farmer adopting GM maize seeds. Another important aspect is the socio-economic background and institutional factors. They determine whether the farmer will adopt GM maize seeds or not. For example, well-educated individuals with greater household income, access to credits, and extension services stand a higher chance of adopting GM maize seeds that will improve their farm income.

Yet, the relationship between GM maize seed adoption and farm returns is not purely direct. There are other mediating factors, such as input costs, which form a crucial component of the conceptual framework. GM maize seed varieties require complementary inputs, which include fertilizers, pesticides, and modern farm management practices. Inputs may lead to a rise in maize production costs, and this might either increase or reduce net income based on whether the productivity gains outweigh the additional costs encountered by a farmer. Therefore, the costs of the inputs may act as both the outcome of adoption as well as the mediating variable that influences farm returns. In addition, there might be external factors such as climate variability, soil quality, and the current market prices, which all can moderate the relationship between adoption and outcomes. For instance, even if the maize farmers adopt GM seeds, if the area has poor rainfall or a low market price of maize, then that might limit or reduce the gains or farm returns. Hence, these factors are considered as the moderating variables within the framework for this study. Therefore, this conceptual framework emphasizes that through GM maize seeds, the productivity and income could be improved while accounting for the role of input costs and other influencing factors.

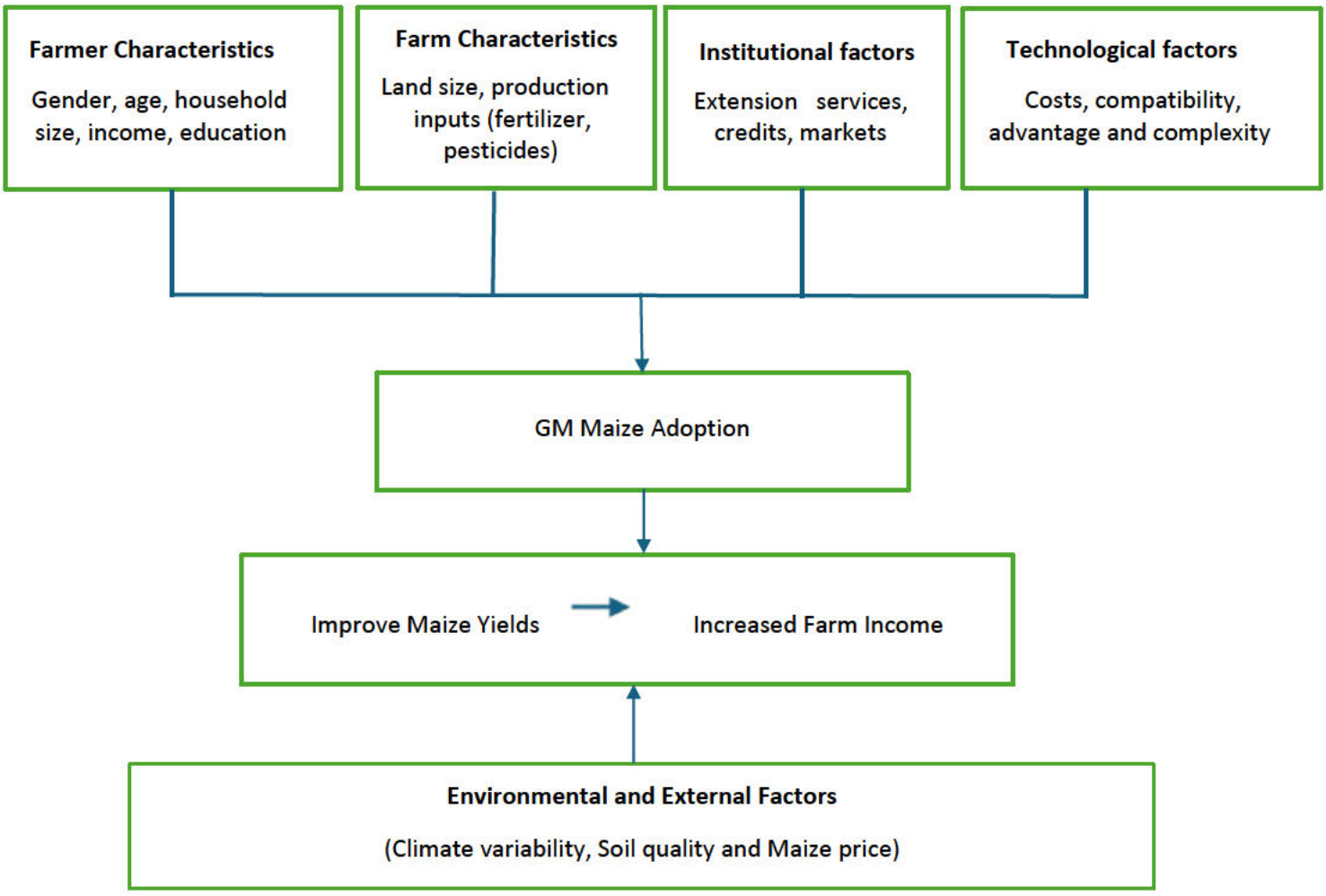


Figure 6.1: Conceptual Framework on GM Adoption Effects on Farm Income and Input Costs.

6.3 Methodology

6.3.1 Description of the Study Area

The study on the yield and economic effects of GM maize seed adoption in smallholder farming systems was conducted in the Eastern Cape Province of South Africa. The province was suitable as a study site as the Eastern Cape Province's agriculture is dominated by smallholder farmers, who are characterised by low levels of maize production, which results in low levels of income. (Mujuru and Obi, 2020). With various government initiatives targeting to improve the state of smallholder agriculture in the province, they are failing to

yield the expected outcomes (Mujuru and Obi, 2020). Hence, it is significant to analyse the impact of GM maize seeds on farm returns in the province. The province is the second largest in South Africa, with an area covering 169000 $km^{2,}$ and the province occupies about 13.9% of the total land area of the country (Fanteso, 2020). The climate is hot in summer, with average temperatures of around 26°C, and an average of 13 °C during the winter season (Gidi et al., 2024). The province has a rainfall average of 1000 mm in the summer season and 400 mm in winter. These conditions are favourable for agricultural activities (Gidi et al., 2024).

To ensure a manageable data collection, the study specifically focused on two districts, the Oliver Regional Tambo [ORTDM] and Chris Hani District Municipalities [CHDM] (Figure 6.2). These two districts were selected as they are among the districts with the highest maize producers in the province. The CHDM is located in the northern region of the province and covers an area of 36,756 km² (Chris Hani District Municipality [CHDM], 2025). A large portion of the district's area is covered by natural grassland
(22,889 km2), while low shrubland in Nama Karoo covers an area of 4183.123 km2 (CHDM, 2025). The CHDM has a total population of 828 387 people. A large portion of the district is covered by natural grassland, with an area of 22,889 km², and Low Shrubland (Nama Karoo) covering an area of 4183.123 Km2, and this is the second highest landcover class. Smallholder farmers typically cultivate a variety of crops, including maize, cabbage, potatoes, butternut, carrots, and spinach, with maize serving as the staple crop among the Black population (Mujuru and Obi, 2020). While the ORTDM is located along the Wild Coast, the district is bordered to the West by the Amatole District Municipality. The district has a land size of 15 947 km2, ranging from rolling valleys to rugged mountainous ranges (ORTDM, 2024). The ORTDM is largely rural which makes it to be classified as a Category C2-Municipality. This district municipality is the most populated region of the province, with 1 501 702 when compared to the other regions of the province (ORTDM, 2024). ORTDM is among the richest districts in terms of natural resources, with the most fertile soils and favourable climatic conditions for agricultural activities (Nkamisa et al.,

2022). It is characterised by diverse vegetation such as grasslands, thicket, forest, and bushveld.

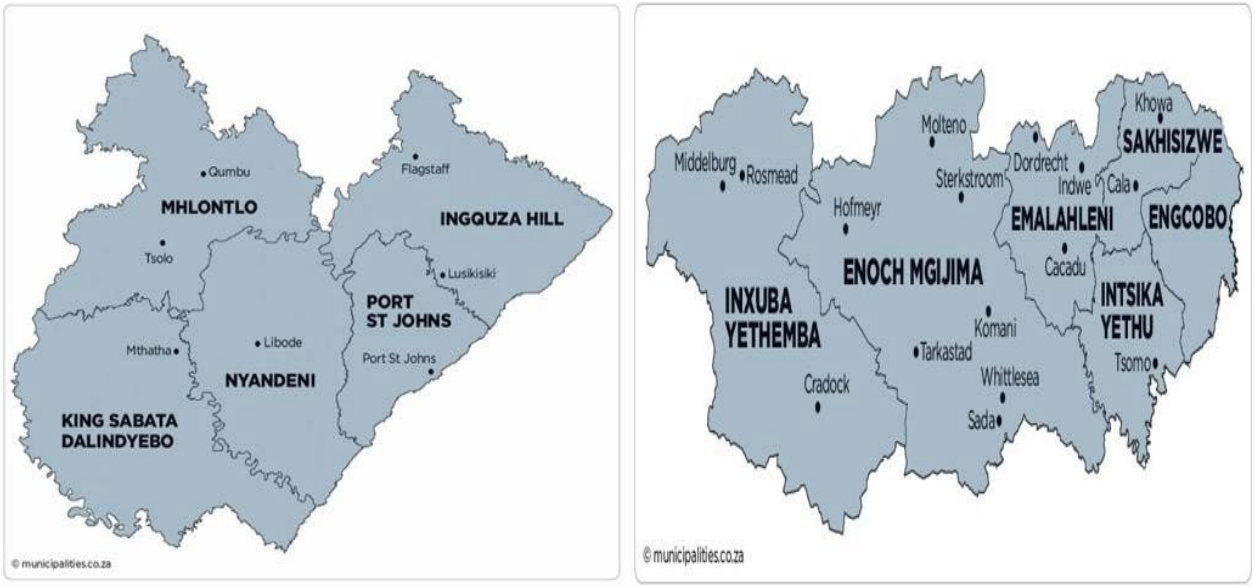


Figure 6.2: Showing the OR Tambo and Chris Hani District Municipalities, Eastern Province

Source: Google Maps

6.3.2 Sampling frame, Size, and Procedure

The quantitative approach and a cross-sectional research design were employed to collect primary data from maize farmers in OR Tambo and Chris Hani District Municipalities in the Eastern Cape Province. The reason for choosing this type of design is that it allowed to collect adopters and non-adopters at a single point in time. This was followed by the multi-stratified sampling method, which was divided into three stages. This sampling method was used because it allowed for an efficient selection of a representative sample from the large population in the study area. The first stage involved the selection of the OR Tambo and Chris Hani District Municipalities. These district municipalities were selected based on agricultural importance, and they are mostly dominated by smallholder farmers, making them ideal for achieving the study objectives. The subsequent stage was to group the farmers into STRATAs; the first strata were maize farmers grouped as B, crop farmers grouped as B, and mix grouped as C. This stage was significant as the respondents are not

homogeneous; grouping them into strata allowed the researcher to group farmers with similar characteristics, and this ensured that the major variations within the population were well represented. The final stage was to select maize farmers in the study sites randomly. The sample size was determined using the Yamani formula described below:

$$n = /((1 + Ne\text{^}2))$$

$$n = 921/((1 + 921\,(\ 〚0.05〛\ \text{^}2))$$

$$n = 921/((1 + 921\ (0.00250)))$$

$$n = 279$$

Based on the Yamani formula, the study received a sample of 279 maize farmers who adopted GM maize seeds. The use of the Yamani formula was necessary as it helps to the study to select a scientifically valid sample size, ensures reliability, and representativeness. 40% of the sample size was added to represent the non-adopters of GM maize seeds, bringing the sample to a total of 391 maize farmers. This was significant as it allowed the comparison of adopters and non-adopters, which helped to judge what would have happened if the farmers had not adopted the GM maize seeds. Due to the limited availability of the farmers, time constraints, and limited budget, the researcher collected data from 306 smallholder maize farmers. From this sample, 200 were adopters, and 106 were non-adopters of GM maize seeds. Despite these challenges, the collected data was enough to capture variations and the statistical significances necessary to achieve the study objectives.

6.3.3 Data Collection

The primary data was gathered using a structured questionnaire, which comprised farmers' socio-economic characteristics, farm characteristics, and institutional factors. The reason for using a structured questionnaire was to ensure that the farmers were asked standard questions that ensured consistency. The questionnaires were translated into the local language, IsiXhosa, and were administered by well-trained enumerators and well-trained enumerators. To ensure validity and reliability, the questionnaires were

pretested using 31 questionnaires, and the farmers used for pretesting were not selected to be part of the study. Furthermore, results from the pretesting were used to refine the questionnaire and remove all repeated questions.

6.3.4 Data analysis

After the primary data was collected, it was cleaned to ensure that there were no duplicates and errors. This was followed by recording the primary data on an Excel spreadsheet, which allows the structuring of the dataset into clear variables and observations. After the data was recorded on Excel, it was then transferred and analysed using the STATA analysis program. To analyse the effects of GM maize seed adoption by smallholder farmers on farm returns, the study adopted a propensity score matching approach. This approach has been used by multiple studies in measuring the impact on two groups (Baiyegunhi et al., 2019; Ndoro et al., 2014; Wordofa et al., 2021; Tesfaye and Gutema, 2022). The PSM was chosen because it reduces the selection bias, as it ensures that both the treatment and control groups are balanced on observable variables. Furthermore, the PSM is flexible, as it can be employed in different settings for examining various treatment effects. Unlike other matching methods, the PSM is easier to use, particularly when there are a lot of potential confounders; it matches the propensity scores, which present the probability of being treated (Wang, 2021). The model is specified below;

The first stage is the probability of a farmer adopting GM maize seeds

$$D_i = \begin{cases} 1 \; if \; farmer \; i \; adopts \; GM \; maize \; seeds \\ 0 \; otherwise \end{cases}$$

The Probit Model for Propensity Score Estimation

The propensity score is estimated as:

$$(X\_i) = P(D\_i = 1|X\_i) = \Phi(\beta_0 + \beta_1 + X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki}$$

Where:

$\Phi =$ represents the cumulative normal distribution function

$X_i =$ vector of covariates affecting adoption

$\beta =$ parameters to be estimated

The Covariates in GM Maize Adoption

The farmer's decision to adopt GM maize seed is modelled using a Probit regression, where the dependent variable is 1 if a farmer adopts GM maize seed and 0 otherwise.

The adoption decision of the maize farmer is specified as follows:

$$D_i^* = \beta_0 + \beta_1 Gender_i + \beta_2 Age_i + \beta_3 Years\ Spent\ in\ school_i + \beta_4 Marital\ Status_i + \beta_5 Household\ Size_i + \beta_6 Household\ Income_i + \beta_7 Land\ Size_i + \beta_8 Memership\ of\ Organization_i + \beta_9 Received\ Extension\ Services_i + \beta_{10} Years\ of\ Farming\ Maize_i + \beta_{11} Amount\ of\ credits_i + \beta_{12} Distance\ to\ markets_i$$

$$D_i = 1 \quad \text{if } {}^* > 0, \ \ 0\ otherwise$$

Where:

$D_i^* =$ The propensity of the maize farmer to adopt GM maize seeds

$X_i =$ vector of explanatory variables

$\beta_0 =$ constant term

$\beta_1 \ldots \beta_9 =$ parameters to be estimated

$_i =$ error term assumed to be normally distributed

Propensity Score Matching

After estimating (X_i), farmers are matched to assess the impact

$0 < (X_i) < 1$ **Outcome Model (Farm Returns)**

Let farm returns be:

$$Y_i = Farm\ returns\ from\ maize\ sales$$

It is estimated as follows:

$$Y_i = \alpha_0 + \alpha_1 D_i + \alpha_2 Z_i + \mu_i$$

Where:

$D_i =$ adoption status

$Z_i =$ control variables

$\alpha_1 =$ treatment effect

Treatment Effect (ATT)

The main PSM estimator is:

$$ATT = [Y_1 - Y_0 | D = 1$$

6.3.5 Data

This section presents the data collected from maize farmers in the Study. It also includes the variable description and the expected sign for each.

Table 6.2: Data collected from maize farmers in the study area

Variables	**Variable Description**	**Expected Sign**
GM Adoption	Whether a farmer adopts GM maize or not (1=Yes; 0=No) (dummy)	
Farm Returns	The amount from maize sales (Rands)	
Gender	Maize farmers gender (0=male; 1 = female)	+/-
Household Age	Actual age of the maize farmer (continuous)	+/-

Education	The number of years spent by the maize farmer	+
Marital Status	Marital status of the maize farmers (0=Married; 1=Single; 2=Divorced and 3=Widowed	+
Household Size	The actual number of members in the household (continuous)	+
Household Income	Monthly income received per household (continuous)	+
Land Size	The size of the land allocated to GM maize seeds. (continuous)	+
Extension Services	Whether the farmer has access to agricultural extension services	+
Credi Access	Whether the farmer has access to production credits	+
Distance to markets	The actual distance to markets (continuous)	-
Farming Experience	The number of years the farmer has been planting maize.	+
Membership in an organization	Whether a farmer is affiliated with a farm organization or not 1=0; 0=No (dummy)	+

6.4 Results and discussion

This section presents the results and discussion of data collected from 306 maize farmers.

6.4.1 Demographic Characteristics of the farmers in the study area

The results reveal important structural and socio-economic dynamics shaping smallholder-farming systems in the study area (Table 6.3). The sample is predominantly composed of female farmers (57%), confirming the feminisation of agriculture in many rural contexts. This pattern aligns with Senyolo (2021), where women were found to play a central role in labour-intensive activities such as weeding and irrigation. The implication is that agricultural interventions and technology dissemination strategies must be gender-responsive, recognising women as primary decision-makers rather than auxiliary participants. The average age of 61 years (with a maximum of 81) highlights an ageing farming population, reinforcing concerns about the sustainability of the sector. This finding supports Mjoli and Manasoe (2026), who argue that youth outmigration to urban areas is driven by limited perceived profitability in agriculture. The ageing demographic may constrain innovation uptake and longterm productivity; older farmers are generally more risk-averse. Despite this, farmers exhibit a moderate level of human capital, with an average of seven years of formal education. This level of education is sufficient to facilitate comprehension and evaluation of improved technologies, supporting findings by Bhekiswayo et al. (2025).

Education enhances farmers' capacity to assess risks, interpret technical information, and make economically rational adoption decisions.

Household characteristics further reinforce production capacity. The relatively large average household size (nine members) suggests the availability of family labour, which is critical for labour-intensive enterprises such as maize production. This supports Shemfe and Modirwa (2026), who link household size to labour endowment. Financial capacity, reflected by an average monthly income of ZAR 6,637.52, also plays a decisive role. Higher-income households are better positioned to absorb risks and invest in productivity-enhancing inputs,

consistent with Ntonjane et al. (2025). Farm-level characteristics also support technology adoption potential. The average landholding of 8 hectares provides scope for experimentation with new technologies such as GM maize without jeopardising subsistence production, as noted by Hu et al.
(2022). Access to credit (ZAR 5,149.26 on average) further strengthens farmers' investment capacity, enabling the acquisition of improved inputs and mechanisation, consistent with Imran et al. (2023). Institutional support systems appear moderately strong. A substantial proportion of farmers (76%) belong to farmer organisations, which facilitate knowledge exchange and access to resources, echoing ThamAgyeekum et al. (2025). However, only 60% reported access to extension services, suggesting gaps in formal knowledge dissemination channels. Finally, the average of 17 years of farming experience indicates a high level of experiential knowledge, which enhances decision-making and complements formal education in technology adoption, as supported by Shemfe and Modirwa (2026).

Table 6.3: Demographic characteristics of maize farmers in the study area

Variables	**Mean**	**SD**	**Minimum**	**Maximum**
Gender	0.57	0.49	0	1
Age	60.84	10.58	26	81
Number of years spent in school	7.38	4.72	0	19
Household Size	9.14	3.09	1	27
Household monthly income (ZAR)	6637.52	5198.85	370	40000
Land Size	8.42	28.50	0.10	205.00
Amount of credits	5149.26	5959.56	250	49000
Member of an organization	0.76	0.43	0	1

Received extension services	0.60	0.49	0	1
Years of farming maize	17.15	8.38	1	48

6.4.2 The adoption of GM maize seeds by smallholder maize farmers

The descriptive statistics and adoption of GM maize seeds are explained in Chapter 3 above, where the analytical framework, adoption criteria, and econometric approach.

6.4.3 The effect of adopting GM maize seeds by smallholder maize farmers

The effect of adopting GM maize seeds by smallholder farmers in the Eastern Cape was estimated using Propensity Score Matching (PSM) to correct for potential selection bias arising from non-random technology adoption. In this study, both Nearest Neighbour Matching and Kernel Matching estimators were employed to ensure robustness and consistency of the results. The propensity scores were first derived from a binary choice model predicting the likelihood of adoption, after which adopters (treated group) were matched with comparable non-adopters (control group) based on similar observable characteristics. Nearest neighbour matching pairs each adopter with the closest non-adopter in terms of propensity score, thereby ensuring intuitive and direct comparison, while kernel matching utilises weighted averages of multiple control observations to improve estimation efficiency. The Average Treatment Effect on the Treated (ATT) was then computed to quantify the causal effect of GM maize adoption on key outcomes such as yield, farm income, and input costs, as shown in Table 6.4.

Table 6.4: Effect of GM Maize Seed Adoption by Smallholder Maize Farmers

Using Nearest Neighbour				
Outcome Variable	**Adopters Mean**	**Matched Controls Mean**	**ATT (Impact)**	**Std. Error**
Maize Yield (Tons/Ha)	4.25	2.15	**2.10 *****	0.31
Farm Income (ZAR/season)	17,500	8,850	**8,650*****	2,340
Input Costs (ZAR/Ha)	7,900	3,250	**4,650*****	910
Using Kernel Matching				
Outcome Variable	**Adopters Mean**	**Matched Controls Mean**	**ATT (Impact)**	**Std. Error**
Maize Yield (Tons/Ha)	4.25	2.0	2.25 ***	0.28
Farm Income (ZAR/season)	17,500	8,320	9,180***	2,150
Input Costs (ZAR/Ha)	7,900	3,100	4,800***	850

The findings of the study reveal strong and statistically significant effects of GM maize seed adoption on both productivity and economic outcomes. Across both matching approaches, adopters consistently achieve higher maize yields compared to nonadopters, confirming the productivity-enhancing nature of GM technology, with increases of 2.1 tons/ha (Nearest Neighbour) and 2.25 tons/ha (Kernel) (Table 6.4). This demonstrates the technological advantage of GM maize seeds in enhancing onfarm productivity, likely driven by improved pest resistance and greater tolerance to environmental stressors, which are critical constraints in smallholder farming systems. From an economic perspective, the results show that adopters earn significantly higher farm income, with gains of ZAR 8,650 and ZAR 9,180 under Nearest Neighbour and Kernel matching, respectively. This indicates that productivity improvements translate effectively into marketable surplus and enhanced household welfare. These findings are consistent with the empirical findings reported by Mailula et al. (2023), Wamatsembe et al. (2017), and Mdoda et al. (2025), which demonstrate that the

adoption of genetically modified (GM) seed varieties significantly enhances both agricultural productivity and farm returns among smallholder farmers. Notably, while input costs are higher among adopters, the magnitude of income gains outweighs these additional expenses, suggesting that GM maize adoption remains economically viable and profitable for smallholder farmers. The consistency of results across both estimators reinforces the robustness and reliability of these findings. This study adds to the existing body of literature by providing micro-level causal evidence on the dual role of GM maize seed adoption as both a productivity-enhancing and income-generating strategy within smallholder farming systems in the Eastern Cape. Unlike conventional studies that focus solely on yield effects, this analysis integrates economic outcomes, thereby offering a more comprehensive assessment of technology adoption. Furthermore, the use of both Radius and Kernel matching strengthens the methodological rigour and highlights the stability of the estimated impacts across different matching algorithms. The findings highlight the importance of promoting access to GM maize seed technologies as a pathway to improving smallholder competitiveness, while also drawing attention to the need for supportive policies that address input affordability constraints. This dual insight positions GM maize adoption not only as a technological intervention but also as a strategic lever for advancing rural economic development and agricultural transformation in South Africa.

6.5 Conclusion and Recommendations

This study evaluated the effects of GM maize seed adoption on farm returns, input costs, and maize yields of smallholder farmers. The descriptive analysis, Probit regression model, and the Propensity Score Matching [PSM] were used to achieve the study objective. Maize farmers reported access to different land tenure systems, such as owning the land, leased land, communal land, and mixed. Furthermore, the results indicated that farmers utilise a range of maize seed varieties, such as GM (HT/Bt) with both herbicide and insect tolerance, GM (Bt), which are tolerant to pests and diseases, and the traditional maize varieties, which are mostly recycled from the previous growing season. The perceived benefits of GM maize seed adoption reported by farmers were improved yields,

drought tolerance, herbicide tolerance, and pest resistance. The results from the Probit regression model revealed that the adoption of GM maize seeds was influenced by several factors, such as gender, years spent in school, marital status, household size, household monthly income, land size access to extension services, amount of credits were positively influencing the adoption of GM maize seeds by farmers, while distance to markets was negatively associated with adoption of GM seeds. While the results from the PSM revealed. The results revealed a strong and statistically significant effect of GM maize seed adoption on both productivity and economic outcomes. Across both matching approaches, adopters consistently achieve higher maize yields compared to non-adopters, confirming the productivity-enhancing nature of GM technology. While from the economic perspective, the results show that adopters earned significantly higher farm income, with gains under Nearest Neighbor and Kernel matching, respectively.

Based on the strong and statistically significant effect of GM seed adoption on productivity and farm returns, there is a clear and pressing need to expand and enhance access to GM maize seed varieties in the study area. Government and developmental agencies should ensure that they strengthen certified seed systems through supporting local seed development and distribution networks by partnering with the existing private seed enterprises. Furthermore, the government must ensure timely availability and access to affordable and high-quality seed, and this will result in more maize farmers benefiting from the GM technology. Given that the adoption of these technologies was influenced by several factors, among the important factors were the years spent at school, household income, access to credit, and extension services. The study, therefore, recommends improving the adoption of GM maize seeds through an integrated approach that strengthens access to farmer education, credit, and agricultural extension services. Extension officers should conduct demonstration plots showing the results of GM maize seeds and provide on-farm training on proper agronomic practices on input use, such as fertilizers, pesticides, and the correct spacing of maize. Furthermore, the government should improve farmers' access to production credits and input financing. Though GM maize seed improves productivity, its adoption often requires higher upfront input costs.

Hence, government programs should work with financial institutions in providing smallholder farmers with affordable credit schemes, including input subsidies that have a farmer-friendly repayment model.

References

Agbugba, I.K., Christian, M. and Obi, A., 2020. Economic analysis of smallholder maize farmers: Implications for public extension services in Eastern Cape. *South African Journal of Agricultural Extension*, *48*(2), pp.50-63.

Ala-Kokko, K., Nalley, L.L., Shew, A.M., Tack, J.B., Chaminuka, P., Matlock, M.D. and
D'Haese, M., 2021. Economic and ecosystem impacts of GM maize in South Africa. *Global Food Security*, *29*, p.100544.

Baiyegunhi, L.J.S., Majokweni, Z.P. and Ferrer, S.R.D., 2019. Impact of outsourced agricultural extension program on smallholder farmers' net farm income in Msinga, KwaZulu-Natal, South Africa. *Technology in Society*, *57*, pp.1-7.

Bhekiswayo, B.T.N., Mudhara, M., Mamabolo, M. and Siwela, M., 2025. Determinants of Smallholder Farmers' Perceptions of Biochar: A Case Study for Okhahlamba Local Municipality. *South African Journal of Agricultural Extension*, *53*(5), pp.62-91.

Chimonyo, V.G.P., Mutengwa, C.S., Chiduza, C. and Tandzi, L.N., 2020. Characteristics of maize growing farmers, varietal use and constraints to increase productivity in selected villages in the Eastern Cape province of South Africa. *South African Journal of Agricultural Extension*, *48*(2), pp.64-82.

Chris Hani District Municipality, 2025. *The Chris Hani District Municipality final Integrated Development Plan.* https://www.chrishanidm.gov.za/ [Accessed online: 11 April 2026].

Department of Agriculture, Land Reform and Rural Development, 2021. A profile of the South African maize market value chain. Directorate, Marketing in Pretoria.
chromeextension://efaidnbmnnnibpcajpcglclefindmkaj/http://webapps1.daff.gov

.za/AmisAdmi n/upload/Maize%20profile%202021.pdf [accessed online: 19 November 2025]

Department of Cooperative Governance and Traditional Affairs, 2020a. Profile and analysis of the district development model. OR Tambo district municipality, Eastern Cape. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cogta.gov.za/ddm/wpcontent/uploads/2020/11/ORTamnco-September-2020.pdf [accessed online: 20 November 2025].

Department of Cooperative Governance and Traditional Affairs, 2020b. Profile and analysis of the district development model. Chris Hani district municipality, Eastern Cape. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cogta.gov.za/ddm/wpcontent/uploads/2020/08/Take3_DistrictProfile_CHRISHANI03072020.pdf

Dorfman, 2025. Theory of production. *Encyclopedia* Britannica. https://www.britannica.com/money/theory-of-production. [Accessed 20 November 2025].

Ebukiba, E.S., Anthony, L. and Adamu, S.M., 2020. Economics and technical efficiency of maize production among small scale farmers in Abuja, Nigeria: Stochastic frontier model approach. *European Journal of Agriculture and Food Sciences*, *2*(6).

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. *Food security*, *14*(5), pp.1295-1319.

Fanteso, B., 2020. *Unlocking alternative water conservation technologies: the case study of the rural Eastern Cape Province, South Africa*. University of Johannesburg (South Africa).

Gheith, E.M.S., El-Badry, O.Z., Lamlom, S.F., Ali, H.M., Siddiqui, M.H., Ghareeb, R.Y., El-Sheikh, M.H., Jebril, J., Abdelsalam, N.R. and Kandil, E.E., 2022. Maize (Zea mays L.) productivity and nitrogen use efficiency in response to nitrogen application levels and time. *Frontiers in Plant Science*, *13*, p.941343.

Gidi, L.S., Mdoda, L., Ncoyini-Manciya, Z. and Mdiya, L., 2024. Climate Change and
Small-Scale Agriculture in the Eastern Cape Province: Investigating the Nexus of Awareness, Adaptation, and Food Security. *Sustainability (2071-1050)*, *16*(22).

Hu, Y., Li, B., Zhang, Z. and Wang, J., 2022. Farm size and agricultural technology progress: Evidence from China. *Journal of Rural Studies*, *93*, pp.417-429.

Imran, M., Haq, S.U. and Phambra, A.M., 2023. Smallholder farmers' access to microcredit and energy efficiency in crop production. In *Handbook of Energy Management in Agriculture* (pp. 739-753). Singapore: Springer Nature Singapore.

Klümper, W. and Qaim, M., 2014. A meta-analysis of the impacts of genetically modified crops. *PloS one*, *9*(11), p.e111629

Mailula, L.P., Mushunje, A. and Nhundu, K., 2023. Impact assessment of Genetically
Modified TELA® Bt. maize variety adoption on yield and household income in South Africa.

Mangani, R., Mazarura, J., Matlou, S., Marquart, A., Archer, E. and Creux, N., 2025. The impact of past and current district-level climatic shifts on maize production and the implications for South African farmers. *Theoretical and Applied*
Climatology, *156*(2), p.109.

Mdoda, L., Ajuruchukwu, O., Mzuyanda, C. and Phiwe, J., 2021b. Technical efficiency of maize-based farm irrigators in the Eastern Cape province: a stochastic frontier model approach. *Journal of Agribusiness and Rural Development*, *62*(4), pp.371-381.

Mdoda, L., Mdletshe, S.T.C., Dyiki, M.C. and Gidi, L., 2022. The impact of agricultural mechanization on smallholder agricultural productivity: Evidence from Mnquma Local Municipality in the Eastern Cape Province. *South African Journal of Agricultural Extension*, *50*(1), pp.76-101.

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D., 2025. Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis. *GM Crops & Food*, *16*(1), pp.272-304.

Msomi, L. and Zenda, M., 2024. An analysis of challenges facing smallholder crop farmers and informal food traders in the agri-food value chain in Gauteng Province, South Africa. *South African Journal of Agricultural Extension*, *52*(2), pp.120-144.

Mujuru, N.M., Obi, A., Mishi, S. and Mdoda, L., 2022. Profit efficiency in family-owned crop farms in Eastern Cape Province of South Africa: a translog profit function approach. *Agriculture & Food Security*, *11*(1), p.20.

Ndoro, J.T., Mudhara, M. and Chimonyo, M., 2014. Livestock extension programmes participation and impact on smallholder cattle productivity in KwaZulu-Natal: A propensity score matching approach. *South African Journal of Agricultural Extension*, *42*(2), pp.62-80.

Ngqulana, A., Oladele, O.I., Mdoda, L., Nontu, Y. and Mdiya, L., A Systematic Review on Enhancing the Technical Efficiency of Genetically Modified Maize Adoption in SubSaharan Africa: The Role of Agricultural Extension Services and Barriers to Success. *Frontiers in Sustainable Food Systems*, *9*, p.1609417.

Nkamisa, M., Ndhleve, S., Nakin, M.D., Mngeni, A. and Kabiti, H.M., 2022. Analysis of trends, recurrences, severity and frequency of droughts using standardised precipitation index: Case of OR Tambo District Municipality, Eastern Cape, South Africa. *Jàmbá-Journal of Disaster Risk Studies*, *14*(1), p.1147.

Ntonjane, P., Mdletshe, S.T.C. and Nontu, Y., 2025. Socioeconomic and Behavioural Factors Influencing Electrical Appliance Adoption Among Rural Farming Households: An Endogeneity Switching Regression Analysis. *South African Journal of Agricultural Extension*, *53*(6), pp.155-179.

O.R. Tambo District Municipality (2024) *Integrated Development Plan 2024/2025*.

Mthatha: O.R. Tambo District Municipality. Available at: https://www.ortambodm.gov.za [Accessed online: 11 April 2026].

Ogujiuba, K., Agholor, A.I. and Mabila, L., 2021. Socio economic factors affecting small scale maize producing farmers in Kamhlushwa, South Africa.

Owethu, Z., 2022. *Perceptions and determinants of genetically modified (GM) maize production among rural households: The case of Ngqushwa Local Municipality, South Africa* (Doctoral dissertation, University of Fort Hare).

Senyolo, M.P., Long, T.B., Blok, V., Omta, O. and van der Velde, G., 2021. Smallholder adoption of technology: Evidence from the context of climate smart agriculture in South Africa. *Journal of Development and Agricultural Economics*, *13*(2), pp.156-173.

Shemfe, O. and Modirwa, S., 2026. Barriers to the Adoption of Information and Communication Technology (ICT) for Accessing Agricultural Information by SmallScale Farmers in Mahikeng, Northwest Province. *South African Journal of Agricultural Extension (SAJAE)*, *54*(1), pp.190-223.

Ssemugenze, B., Ocwa, A., Kuunya, R., Gumisiriya, C., Bojtor, C., Nagy, J., Széles, A. and Illés, Á., 2025. Enhancing maize production through timely nutrient supply: The role of foliar fertiliser application. *Agronomy*, *15*(1), p.176.

Tesfaye, M. and Gutema, P., 2022. Impact of improved forage technology adoption on dairy productivity and household income: a propensity score matching estimation in Northern Ethiopia. *Advances in Agriculture*, *2022*(1), p.6197119.

Tham-Agyekum, E.K., Appiah, P., Koomson, A., Bawa, A.Z. and Manso, E., 2025.
Dialing into Agricultural Innovation Via Mobile Phones: Experiences of Smallholder Cocoa Farmers in Sekyere South, Ghana. *South African Journal of Agricultural Extension*, *53*(6), pp.34-63.

Wamatsembe, I.M., Asea, G. and Haefele, S.M., 2017. A survey: potential impact of genetically modified maize tolerant to drought or resistant to stem borers in Uganda. *Agronomy*, *7*(1), p.24.

Wang, J., 2021. To use or not to use propensity score matching?. *Pharmaceutical Statistics*, *20*(1), pp.15-24.

Wordofa, M.G., Hassen, J.Y., Endris, G.S., Aweke, C.S., Moges, D.K. and Rorisa, D.T., 2021. Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agriculture & Food Security*, *10*(1), p.5.

Yazdan-Bakhsh, S., 2024. Analyzing Smallholder Farmers Performance-Farmer Typology, Technical Efficiency, Market participation, Policies and Management Practices Evidence from Limpopo Region of South Africa.

CHAPTER 7

Genetically Modified Maize Seed Adoption on Input Elasticities and Productivity among Smallholder Farming Systems: Insights from Eastern Cape Province, South Africa

Abstract

Smallholder maize farmers in South Africa, particularly in the Eastern Cape Province, continue to experience low productivity due to limited access to improved technologies, suboptimal use of inputs, and reliance on traditional seed varieties. These constraints perpetuate yield gaps, undermine food security, and threaten rural livelihoods. This study investigates the impact of adopting Genetically Modified (GM) maize seed on input responsiveness, technical efficiency, and overall productivity among smallholder farmers. Primary data were collected from 306 farmers, classified as adopters and non-adopters of GM maize. Analytical methods included descriptive statistics and a Cobb-Douglas Stochastic Production Frontier (SPF) approach. Descriptive results revealed that adopters cultivated larger farm areas, applied higher quantities of improved seed and fertilizer, and allocated more labour, achieving an average yield of 6472.74 kg/ha compared to 2800.42 kg/ha among non-adopters. SPF results indicated that adopters revealed significantly higher input elasticities for seed (0.40, $p < 0.01$) and fertiliser (0.20, $p < 0.01$), while non-adopters showed limited responsiveness to modern inputs. Technical efficiency was markedly higher among adopters ($\gamma = 0.75$) than non-adopters ($\gamma = 0.60$), with adopters operating under constant returns to scale and non-adopters under decreasing returns. These findings demonstrate that GM maize adoption enhances input efficiency, boosts productivity, and provides a pathway for sustainable intensification of smallholder maize systems. The study highlights that targeted interventions to promote adoption can strengthen food security and improve rural livelihoods. Moreover, the results provide policymakers and agricultural extension personnel with evidence to design effective input support, extension, and technology dissemination programs.

Keywords: Smallholder maize farmers, GM maize seeds, Input elasticities, Productivity, Cobb-Douglas Stochastic Production Frontier, Technical efficiency, Eastern Cape Province.

7.1 Introduction

The agricultural sector continues to be a major source of employment worldwide, particularly in rural areas of developing countries where farming is the main livelihood strategy (Dethier and Effenberger, 2012; Williams, 2025). Globally, approximately 1.3 billion people are employed within agrifood systems, accounting for about 39.2% of total employment (FAO, 2024). Despite its relatively modest contribution to global GDP (around 4%), agriculture plays a disproportionately large role in food security, rural livelihoods, and economic stability in developing economies, where its contribution can reach up to 25% of GDP (Yogi et al., 2024). The sector is undergoing rapid transformation driven by technological innovations such as precision agriculture, biotechnology, and improved seed systems, which are reshaping productivity and input use patterns (Tiwari and Park, 2024).

In South Africa, agriculture contributes approximately 2.5-3% to GDP, accounts for about 5% of total employment, and generates around 5% of total exports (Mpundu and Bopape, 2022). Although its macroeconomic share appears limited, the sector remains central to rural livelihoods, poverty reduction, and food security, particularly in historically marginalised communities (Mutengwa et al., 2023). However, South African agriculture is characterised by a persistent dual structure, consisting of a highly commercialised sector alongside a resource-constrained smallholder sector located predominantly in rural areas (Mpundu and Bopape, 2022). This dualism is reinforced by unequal land distribution, where commercial farmers occupy approximately 87% of agricultural land, while approximately 2 million black smallholder households operate on the remaining 13% (Mpundu and Bopape, 2022).

Smallholder farmers typically operate on less than two hectares of land and are characterised by low input use, limited mechanisation, and low productivity levels (Apanovich and Nyairo, 2025). Their production systems are largely

subsistence oriented, with surplus output sold in local markets for income generation (Carelsen et al., 2021). These systems are heavily reliant on family labour, particularly women, children, and elderly household members (Kapari et al., 2023). Despite these constraints, smallholder agriculture remains a critical pathway for rural development, employment creation, and household food security in South Africa (Thibane et al., 2023). Maize is among the most significant and staple crops within these systems, particularly in provinces such as the Eastern Cape, where it serves as a key source of food, livestock feed, and income generation (Ogujiuba et al., 2021; Mdoda et al., 2025).

However, smallholder maize production remains constrained by low productivity, limited access to improved inputs, climate variability, and inefficiencies in resource allocation (Mdoda et al., 2025). The Eastern Cape, in particular, is among the lowest maize-producing provinces in South Africa, necessitating reliance on surplus production from other provinces such as Mpumalanga, the Free State, and North West (Mujuru and Obi, 2020; Mamashila et al., 2025). These persistent production deficits highlight structural inefficiencies within smallholder farming systems and underscore the need for productivity-enhancing and resource-efficient technologies.

One of the most widely promoted interventions is the adoption of Genetically Modified (GM) maize, which has been introduced to improve yields, enhance pest resistance, and strengthen resilience against climate-related shock such as drought and pest infestations (Mdoda et al., 2025; Kerorsa, 2025). Evidence suggests that GM maize can improve technical efficiency and reduce crop losses, while also lowering labour requirements, particularly for weeding in herbicide-tolerant systems (Gcaba et al., 2024; Ngqulana et al., 2025). Despite these potential benefits, adoption among smallholder farmers remains uneven, particularly in marginal production environments such as the Eastern Cape.

More critically, existing literature has largely focused on yield and productivity gains, with limited attention to how GM maize adoption reshapes input use behaviour, input substitution patterns, and production responsiveness. Specifically, there is insufficient empirical evidence on how GM maize affects input elasticities for key production factors such as land, labour, fertiliser, and

pesticides. It remains unclear whether labour savings from herbicide-tolerant varieties are reallocated to other productive farm activities or result in underutilised household labour resources. Similarly, the extent to which GM maize influences fertiliser responsiveness and seed price sensitivity among resource-constrained farmers remains underexplored.

In addition, most existing studies rely on aggregated provincial or national datasets, with limited micro-level evidence capturing heterogeneity in agro-ecological conditions. This creates a gap in understanding how GM maize performs under varying soil quality, rainfall variability, and market access conditions, particularly in drought-prone smallholder systems. Furthermore, gender-differentiated impacts of GM maize adoption remain insufficiently examined, despite evidence suggesting that male and female farmers may derive different utility from labour-saving and yield-enhancing technologies. Finally, there is limited evidence on the long-term socioeconomic implications of GM maize adoption, particularly in terms of financial risk exposure, input cost burdens, and household resilience.

Against this background, this study assesses the effects of GM maize seed adoption on input elasticities and productivity among smallholder farmers in the Eastern Cape Province. The study is motivated by the need to move beyond traditional yield-based assessments and instead provide a more comprehensive understanding of how GM technology influences resource allocation efficiency and input demand behaviour within smallholder farming systems.

7.2 Theoretical Framework

The study is grounded in Production and Cost Theory, which provides a foundational economic framework for understanding how farmers allocate inputs to maximise output while minimising costs (Alaghehband et al, 2011). At its core, this theory posits that agricultural production is a function of multiple inputs (such as land, labour, seed, fertiliser, pesticides, and mechanisation) combined efficiently to generate output. The theory further assumes that farmers aim to achieve the optimal combination of these inputs, given their availability, prices, and technology, to maximise productivity or profit. It allows for the analysis of

both technical efficiency, how well inputs are converted into output (and allocative efficiency), and how inputs are used in cost-minimising proportions relative to their prices.

In this study, total productivity is measured as the output response to changes in input factors, reflecting the sensitivity of maize yield to variations in land, labour, seed, fertilisers, pesticides, and mechanisation. To operationalise this, the study employs the Cobb–Douglas (C-D) production function, a commonly used specification in agricultural economics because of its flexibility, ease of interpretation, and ability to estimate output elasticities for individual inputs. The C-D function expresses output as a multiplicative function of input quantities raised to their respective elasticity coefficients. These coefficients indicate the percentage change in output resulting from a one percent change in each input, holding other inputs constant. Consequently, the C-D function enables quantification of the marginal productivity of inputs, identification of critical productivity drivers, and estimation of returns to scale, all of which are central to production and cost theory.

By applying the Cobb-Douglas function, this study links the theoretical principle that output depends on input combination to empirical estimation. For instance, higher fertiliser elasticity or improved seed reflect greater responsiveness of maize output to these inputs, supporting the production theory assertion that different inputs contribute differently to total output. Additionally, decomposing labour into hired and family labour, and mechanisation into tractor use and animal draft power, aligns with the theory's emphasis on input heterogeneity and cost-effective resource allocation. The theoretical framework thus provides a structured approach for assessing how farmers convert inputs into outputs and where efficiency gains or constraints may exist.

Furthermore, the inclusion of returns to scale analysis within the Cobb-Douglas framework is directly informed by production and cost theory. Returns to scale measure whether proportional increases in all inputs result in proportional, greater than proportional, or less than proportional changes in output, which have implications for farm expansion, resource utilisation, and policy interventions. The theory predicts that farms operating under increasing returns

to scale can achieve higher productivity by expanding input use, whereas decreasing returns highlight inefficiencies and input limitations. This concept is crucial for understanding productivity differences between adopters and non-adopters of improved maize technologies.

The theoretical framework positions the study within the broader discourse on technical efficiency and productivity measurement in agriculture. By adhering strictly to production and cost theory, the study provides a rigorous economic lens for evaluating maize production systems, assessing input complementarities, and generating actionable insights for agribusiness development and technology dissemination. The Cobb-Douglas functional form operationalises these theoretical principles, offering precise, interpretable, and policy-relevant measures of input-output relationships, efficiency, and scale effects.

7.3 Methodology

7.3.1. The Study Areas

This study was conducted in the Eastern Cape Province of South Africa. The province was chosen as the study site due to the high concentration of smallholder farmers, with very low levels of maize production and high levels of rural poverty. Furthermore, the province is suitable for assessing technical efficiency, adoption challenges, and input use allocation, as smallholder farmers face several production and resource-related constraints, which include access to production inputs, agricultural extension services, infrastructure, and markets. Empirical evidence from previous studies has shown that the province continues to persist with maize yields of less than 25% of their potential yields (Mdoda et al., 2025; Fanadzo, 2010; Sigigaba et al., 2021). According to Chimonyo et al. (2020), this is a result of both abiotic and biotic stresses, highly variable environmental conditions, the selection of inappropriate maize seed varieties, and input allocation.

Within the Eastern Cape Province, the study further focuses on selected districts, namely the Oliver Regional Tambo District Municipality [ORTDM] and the Chris Hani District Municipality [CHDM] (Figure 7.1). The District Municipalities were selected as they are both concentrated with smallholder and subsistence while also both have a history with GM technology in the Eastern Cape (Stats SA, 2017). The ORTDM is composed of five local municipalities, namely King Sabata Dalindyebo, Nyandeni, Ngquza Hill, Mhlontlo, and Port St Johns Local Municipalities (Figure 7.1). The district encompasses a diverse range of agroecological zones that receive an average of about 800 to 1000 mm of rainfall annually, with peak rainfall starting in September. The highest rainfall occurs in November and December, whereas the driest period is from May to August (Maponya et al., 2023). The coastal municipalities of ORTDM receive higher rainfall than inland municipalities, with Port St Johns Municipality showing better rainfall (Nkamisa et al., 2022). The inland municipalities benefit from the Umzimvubu River's catchment and tributaries as relevant irrigation water resources.

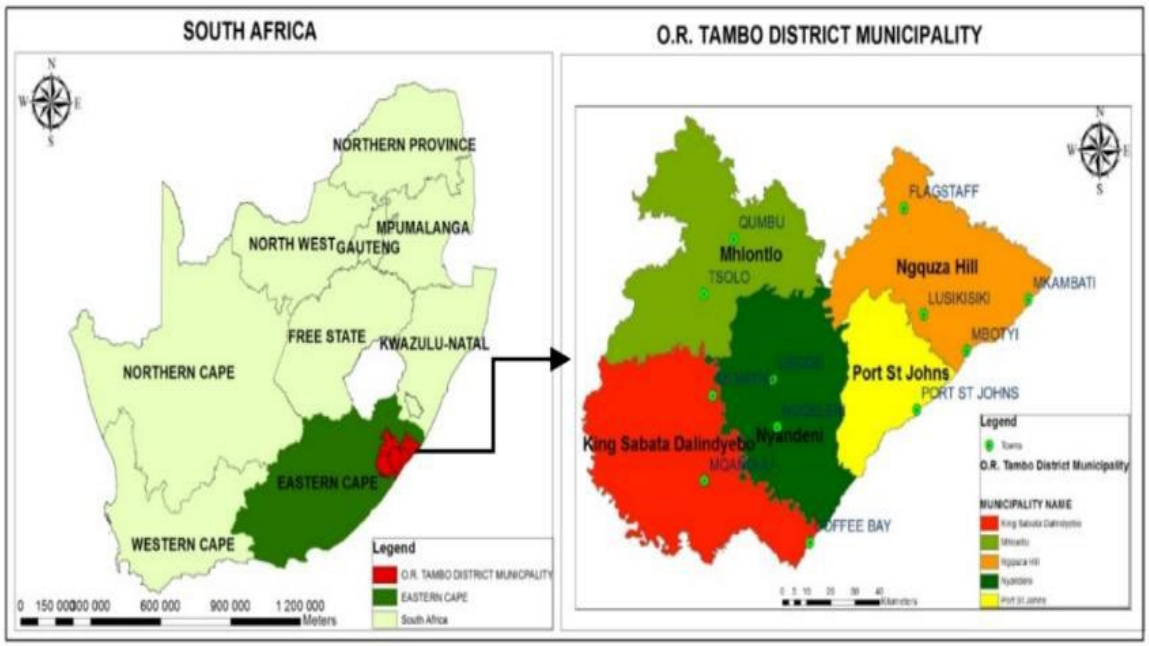


Figure 7.1: Map indicating the local municipalities of the ORTDM.

Source: Google Maps (2026)

The ORTDM has high summer temperatures ranging from 16 ºC to 28 ºC, whilst winter

(April and August) temperatures range from 7 ºC to 20 ºC. The area's soils are primarily derived from dolomitic intrusions of the Karoo Dolerite. The soils are well-structured red or black clay types that are highly susceptible to erosion (Sibanda et al., 2016). In the topsoil, clay content is relatively high (26–35%), indicating low infiltration rates but strong water-holding capacity. Most areas also have shallow soils ranging between 300 and 600 mm in depth, which can be highly limiting crops. Generally, soil-related challenges in the district are soil erosion and soil acidity. Nevertheless, the climate of the area does suit rainfed agriculture. As such, most economically related activities in this area are mainly based on agricultural activities (communal and subsistence farming) (Taruvinga et al., 2022). Although most farming households can be described as low-income and resource-poor.

The CHDM is composed of six local municipalities, namely Inxuba Yethemba, Enoch Mgijima, Emalahleni, Sakhisizwe, Insika Yethu, and Engcobo local municipality (Figure 7.2) (Twalo, 2025). Similar to the ORTDM, the CHDM comprises various agroecological zones, with the three main agroecological zones being Semi-Arid Moderate Midlands (Western Chris Hani), Semi-Arid Cold High-Lying Land (Western
Chris Hani), and Moist Uplands and Grassland Hills (Eastern Chris Hani). The area experiences summer rainfall, which is highly variable across the district and is prone to severe water shortages caused by drought (Gunya et al., 2014; Twalo, 2025).

Average rainfall in the west is around 300 mm annually, while in the east it is around 1000 mm (Twalo, 2025). The district also benefits from the four major rivers, including the Great Fish, Kei, Mbashe, and Orange Rivers. In Summer, the temperatures reach over 35 °C, while in winter temperatures often drop to 0 °C, with snow in high-lying areas (Molteno, Sterkstroom) (Kiggundu, 2009; Gunya et al., 2014). Because of the variation in topography, soils in the area vary; however, the most predominant soils are shallow (<300 mm before bedrock), rocky, weakly developed soils with deeper (> 900 mm before bedrock), fertile soils (Hutton, Oakleaf, Clovelly, Dundee, Valsrivier). Nevertheless, agriculture (predominantly livestock and small-scale cropping) is the most

economically related activity in the area (Kiggundu, 2009). The eastern side of CHDM is wetter and agriculturally stronger, and the western side is more arid and livestock-dependent (CES Environmental and Tourism Services, 2022).

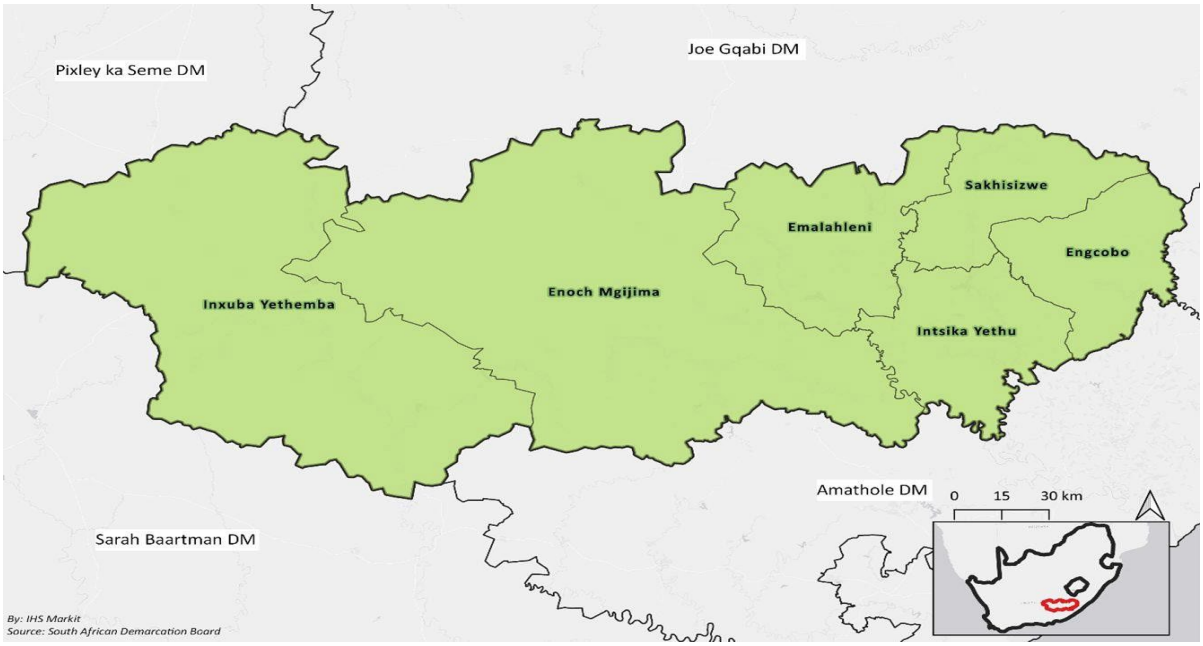


Figure 7.2: Map indicating the local municipalities of the CHDM.

Source: Google Maps (2026)

7.3.2. Sampling Procedure and Size

To investigate GM maize adoption and its effects on input elasticities and productivity among smallholder farmers, the study utilised the multistage method to purposively select the farmers. Specifically, both the OR Tambo and Chris Hani District

Municipalities were purposively selected within the Eastern Cape Province.

Additionally, a cross-sectional research design was employed. The reason the study chose this design was that it would be conducted at a single point in time. To refine the focus of the study, the multistage sampling was conducted in three stages;

i. **Stage 1:** Selection of the Eastern Cape Province and the two districts (ORTDM and CHDM) included in the study.

ii. **Stage 2:** The second stage involved the dividing of the smallholder farmers into

STRATA: maize farmers (A), livestock farmers (B) and mixed farmers (C)

iii. **Stage 3:** The last stage was to purposively select smallholder maize farmers from villages under the selected local municipalities.

The Yamani formula was employed to calculate the final sample for the study.

$$n = \ /((1 + Ne\text{^}2))$$

$$n = \ 921/((1 + 921\ (\ 〚0.05〛\ \text{^}2))$$

$$n = \ 921/((1 + 921\ (0.00250)))$$

$$n = 279$$

Based on the above Yamani formula, the sample was 279 GM maize seed adopters. Furthermore, 40% of the received sample was added, which represented the nonadopters of GM maize seeds. This stage was significant as it allowed the researcher to analyse the difference in input elasticities for both GM maize seed adopters and non-adopters. Therefore, this brought the sample size to 391 maize farmers. The study could not collect data from the initial sample and was able to collect data from 306 maize farmers. This was due to practical field constraints such as limited availability of the maize farmers, time constraints, and accessibility challenges in rural communities. Despite this, the collected data was enough to support a reliable analysis. Therefore, data were collected from 306 smallholder maize farmers.

7.3.3. Data Collection

For data collection, the study used a structured questionnaire. The use of questionnaires ensured that maize farmers were interviewed using the same questions, in a similar pattern, which improves consistency and makes it easier for the researcher to compare the two groups. The questionnaire was administered to the sampled farmers by well-trained enumerators to enhance the quality of the collected data. The questionnaire captured the demographic characteristics, farm characteristics, institutional factors, the maize output, and the inputs used by maize farmers. Before data was collected, a pilot study was conducted where the questionnaire was administered to 31 farmers. These 31

farmers were excluded from the final study sample. The feedback obtained from the pilot study was used to refine the instrument and ensure clarity, relevance, and consistency of the questions.

7.3.4. Data Analysis

Primary data was captured and coded on Microsoft Excel and exported to STATA for further analysis. Descriptive analysis summarises the demographics and farm characteristics into means, percentages, and tables. To assess the Adoption of genetically modified maize and its effects on input elasticities and productivity among smallholder farmers, the study employed the Cobb-Douglas Stochastic Production Frontier model [CSPF]. Several studies have utilized the CSPF model to measure the technical efficiency and input utilization among farmers (Ngeno, 2024; Desta, 2025; Mansor et al., 2025; Lutonja, 2024). The CSPF model was adopted because it helps to estimate efficiency of the farmers as it addresses stochastic noise and allows the noise and allows the statistical testing of the research hypothesis (Obalola et al., 2025). Furthermore, this model has the ability to separate the variation between the actual performance and the best possible performance based on the same resources. Therefore, this model allows us to examine the effect of different production factors on productivity and be able to calculate their contribution to agricultural production (Zhang et al. 2020). The CSPF has been expressed in the formula below:

The Cobb–Douglas Production Function

$$Y_i = A \prod_{k=1}^{K} X_{ki}^{\beta k} e^{\varepsilon i}$$

Where Y_i represents the maize output of the farmers, X_{ki} which shows the vector of inputs used, β_k are the factors that are to be estimated, and $_i$ is the error term. For estimation purposes, the model is transformed into a log-linear form:

$$\ln Y_i = \beta_0 + \sum_{k=1}^{K} \beta_k \ln X_{ki} + \quad _i$$

Empirical Model with Adoption Effects

For the differences between the two groups (adopters and non-adopters of GM maize seeds, a dummy variable and interaction terms were included in the model. The model is specified in the formula below:

$$\ln Y_i = \beta_0 + \beta_1 \ln Land_i + \ln \beta_2 Fertilizer_i + \ln \beta_3 Seed\ Input_i + \ln \beta_4 Pesticides_i + \ln \beta_5 Tractor\ Use_i + \ln \beta_6 Animal\ Draft_i + \gamma D_i + \theta_1 + (D_i \times \ln Land_i) + \theta_2(D_i \times \ln Fertilizer_i) + \theta_3(D_i \times \ln Seed\ Input_i) + \theta_4(D_i \times \ln Pesticides_i) + \theta_5 + (D_i \times \ln Tractor\ Use_i) + \theta_6(D_i \times Animal\ Draft_i)$$

Where:

Y_i: Total maize yields (KGs)

$Land_i$: Amount of Land allocated to GM maize seeds (Hectares)

$Fertilizer_i$: Amount of Fertilizer utilized (KGs)

$Seed_i$: Amount of seeds utilized (KGs)

$Pesticides_i$: Quantity of Pesticides used (litres)

$Tractor\ Use_i$: Amount of tractor in Rands

$Animal\ Draft_i$: $Amount\ paid\ in\ Rands$

D_i: Dummy variable (1= GM maize seed adopter; 0= none-adopter)

$_i$: Random error term

The coefficients for β_k represent the input elasticities for non-adopters, and $\beta_k + \theta_k$ depicts elasticities for GM seed adopters. While the parameter measures the shift in productivity attributable to GM seeds adoption.

Presents Input Responsiveness and Returns to Scale:

The responsiveness of inputs is measured by the estimated elasticities in the production of maize. For non-adopters of GM maize seed, the elasticity of output with respect to input k which is presented by β_k whereas for GM seed adopters it is $\beta_k +$

θ_k.

Returns to scale (RTS) are computed as:

For non-adopters of GM maize seeds

$$RTS_{non} = \sum_{k=1}^{5} \beta_k$$

For the adopters of GM maize seeds:

$$RTS_{adopters} = \sum_{k=1}^{5} (\beta_k + \theta_k)$$

When a value of RTS is more than one, it shows increasing returns to scale; when it is equal to one, it indicates constant returns to scale, and when it is less than one, it indicates decreasing returns to scale.

Stochastic Frontier Model for Technical Efficiency

To assess the technical efficiency differences among adopters and non-adopters, the study further extends the production function into a Stochastic Frontier Analysis:

To further examine technical efficiency differences between adopters and nonadopters of GM maize seeds, the study extends the production function into a Stochastic Frontier Analysis framework, which is expressed as follows:

$$\ln Y_i = \beta_0 + \sum_{k=1}^{5} \beta_k \ln X_{ki} + \gamma D_i + v_i - u_i$$

Where:

v_i: Symmetric random error term representing statistical noise

u_i: Non-negative inefficiency term

Measurement of Technical Efficiency

The technical efficiency of each maize farmer is measured as:

$$TE_i = \exp(-u_i)$$

The values of TE range between 0 and 1, where values closer to 1 indicate that the maize farmers have higher levels of efficiency in the area.

7.4 Results and discussion

This section presents the results from the sampled farmers in the study area. The section further discusses the demographic profile of the farmers and further discusses the input use elasticities among the farmers.

7.4.1 The Demographic Characteristics of Maize Farmers in the Study Area

The area was dominated by females at 57%, which is attributed to men migrating into bigger cities to seek better opportunities (Bekker, 2000). Migrating men, driven by economic necessity, leave their wives as primary producers and become household heads (Nanda and Ghosh, 2025). Findings indicating a similar trend among smallholder farmers of KwaZulu-Natal were reported by Ndlovu et al. (2024). These authors found that the vast majority (79.5%) of the farmers were female. The authors further attributed the high proportion of female urban farmers to traditional household roles and labour dynamics. They noted that men in these areas are generally employed in off-farm work, while women take on urban farming because they are traditionally responsible for food distribution within the household. The study by Ndlovu et al. (2024) and the current study differ, as the former was conducted in a township closest to big cities, while the current study was conducted in rural areas. The difference in the areas' proximity to big cities where men obtain employment may be the leading factor for the discrepancy (56.9% in the current study vs. 79.5% in Ndlovu et al., 2024) in the % values indicated above. For instance, men residing in townships may work in the cities, then return home in the evening to assist their wives with

the labourers' farming work, thereby encouraging more farming engagement by the wives during the day. However, migrated men are unable to return home, often leaving most of the work to their wives, who may also start looking for local work to increase household income. This is consistent with the findings of Ullah (2017), who found that a change in gender roles has occurred due to men's migration, leading to the expansion of women's traditional duties to include breadwinning. Furthermore, the results of this study (Table 7.1) show that the majority of the farmers (68.6%) were married, while 18.9% reported being widowed, 10.8% were single, and only 1.6% of the farmers reported having divorced. Marriage enhances the availability of labour to assist in carrying out farm operations, especially for labour-intensive technologies such as GM maize.

Apart from the labour (physical) perspective, married households often benefit from the combined financial and human resources of both partners, which enhances the household's overall productive capacity. Additionally, in married households, partners can share traditional knowledge and management expertise (Mdiya et al., 2025). Kom et al. (2022) also revealed that married households were more productive than single or divorced households, as married households tend to be larger in size, which serves as the required labour. While Mdiya et al. (2025) indirectly supports the view, as it was reported that in Raymond Mhlaba Local Municipality within the Eastern Cape, married smallholder farmers are 1.62 times more likely to achieve food security than their unmarried counterparts. Regardless of the pooling of resources, agricultural extension services are still essential in enhancing farmers with knowledge, skills, and production resources for the adoption of innovative practices and technologies such as GM maize (Ngqulana et al., 2025). Extension officers also act as an important bridge between researchers and smallholder farmers in accessing information on improved technologies. Extension officers not only provide improved technologies to farmers, but they also provide information on applying correct and recommended quantities to avoid wastage and improve the efficiency of the farmers. In this study, only 59.8% of the maize farmers reported receiving agricultural extension services. These findings raise serious, high-priority concerns, especially because extension services enhance the capacity

of smallholder farmers by linking them with current agricultural information, technologies, and improved practices (Jolex, 2022).

Nevertheless, 75.8% of the respondents reported being members of agricultural organisations (Table 7.1). This high engagement with agricultural organisations suggests a strong self-reliance and peer-to-peer learning while also indicating a strong will in the areas for private sector engagement. Furthermore, being affiliated with an agricultural organisation serves as an important channel to receive extension services, early exposure to information on innovation, such as GM seeds, which helps improve production and enhance farmers' efficiency. Especially because agricultural organisations are a key source of knowledge and technology transfer among farmers, which enhances farmers' efficiency (Manda, 2020). Also in this study, farmers were mostly old, with an average age of 60 years old (Table 7.1). Age may affect technology adoption both positively and negatively. Older farmers may have more farming experience and be more aware of the local conditions, with more established networks for information. Partly due to having acquired relevant knowledge, connections and experience over time that is required for them to be able to evaluate new technologies (Allotey and Adraki, 2018). On the other hand, older farmers may be more risk-averse and prefer using traditional farming practices that they are used to (Tong et al., 2024). Favourably, the farmers in the study were moderately educated, with an average of 7 years of schooling. Educated farmers can seek information and can understand difficult technical words better than their counterparts (Mthi et al., 2023). The farmers can read instructions, extension materials, and can understand instructions on recommended dosages of production inputs like seeds, fertilisers, and pesticides, which helps improve their usage. Generally, higher levels of education significantly influence farmers' ability to adapt to the rapidly changing technologies in agriculture (Kirui, 2019).

The respondents reported a household average monthly income of ZAR 6637.52; this amount is generally sufficient to support farming operations but not necessarily to drive high adoption of modern inputs and technology among smallholder farmers. Sinyolo (2020) mentions that the poverty line in South Africa was about ZAR 544 per month in the year 2020, which is significantly

lower than the average income among these farmers. Households with higher income have the financial ability to purchase and invest in expensive inputs and technology that improve farmers` productivity and efficiency. In general, off-farm income enhances farmers' capacity to purchase expensive technologies and inputs (Fadeyi et al. 2022).

Table 7.1: Demographic characteristics of maize farmers in the study area.

VARIABLE	**FREQUENCY**	**PERCENTAGES**
GENDER		
Male	132	(43.1%)
Female	174	(56.9%)
MARITAL STATUS		
Married	210	(68.6%)
Single	33	(10.8%)
Divorced	5	(1.6%)
Widowed	58	(18.9%)
EMPLOYMENT STATUS		
Employed	19	(6.2%)
Self Employed	59	(19.3%)
Unemployed	104	(33.9%)
Retired	124	(40.5%)
EXTENSION SERVICES		
Yes	183	(59.8%)
No	123	(40.2%)
FARM ORGANIZATION		
Yes	232	(75.8%)
No	74	(24.2%)
VARIABLES	**MEAN**	**SD**
Age	60.84	10.58
Years Spent in School	7.38	4.72
Household Monthly Income	6637.52	5198.85

Source: Authors' own Computation

7.4.2 Descriptive Overview of Adoption Status

Table 7.2 presents the distribution of maize farmers by the adoption status of improved maize varieties. There is a clear segmentation between adopters and non-adopters, allowing for a comparative assessment of production behaviour and responsiveness to inputs (Table 7.2). A total of 306 farmers were surveyed, of which 65% were adopters of improved maize varieties, and 35% were non-adopters. The analysis reveals notable differences in production practices, input utilisation, and output levels between the two groups.

Table 7.2: Descriptive Statistics of Production Variables by Adoption Status

Variable	**Adopters**		**Non-Adopters**		**Total**		**T-value**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	
Maize Area (ha)	9.19	30.97	1.80	3.41	8.42	28.50	11.73***
Improved Seed (kg/ha)	29.65	51.9	12.05	8.43	23.61	43.11	58.12***
Fertilizer (kg/ha)	444.08	1098.49	98.19	78.76	335.25	905.78	20.31***
Labour (mandays/ha)	7.90	4.55	4.49	1.66	6.73	4.14	6.52***
Maize Output (kg/ha)	6472.74	11605.95	2800.42	1696.80	5394.22	9830.84	23.01***

** and *** mean significant at 5% and 1%, respectively

The results reveal substantial and statistically significant differences in production characteristics between the two groups (Table 7.2). Adopters cultivate larger maize areas (9.19 ha) compared to non-adopters (1.80 ha), and

the difference is highly significant ($t = 11.73$, $p < 0.01$). This suggests that adoption is more prevalent among relatively better-resourced farmers with greater land endowment, which may enhance their capacity to absorb production risks and invest in improved technologies. More striking are the differences in input intensity: adopters apply significantly higher quantities of improved seed (29.65 kg/ha vs. 12.05 kg/ha; $t = 58.12$) and fertiliser (444.08 kg/ha vs. 98.19/ha; $t = 20.31$). The magnitude of these t-values indicates not only statistical significance but also economically meaningful differences in production strategies. These findings imply that adoption is associated with a more commercialised and input-intensive production system, reflecting stronger integration into modern agricultural value chains and potentially better access to input markets, extension services, or credit facilities. The differences in labour use and output further reinforce the productivity-enhancing role of adoption. Adopters utilise more labour per hectare (7.90 man-days) than non-adopters (4.49 man-days), with the difference remaining statistically significant ($t = 6.52$). This suggests that adoption may require complementary labour investments, possibly due to improved management practices or higher cropping intensity. Most importantly, maize output among adopters (6472.74 kg/ha) substantially exceeds that of non-adopters (2800.42 kg/ha), with a highly significant difference ($t = 23.01$). The yield gap of 3672.32 kg/ha indicates a productivity increase, highlighting the transformative potential of adoption for on-farm performance. Collectively, these results provide strong descriptive evidence that technology adoption is associated with higher input utilisation and significantly improved productivity outcomes.

7.4.3 Input Elasticities for Adopters and Non-adopters (Cobb-Douglas Analysis)

The Cobb-Douglas production function in agriculture models the relationship between agricultural output and inputs such as labour and capital (Table 7.3). It measures input elasticity, determines how changes in inputs affect output, and is widely used to analyse efficiency, economies of scale, and technological progress in farming systems (Gautam, 2024). The Cobb-Douglas production estimates in this study provide convincing evidence of structural, technological, and efficiency differences between adopters and non-adopters of GM maize

technologies. The model demonstrates strong explanatory power across all specifications (R^2 = 0.76 for adopters, 0.65 for non-adopters, and 0.73 for the pooled sample), indicating that the included production inputs adequately explain variations in maize output. More importantly, the elasticity structure reveals that adopters operate within a more technologically responsive and productivity-enhancing production regime. The substantially higher multi-factor productivity (MFP) among adopters (8.35) compared to non-adopters (7.02) further confirms that, beyond observable input quantities, superior technology, management practices, and institutional alignment significantly elevate output performance.

Table 7.3: Input Elasticities of Maize Production by Adoption Status (Cobb–Douglas Estimates)

Input Variables	***β_i for adopters***	***β_i for non-adopters***	***β_i for Average***
All inputs			
Land (ha)	0.24***	**0.30*** **	0.26***
Fertiliser (kg)	**0.22*** **	0.18***	0.20***
Seed Input (kg)	**0.19*** **	0.11**	0.16***
Pesticides (litres/kg)	**0.12*** **	0.07*	0.10***
Tractor Use (rands)	**0.10** **	0.05	0.08**
Animal Draft Power (rands)	0.04	**0.09** **	0.06*
Multi-Factor Productivity (A)	**8.35**	7.02	7.69
Seed Technology in kg (Base = Traditional)			
GM (HT/BT)	0.14***	—	0.12***
GM (BT)	0.08**	—	0.07**
Labour Input (man-days)			
Hired Labour	**0.13*** **	0.07*	0.11***
Family Labour	0.10**	**0.14** **	0.11***
Farm Organisation (dummy)	**0.07** **	0.04	0.06**
Returns to Scale (Σ Elasticities)	1.03	0.91	0.99
R^2	**0.76**	**0.65**	**0.73**

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

Land remained a fundamental determinant of maize production across all groups. However, the elasticity is higher among non-adopters (0.30) than among

adopters (0.24), suggesting that non-adopters rely more heavily on land expansion to increase output. Although non-adopters cultivate smaller land areas, this indicates a relatively extensive production strategy, in which productivity gains are achieved primarily through land reallocation rather than input intensification. In contrast, adopters display slightly lower land elasticity but greater responsiveness to yield-enhancing inputs such as fertiliser and improved seed. This reflects a shift from land-driven growth to inputdriven intensification, which is characteristic of structurally transforming agricultural systems. Overall, raising yields through intensification benefits natural ecosystems and saves them from agricultural encroachment (Byerlee et al., 2014). Davis et al. (2024) also suggested that increasing land and labour productivity, together with improving resource use efficiency, represents the most effective way to prevent land expansion while enhancing income-generating opportunities. Increasing cropping land for increased total crop yields has significant environmental, economic, and operational disadvantages. These disadvantages include long-term sustainability issues, including habitat loss (deforestation), soil degradation, and high management costs (Inwood and Sharp, 2012; Röös et al., 2018). These results are consistent with the findings of Aramburu-Merlos et al. (2024) that adoption of improved technologies reduces the need for land expansion among farmers.

The responsiveness to modern agronomic inputs further differentiates the two groups. Fertiliser elasticity is higher among adopters (0.22) relative to non-adopters (0.18), indicating more efficient nutrient utilisation when combined with improved seed technologies. Similarly, seed elasticity among adopters (0.19) nearly doubles that of non-adopters (0.11), highlighting the productivity gains associated with improved genetic material. Pesticide elasticity follows the same pattern (0.12 vs. 0.07), suggesting that adopters benefit from integrated crop management practices. This responsiveness trend among these inputs can be attributed to the design of GM technologies. These technologies operate most efficiently when combined with inorganic fertilisers and pesticides while also being applied in lands adopting conventional ploughing (Kotey et al., 2017). As such, these findings illustrate the complementarity between improved seed, fertiliser, and crop protection inputs, where their joint application generates

synergistic productivity effects. These findings are similar to the results of Miehe (2025), who noted that, for maximum efficiency and to ensure that farmers reap the best out of new improved technologies, adopters of improved seeds should also invest in complementary inputs, which include the use of fertilisers, pesticides, recommended planting patterns, and weeding.

The technology-specific coefficients reinforce these findings. Using traditional seed as the base category, GM (HT/BT) varieties exhibit the highest productivity premium (0.14 among adopters and 0.12 in the pooled sample), followed by GM (BT) at 0.08 and 0.07, respectively. The GM (BT) maize is modified for specific pest resistance, which allows for reduced pesticide application (Shelton et al., 2008; Ala-Kokko et al., 2021). On the other hand, GM (HT/BT) maize is strategically modified for resistance against specific pests and herbicides (stacked traits) such as glyphosate, glufosinate, and dicamba, which simplifies weed control (Shelton et al., 2008; Dodson, L., 2025). In this study, GM (HT/BT) varieties have a higher resource usage efficiency than varieties with only a single resistance. Nevertheless, overall, these positive and significant elasticities also indicate that genetically modified varieties contribute directly to output gains beyond conventional input effects. The magnitude of these coefficients reflects not only yield advantages but also improved resistance to pests and herbicides, thereby reducing yield variability and production risk. This technological premium partly explains the higher multi-factor productivity observed among adopters. The findings are consistent with those of Daksa (2024), who found that GM crops help farmers to enhance their yields, leading to more resilience to environmental stressors.

Mechanisation and power source dynamics further illuminate structural transformation. Tractor-use elasticity is positive and significant among adopters (0.10) but relatively weak among non-adopters (0.05), indicating that mechanisation enhances operational efficiency primarily in technologically advanced systems. Conversely, animal draft power shows stronger elasticity among non-adopters (0.09) compared to adopters (0.04), revealing continued reliance on traditional traction systems. This divergence underscores a transitional dualism within the farming sector: adopters are moving toward

capital-intensive mechanised production, while nonadopters remain embedded in labour- and animal-based systems that may limit longterm productivity growth. These are critical but distinct components of smallholder maize farming in Africa (Mugabe and Ferrara, 2025). Mechanisation (tractors) clearly offers efficiency and higher productivity for adopters, while animal-drawn power remains crucial for non-adopters, potentially due to lower initial costs and accessibility.

Hired labour, family labour, and farm organisation are critical components of smallholder agriculture, and each has a distinct but often interconnected role in ensuring productivity and income generation among smallholder farmers (Zantsi, 2024). Smallholder farms are predominantly characterised by their reliance on family labour to manage costs (Msomi and Zenda, 2024). Nevertheless, from these results, it is clear that hired labour is significantly preferred to augment GM technology adoption. This may be attributed to the requirements of highly specialised tasks such as tractor operation for pesticide application and conventional ploughing, which require specialised or trained labour. Hired labour displayed a stronger elasticity among adopters (0.13) compared to non-adopters (0.07). This may reflect better task knowledge, skilled labour placement, and stronger managerial oversight in adopter farms. This is consistent with the suggestion of Ngqulana et al. (2025) that intensive farming practices required for GM maize include specialised knowledge. In contrast, family labour shows a larger elasticity among non-adopters (0.14) than adopters (0.10), highlighting the subsistence-oriented nature of non-adopting farmers. For these farmers, family labour constitutes the backbone of production, compensating for limited access to capital-intensive technologies. While family labour contributes meaningfully to output, its higher elasticity among non-adopters may also signal labour-intensive production practices that are not complemented by productivityenhancing inputs, potentially limiting overall efficiency gains. These results are in line with the findings of Kostov et al. (2019), who found no positive output effects of using family labour on farms.

The coefficient on farm organisation further highlights the importance of institutional and managerial structures in driving productivity. The positive and significant elasticity among adopters (0.07) and in the pooled sample (0.06)

suggests that structured farm management, formalised production planning, and stronger market integration positively influence output performance. The insignificant effect among non-adopters (0.04) indicates that organisational improvements alone may not translate into productivity gains without complementary technological and capital inputs. This underscores the interdependence between managerial capacity and technological adoption; effective farm organisation amplifies the benefits of modern inputs but cannot fully substitute for them in low-technology systems.

The returns to scale estimates merge the structural description emerging from the elasticity results. Adopters exhibit increasing returns to scale (1.03), indicating that a proportional increase in all inputs leads to a more than proportional increase in output. This reflects efficiency gains arising from input complementarities, technological synergy, and better management. In contrast, non-adopters face decreasing returns to scale (0.91), indicating diminishing marginal productivity when scaling up inputs within traditional production frameworks. The pooled sample shows near-constant returns to scale (0.99), which masks the internal heterogeneity between the two groups. Collectively, these findings demonstrate that technology adoption, labour structuring, and farm organisation jointly shape the productivity frontier, positioning adopters within a more dynamic and efficiency-enhancing production regime compared to non-adopters.

7.4.4 Implications of Adoption on Productivity and Agribusiness

The adoption of improved maize technologies, particularly GM (HT/BT) and GM (BT) seed cultivars, has significant implications for productivity in smallholder farming systems. The Cobb–Douglas elasticity results indicate that adopters experience higher responsiveness to critical yield-enhancing inputs such as improved seeds, fertilisers, and pesticides, translating into higher output gains relative to non-adopters. Specifically, the higher elasticity of GM (HT/BT) seeds (0.14) among adopters demonstrates that genetic improvements directly augment productivity by enhancing resistance to pests and weeds, improving plant strength, and reducing production risk. This technological edge allows adopters to achieve higher multi-factor productivity (MFP = 8.35) compared to

non-adopters (MFP = 7.02), reflecting more efficient use of combined inputs and optimal allocation of resources.

From an agribusiness perspective, technology adoption enhances commercial viability and creates opportunities for scaling production. Higher returns to scale among adopters (1.03) suggest that expanding input use (including land, mechanisation, and hired labour) yields more than proportional increases in output, supporting economies of scale. This efficiency gain has direct implications for the supply chain, as it enables adopters to produce surplus maize for markets, engage in value-adding activities, and establish stronger linkages with input suppliers, agro-processors, and buyers. In contrast, non-adopters, operating under decreasing returns to scale (0.91), face constraints in expanding production efficiently, limiting their ability to participate competitively in agribusiness markets. Therefore, technology adoption acts as a key driver of both farm-level productivity and market-oriented agricultural growth.

Moreover, the interplay between technology adoption, labour use, and farm organisation has broader implications for rural agribusiness development. Adopters rely more on hired labour (elasticity = 0.13) and structured farm management (elasticity = 0.07), indicating a transition toward professionalised and marketresponsive production systems. This shift fosters employment opportunities, enhances managerial capacity, and strengthens the link between smallholder farmers and agribusiness value chains. The increased productivity and efficiency from adopting modern technologies can catalyse investment in mechanisation, input procurement, and storage infrastructure, thereby reinforcing the sustainability and competitiveness of smallholder agribusinesses. Inclusive promotion of technology adoption among farmers is essential not only for improving yields but also for stimulating rural economic development and integrating smallholders into formal agricultural markets.

7.5 Conclusions and Recommendations

The study investigated genetically modified maize seed adoption on Input elasticities and productivity among smallholder farming systems in Eastern Cape Province of South Africa. The study employed Cobb-Douglas analysis to estimate input elasticities among maize farmers. The descriptive statistics results showed substantial and statistically significant variation in production levels between adopters and nonadopters. Adopters cultivated larger maize areas (9.19) than non-adopters (1.80). This suggests that farmers with bigger areas of land stand a greater potential in increasing total maize production as they might have more available land, which allows them to invest more in improved technologies. Furthermore, the results revealed that there was a greater variation in input use among farmers, with adopters applying more quantities of seeds and fertiliser compared to non-adopters. While the number of labourers used per hectare was greater for adopters at 7.90 man-days, non-adopters had 4.49 man-days. Most importantly, the study revealed larger maize outputs of 6472.74 compared to those of non-adopters, 2800.42 kg/ha. This huge gap depicts the potential of technology adoption for on-farm performance, and that technology adoption may be associated with high input utilisation, which significantly improves farm productivity.

The Cobb-Douglas Estimates revealed that land remains an important determinant of maize across all groups; estimates were higher among non-adopters compared to adopters, implying that non-adopters relied more heavily on land expansion to increase their maize output. Though adopters showed a slightly lower land elasticity, they had greater responsiveness to yield-enhancing inputs such as fertilisers and improved seeds. Hence, the study revealed a markedly higher technical efficiency among adopters (γ =0.75) than non-adopters (γ = 0.60), with the adopters operating under constant returns to scale and non-adopters under decreasing returns. Therefore, the study recommends the promotion of technology adoption programs, since GM adopters exhibited greater responsiveness to yield-enhancing inputs and had higher technical efficiency than their counterparts. This requires extension services to prioritise the scaling up of the adoption of GM technologies, especially the GM (HT/BT),

which is resistant to both herbicides and diseases, including fertilisers and other production technologies. These programs should utilise on-farm demonstration plots, farmer-field schools, including hands-on training, which might encourage the adoption and the proper use of inputs. Furthermore, policymakers should develop policies that will encourage the optimisation of inputs rather than land expansion. This can be implemented by ensuring that extension programs educate smallholder farmers on optimal input combinations and usage to ensure the maximisation of productivity per hectare instead of simply expanding the cultivated area. Such an approach might help move smallholder farm systems from extensive to intensive production, which would help improve the overall efficiency and sustainability of maize in the Eastern Cape Province. Lastly, improving farmer access to both production credits and input markets would be significant, as this would allow farmers to invest more in production inputs such as fertilisers and improved seeds.

References

Alaghehband, F.K., Rivard, S., Wu, S. and Goyette, S., 2011. An assessment of the use of transaction cost theory in information technology outsourcing. *The Journal of Strategic Information Systems*, *20*(2), pp.125-138.

Ala-Kokko, K., Nalley, L.L., Shew, A.M., Tack, J.B., Chaminuka, P., Matlock, M.D. and
D'Haese, M., 2021. Economic and ecosystem impacts of GM maize in South Africa. *Global Food Security*, *29*, p.100544.

Allotey, S.S.K. and Adraki, P.K., 2018. The influence of socio-economic factors on uptake of rhizobia inoculant technology in the northern region.

Apanovich, N. and Nyairo, R., 2025. Dominant smallholder farming system typologies in Southcentral Uganda and their food security status. *Agriculture & Food Security*, *14*(1), p.17.

Aramburu-Merlos, F., Tenorio, F.A., Mashingaidze, N., Sananka, A., Aston, S., Ojeda, J.J. and Grassini, P., 2024. Adopting yield-improving practices to meet

maize demand in Sub-Saharan Africa without cropland expansion. *Nature communications*, *15*(1), p.4492.

Bekker, S., 2000. Diminishing returns: circulatory migration linking Cape Town to the Eastern Cape. *Southern african journal of demography*, *8*(1), pp.1-8.

Berhanu, A.A., Ayele, Z.B. and Dagnew, D.C., 2024. Impact of climate-smart agricultural practices on smallholder farmers' resilience in Ethiopia. *Journal of Agriculture and Food Research*, *16*, p.101147.

Buso, S., Nakin, M.D.V., Abraham, A. and Musampa, C.M., 2015. Environmental and community impacts of waste disposal in OR Tambo District Municipality (South Africa). *WIT Transactions on Ecology and the Environment*, *193*, pp.509-520. https://doi.org/10.2495/SDP150441

Byerlee, D., Stevenson, J. and Villoria, N., 2014. Does intensification slow crop land expansion or encourage deforestation?. *Global food security*, *3*(2), pp.92-98.

Carelsen, C.P.R., Ncube, B. and Fanadzo, M., 2021. Classification and characterisation of smallholder farmers in South Africa: a brief review. *South African*
Journal of Agricultural Extension, *49*(2), pp.97-106. https://doi.org/10.17159/2413-3221/2021/v49n2a12821

Chimonyo, V.G.P., Mutengwa, C.S., Chiduza, C. and Tandzi, L.N., 2020. Characteristics of maize growing farmers, varietal use and constraints to increase productivity in selected villages in the Eastern Cape province of South Africa. *South African Journal of Agricultural Extension*, *48*(2), pp.64-82.

Daksa, T.W., 2024. Review of Foods from Genetically Modified Agricultural Products. *Journal of Chemical and Biomedical Engineering,* 10 (4), pp.27-42.

Davis, B., de la O Campos, A.P., Farrae, M. and Winters, P., 2024. Whither the agricultural productivity-led model? Reconsidering resilient and inclusive rural transformation in the context of agrifood systems. *Global Food Security*, *43*, p.100812.

Desta, S., 2025. Technical efficiency of teff production: the case of Mareka district in Dawuro Zone, Southwestern Ethiopia. *Int J Appl Agric Sci*, *11*(2), pp.29-38.

Dethier, J.J. and Effenberger, A., 2012. Agriculture and development: A brief review of the literature. *Economic systems*, *36*(2), pp.175-205.

Dodson, L., 2025. Adoption of genetically engineered crops in the united states— recent trends in GE adoption'United States Department of Agriculture. *Economic Research Service*.

Environmental and Tourism Services. 2022. *Chris Hani District Municipality: Environmental Management Framework – Draft Literature Review Report*. Chris Hani District Municipality, Eastern Cape, South Africa.

Fadeyi, O.A., Ariyawardana, A. and Aziz, A.A., 2022. Factors influencing technology adoption among smallholder farmers: a systematic review in Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *123*(1), pp.13-30.

Fanadzo, M., 2010. Improving productivity of maize-based smallholder irrigated cropping systems: a case study of Zanyokwe Irrigation Scheme, Eastern Cape, South Africa.

Food and Agriculture Organization, 2024. *FAO adds to data coverage of employment in agrifood systems*. Available at: https://www.fao.org/newsroom/detail/faostat-afsemployment-data/ (Accessed online: 11 April 2026).

Gautam, S., 2024. Understanding Cobb-Douglas production function in agricultural economics. *Journal of Technology & Innovation*, *4*(2), pp.75-78.

Gcaba, K., Christian, M. and Usapfa, L., 2024. Does the adoption of genetically modified seeds improve the technical efficiency of family-owned maize farms? A case of Alfred Nzo In The Eastern Cape. *South African Journal of Agricultural Extension*, *52*(4), pp.148-165.

Gunya, B., Mlisa, N.L. and Muchenje, V., 2014. Seasonal effects on village chicken flock dynamics in the Chris Hani Municipality, Eastern Cape Province of South Africa.

Inwood, S.M. and Sharp, J.S., 2012. Farm persistence and adaptation at the rural– urban interface: Succession and farm adjustment. *Journal of Rural Studies*, *28*(1), pp.107-117.

Jolex, A., 2022. Influence of agricultural extension services on technical efficiency of maize farmers in Malawi. *African Journal of Agricultural and Resource Economics*, *17*(1), pp.92-105.

Kapari, M., Hlophe-Ginindza, S., Nhamo, L. and Mpandeli, S., 2023. Contribution of smallholder farmers to food security and opportunities for resilient farming systems. *Frontiers in Sustainable Food Systems*, *7*, p.1149854. https://doi.org/10.3389/fsufs.2023.1149854

Kerorsa, G.M., 2025. Determinants of technical efficiency among smallholder maize producing farmers in Guto Gidda district, Oromia, Ethiopia. *Discover Global Society*, *3*(1), pp.1-24.

Kiggundu, S.N. 2009. *Water Quality Monitoring in the Eastern Cape: A Case Study of the Chris Hani District Municipality*. MSc Eng thesis, University of Cape Town. http://hdl.handle.net/11427/11846

Kirui, O., 2019. The complementarity of education and use of productive inputs among smallholder farmers in Africa. *ZEF-Discussion Papers on Development Policy*, (277).

Kom, Z., Nethengwe, N.S., Mpandeli, N.S. and Chikoore, H., 2022. Determinants of small-scale farmers' choice and adaptive strategies in response to climatic shocks in Vhembe District, South Africa. *GeoJournal*, *87*(2), pp.677-700.

Kostov, P., Davidova, S. and Bailey, A., 2018. Effect of family labour on output of farms in selected EU Member States: a non-parametric quantile regression approach. *European Review of Agricultural Economics*, *45*(3), pp.367-395.

Kotey, D.A., Assefa, Y. and Van den Berg, J., 2017. Enhancing smallholder farmers' awareness of GM maize technology, management practices and compliance to stewardship requirements in the Eastern Cape Province of South Africa: the role of public extension and advisory services. *South African Journal of Agricultural Extension*, *45*(2), pp.49-63.

Lutonja, E., 2023. Technical efficiency of smallholder farmers in Tanzania: A stochastic frontier approach. *Asian Journal of Agricultural Extension, Economics & Sociology*, *41*(12), pp.89-105.

Mamashila, M.J., Antwi, M.A. and OS, O., 2025. Technical and Allocative Efficiency Challenges Smallholder Maize Farmers Face in Limpopo Province, South Africa. *Afr. J. Food Agric. Nutr. Dev*, *25*(8), pp.27491-27508.

Manda, J., Khonje, M.G., Alene, A.D., Tufa, A.H., Abdoulaye, T., Mutenje, M., Setimela, P. and Manyong, V., 2020. Does cooperative membership increase and accelerate agricultural technology adoption? Empirical evidence from Zambia. *Technological forecasting and social change*, *158*, p.120160.

Mansor, S.S., Nor, K.N.M. and Fatah, F.A., 2024. Determinants of Technical Efficiency among Rubber Smallholders Production in Lipis, Pahang: a Cobb-Douglas Stochastic Frontier Production Approach. *International Journal of academic research in business and social sciences*, *14*(9).

Maponya, P., Madakadze, C., Mbili, N., Dube, Z., Nkuna, T., Makhwedzhana, M., Tahulela, T. and Mongwaketsi, K., 2023. Potential constraint of rainfall availability on the establishment and expansion of agroforestry in the Joe Gqabi, Alfred Nzo and OR
Tambo Districts, Eastern Cape in South Africa. In *Agricultural Bioeconomy* (pp. 121-
141). Academic Press. https://doi.org/10.1016/B978-0-323-90569-5.00009-3

Mdiya, L., Shiba, W.T., Mdoda, L. and Van Niekerk, J., 2025. Assessing the Role of Smallholder Livestock Farmers on Rural Household Food Security: Experiences from Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, *53*(3), pp.96-110.

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D., 2025. Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis. *GM Crops & Food*, *16*(1), pp.272-304.

Miehe, C., Nabwire, L., Sparrow, R., Spielman, D.J. and Van Campenhout, B., 2025. Miracle seeds: Biased expectations, complementary input use, and the dynamics of smallholder technology adoption. *Economic Development and Cultural Change*, *74*(1), pp.305-334.

Mpundu, M. and Bopape, O., 2022. Analysis of farming contribution to economic growth and poverty alleviation in the South African economy: A sustainable development goal approach. *International Journal of Economics and Financial Issues*, *12*(5), pp.151-159.

Msomi, L. and Zenda, M., 2024. An analysis of challenges facing smallholder crop farmers and informal food traders in the agri-food value chain in Gauteng Province, South Africa. *South African Journal of Agricultural Extension*, *52*(2), pp.120-144.

Mthi, S., Thubela, T., Mgujulwa, N., Rumosa-Gwaze, F., Jokana, N., Ntsabo, T., Mfono, A. and Tokozwayo, S., 2023. Perceived training needs among livestock farmers in the North Eastern region of the Eastern Cape province: A case of Ugie commonage. *Appl. Anim. Husb. Rural Dev*, *16*(6), pp.1-6.

Mugabe, D. and Ferrara, G., 2025. Harnessing draft animal power: boosting efficiency in smallholder conventional farming. *Applied Economics*, pp.1-14.

Mujuru, N.M. and Obi, A., 2020. Effects of cultivated area on smallholder farm profits and food security in rural communities of the Eastern Cape Province of South Africa.
Sustainability, *12*(8), p.3272.

Nanda, M. and Ghosh, S., 2025. How does male out-migration impact the lives of leftbehind women? Trade-off between feminization of agriculture and empowerment of farm women. *Evaluation and Program Planning*, *111*, p.102603.

Ndlovu, P.N., Thamaga-Chitja, J.M. and Ojo, T.O., 2024. Drivers of the level of market participation among smallholder urban vegetable farmers in KwaZulu-Natal, South Africa. *Cogent Food & Agriculture*, *10*(1), p.2437139.

Ngeno, V., 2024. *Profit efficiency among Kenyan maize farmers. Heliyon 10: e24657* [online].

Ngqulana, A., Oladele, O.I., Mdoda, L., Nontu, Y. and Mdiya, L., 2025. A Systematic Review on Enhancing the Technical Efficiency of Genetically Modified Maize Adoption in Sub-Saharan Africa: The Role of Agricultural Extension Services and Barriers to
Success. Frontiers in Sustainable Food Systems, 9, p.1609417. http://dx.doi.org/10.3389/fsufs.2025.1609417

Nkamisa, M., Ndhleve, S., Nakin, M.D., Mngeni, A. and Kabiti, H.M., 2022. Analysis of trends, recurrences, severity and frequency of droughts using standardised precipitation index: Case of OR Tambo District Municipality, Eastern Cape, South Africa. *Jàmbá-Journal of Disaster Risk Studies*, *14*(1), p.1147. https://doi.org/10.4102/jamba.v14i1.1147

Obalola, O.T., Obayelu, A.E., Coster, A.S. and Alarima, C.I., 2025. Comparing Cobb– Douglas and translog stochastic frontier models for estimating technical efficiency in rice farming in Northwestern Nigeria. *SN Business & Economics*, *5*(6), p.73.

Ogujiuba, K., Agholor, A.I. and Olamide, E., 2021. Impact of sustainable entrepreneurial indicators on SMEs business success in South Africa. *Academy of Entrepreneurship Journal*.

Röös, E., Mie, A., Wivstad, M., Salomon, E., Johansson, B., Gunnarsson, S., Wallenbeck, A., Hoffmann, R., Nilsson, U., Sundberg, C. and Watson, C.A., 2018. Risks and opportunities of increasing yields in organic farming. A review. *Agronomy for sustainable development*, *38*(2), p.14.

Shelton, A.M., Romeis, J. and Kennedy, G.G., 2008. IPM and insect-protected transgenic plants: thoughts for the future. *Integration of insect-resistant,*

genetically modified crops within IPM programs. Springer, Dordrecht, pp.419-429.

Sibanda, M., Mushunje, A. and Mutengwa, C.S., 2016. An evaluation on the profitability of growing improved maize open pollinated varieties in the Eastern Cape Province, South Africa. *Journal of Development and Agricultural Economics*, *8*(1), pp.1-13.

Sigigaba, M., Mdoda, L. and Mditshwa, A., 2021. Adoption drivers of improved OpenPollinated (OPVs) maize varieties by smallholder farmers in the Eastern Cape province of South Africa. *Sustainability*, *13*(24), p.13644.

Sinyolo, S., 2020. Technology adoption and household food security among rural households in South Africa: the role of improved maize varieties. *Technology in Society*, *60*, p.101214.

Taruvinga, A., Kambanje, A., Mushunje, A. and Mukarumbwa, P., 2022. Determinants of livestock species ownership at household level: Evidence from rural OR Tambo District Municipality, South Africa. Pastoralism, 12(1), pp.1-11. https://doi.org/10.1186/s13570-021-00220-6

Thabane, V.N., Agholor, I.A., Sithole, M.Z., Morepje, M.T., Msweli, N.S. and Mgwenya, L.I., 2024. Socio-Demographic determinants of Climate-Smart agriculture adoption among smallholder crop producers in Bushbuckridge, Mpumalanga Province of South Africa. *Climate*, *12*(12), p.202.

Thibane, Z., Mdoda, L., Gidi, L. and Mayekiso, A., 2023. Assessing the venturing of rural and peri-urban youth into micro-and small-sized agricultural enterprises in the Eastern Cape Province, South Africa. *Sustainability*, *15*(21), p.15469.

Tiwari, P. and Park, K.I., 2024. Seed biotechnologies in practicing sustainable agriculture: Insights and achievements in the decade 2014–2024. *Applied Sciences*, *14*(24), p.11620.

Tong, T., Ye, F., Zhang, Q., Liao, W., Ding, Y., Liu, Y. and Li, G., 2024. The impact of labor force aging on agricultural total factor productivity of farmers in China: Implications for food sustainability. Frontiers in Sustainable Food Systems, 8, p.1434604.

Twalo, T., 2025. Water sector value chain challenges: The case of Chris Hani District

Municipality. *Africa's Public Service Delivery and Performance Review*, *13*(1), p.870.

https://doi.org/10.4102/apsdpr.v13i1.870

Ullah, A.A., 2017. Male migration and 'left–behind'women: Bane or boon?. *Environment and Urbanization ASIA*, *8*(1), pp.59-73.

Williams, D.J., 2025. *Addressing the Leaky Pipeline: Perspectives from Secondary Educators* (Master's thesis, North Carolina Agricultural and Technical State University).

Yogi, V. and Kumari, V., 2024. Instability Analysis and Decomposition of Output of Major Oilseeds Crops in Rajasthan and India. *Journal of Scientific Research and Reports*, *30*(10), pp.1021-1030.

Zantsi, S., 2024. Agricultural labour dynamics in small-scale farming systems in rural South Africa. *Development in Practice*, *34*(4), pp.426-436.

Zhang, Q., Dong, W., Wen, C. and Li, T., 2020. Study on factors affecting corn yield based on the Cobb-Douglas production function. *Agricultural Water Management*, *228*, p.105869.

CHAPTER 8
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 Introduction

This chapter presents the overall summary of the current study. It presents the key results of the study, conclusions, and recommendations based on the aim and the study objectives.

8.2 Study Summary

Maize is among the most significant crops grown and consumed worldwide and is a key contributor to the economy of South Africa, as it creates employment and provides food to both humans and animals. This crop is significant as it is one of the human food crops, as it contributes to over 20% of food calories. In South Africa, maize is mainly cultivated under rain-fed conditions for human consumption, animal feed, and income generation, and it covers about 90% of the total production area. The crop is mostly produced by the poor in rural areas and is regarded as a key crop for sustainable livelihoods. Despite the important contribution of the maize crop in South Africa, its productivity remains relatively very low. Smallholder maize farmers continue to experience low productivity and unstable incomes despite the availability of improved maize varieties and production technologies. A major contribution to these constraints is that smallholder farmers continue to use traditional maize varieties, which are characterized by poor yields, are prone to pests and diseases, and are poorly adapted to climate variability.

In response, Genetically Modified (GM) maize seeds have been promoted as productivity-enhancing technologies that reduce production risks and improve farm incomes, positioning South Africa as a continental leader in agricultural biotechnology and a signatory to international agreements such as the Chatham Convention on the use of GMOs. Despite this enabling policy environment, the adoption of GM crops in South Africa remains relatively slow, particularly among smallholder farmers. Therefore, the introduction of agricultural extension programs through agricultural extension advisory services can be one of the

main conduits of addressing the issue of the adoption of GM seeds. Agricultural extension can be described as a rural development strategy that depends on non-formal education and a traditional curriculum, which is closely linked with both applied and academic agricultural research.

The main objective of the study was to evaluate the impact of agricultural extension services on the technical efficiency of maize farmers. This study was quantitative in nature and employed the cross-sectional research design. This research design was chosen because it allowed the collection of primary data from a large number of farmers at a single point in time, which made it the most efficient and cost-effective research design. The study used a multi-stratified sampling method with three stages to select 306 maize farmers in Chris Hani and OR Tambo District Municipalities. The first stage was to select the district, local municipalities, and wards purposefully. The second stage was to stratify the smallholder maize farmers into strata: A crop farmers (maize), B livestock farmers, and C mixed farmers, with strata being selected. The last stage was to randomly select the smallholder maize farmers in the areas.

Descriptive statistics were used to describe the demographic characteristics of the farmers, while the econometric models were employed to analyse the study objectives. The gender distribution of maize farmers, which reveals notable patterns. The overall sample indicates that 43.1% were males compared to 56.9% females. The overall pool showed that 39.5% of the adopters and non-adopters had primary, 33.7% had secondary, 12.1% tertiary, and only 14.7% of the adopters and non-adopters had no formal education. The maize farmers had spent 7 years on schooling, which in the South African education system is primary education. Farmers were old, with 61 years. The results for household size indicated a mean household size of 8.19 members, which indicates a larger household size. The farmers had larger land sizes with a mean land size of 8.42hectares.

Grounded in the Technology Acceptance Model [TAM], the Diffusion Theory, the Scaling Theory, and the Double-Hurdle Model using Probit regression and truncated regression. The study investigated the determinants and Intensity of GM Maize Seed use among maize farmers in the Eastern Cape Province, South

Africa. The probit regression model revealed several factors that influenced adoption, such as gender, years spent in school, marital status, household size, household monthly income, land size, access to extension services, and amount of credits, which were positively influencing the adoption of GM maize seeds by farmers, while distance to markets was negatively associated with the adoption of GM seeds. The second hurdle revealed that household size, household income, land size, and credits positively influenced both adoption and adoption intensity, and distance to markets was negatively associated with both adoption and intensity of adoption of GM maize seeds. Highlighting the importance of these factors in the entire adoption process in the study area.

Furthermore, the study assessed the productivity effects of agricultural extension on smallholder maize efficiency in the Eastern Cape Province, South Africa. To achieve this, the stochastic frontier analysis, endogenous switching regression, and a stochastic meta-frontier framework were employed. The Stochastic Frontier Production model revealed that the mean technical efficiency of farmers was 0.71, which was moderate. This means that the maize farmers were producing below the production frontier. The logit regression model revealed that access to extension services was positively influenced by household size, school years, average household income, credit access, years of maize farming, membership in organizations, and access to markets. The results from the Endogenous Switching Regression (ESR) model showed that having access to agricultural extension services had a significant and positive effect on maize productivity among farmers. Consequently, the results demonstrate that farmers who participated in extension programs benefited from improved technical knowledge and management capacity, which translates into higher maize productivity. Furthermore, a mean comparison test was conducted between farmers who had access to extension services and those who did not. The mean test results showed that farmers who received extension services had higher technical efficiency than those who did not, suggesting that they were closer to achieving maximum output from the available resources.

Further analysis unpacked the smallholder maize farmers' preferences for genetically modified maize seeds in the Eastern Cape Province, South Africa.

The study adopted both the Theory of Planned Behaviour [TPB] and Diffusion Theory and employed a multinomial regression model. Farmers' seed choices included GM (HT/BT), GM (BT), and traditional maize. The multinomial regression analysis revealed that the adoption of Genetically Modified maize seeds (BT/HT) was influenced by household age, education, income, years of maize farming, and organizational membership, which positively influenced both GM (HT/BT) and GM (BT) selection. In contrast, extension services and credit access influenced GM (HT/BT) adoption only. This implies that GM seeds (HT/BT) require more resources and knowledge than GM (BT).

The study further investigated the productivity-profitability trade-offs and the welfare effects of GM maize adoption among smallholder systems in the Eastern Cape

Province, South Africa. The Probit regression model and the Propensity Score Matching [PSM] were used to achieve the study objective. The farmers utilise a range of maize seed varieties, such as GM (HT/Bt) with both herbicide and insect tolerance, GM (Bt), which are tolerant to pests and diseases, and the traditional maize varieties, which are mostly recycled from the previous growing season. The results from the Probit regression model revealed that the adoption of GM maize seeds was influenced by several factors, such as gender, years spent in school, marital status, household size, household monthly income, land size access to extension services, amount of credits were positively influencing the adoption of GM maize seeds by farmers, while distance to markets was negatively associated with adoption of GM seeds. While the results from the PSM revealed. The findings of the study revealed a strong and statistically significant effect of GM maize seed adoption on both productivity and economic outcomes. Across both matching approaches, adopters consistently achieve higher maize yields compared to non-adopters, confirming the productivity-enhancing nature of GM technology. While from the economic perspective, the results show that adopters earned significantly higher farm income, with gains of under Nearest Neighbor and Kernel matching, respectively.

Moreover, the study assessed the adoption of genetically modified maize seed on input elasticities and productivity among smallholder farming systems from the Eastern Cape

Province, South Africa. Analytical methods included descriptive statistics and a Cobb-Douglas Stochastic Production Frontier (SPF) approach. The results revealed that adopters cultivated larger farm areas, applied higher quantities of improved seed and fertilizer, and allocated more labour, achieving higher yields on average compared to non-adopters. SPF results indicated that adopters revealed significantly higher input elasticities for seed and fertiliser, while non-adopters showed limited responsiveness to modern inputs. Technical efficiency was markedly higher among adopters than among non-adopters, with adopters operating under constant returns to scale and non-adopters under decreasing returns to scale. These findings demonstrate that GM maize adoption enhances input efficiency, boosts productivity, and provides a pathway for sustainable intensification of smallholder maize systems.

Constituents of the Philosophy of the PhD

The current study makes an original contribution to knowledge by providing a comprehensive empirical assessment of the role of agricultural extension services in influencing the adoption of genetically modified (GM) maize seeds and improving the technical efficiency, productivity, profitability, and welfare of smallholder maize farmers in the Eastern Cape Province of South Africa. Unlike previous studies that examined these issues separately, this research integrates multiple theoretical frameworks, including the Technology Acceptance Model (TAM), Diffusion Theory, the Theory of Planned Behaviour (TPB), Scaling Theory, and the Double-Hurdle Model, to provide a holistic understanding of farmers' adoption behaviour. Furthermore, the study applies a combination of advanced econometric techniques, including the Double-Hurdle Model, Stochastic Frontier Analysis, Endogenous Switching Regression, Stochastic Meta-Frontier Analysis, Propensity Score Matching, Multinomial Regression, and the Cobb-Douglas Stochastic Production Frontier, enabling a robust evaluation of the relationships between extension services, GM maize adoption, technical efficiency, productivity, and welfare outcomes. The findings generate

new empirical evidence demonstrating that agricultural extension services significantly enhance farmers' access to modern technologies, improve technical efficiency, strengthen input use efficiency, increase productivity and farm income, and ultimately contribute to the sustainable intensification of smallholder maize production systems. These contributions provide a stronger evidence base for agricultural policy and extension programme design aimed at improving food security and the livelihoods of smallholder farmers in South Africa.

Based on the findings of the study, the following recommendations have been proposed to improve the impact of agricultural extension services on the technical efficiency of adopters and non-adopters of genetically modified maize in the Eastern Cape Province.

- The study recommends that the expansion and adequate funding of agricultural extension services, with a specific focus on GM crop management and biosafety, be implemented in the study area. This can be done through initiatives such as farmer field schools and method demonstrations to improve awareness and practical understanding of GM maize by farmers. Furthermore, the extension practitioners in the study area can also improve access to production credits and financial resources of the farmers through the facilitation of many affordable agricultural credit schemes that are tailored to smallholder farmers. There is also a need to invest in building rural roads and infrastructure, as this will help reduce transportation costs while also improving market connectivity among farmers in the area.
- The study recommends that the Eastern Cape Department of Agriculture and agricultural institutions should develop policies to scale the impact, improve access, and strengthen the agricultural extension services and further increase farmer participation in these services, especially for poor resource farmers with limited access to agricultural information. These services can be improved by encouraging extension officers to offer flexible training schedules for farmers and by implementing mobile-based agricultural services, which can help reach and spread services to even the most remote rural areas and communities. Furthermore, increasing

the number of extension officers and improving their reach will help reduce the gap between farmers and advisory services in the Eastern Cape Province. This can be done by training lead farmers, who then assist extension officers in delivering the services, and this will encourage farmer-to-farmer extension. Policies should further be designed to support broader productivity and technical efficiency goals of the farmers instead of focusing on merely the adoption of improved technologies and practices.

- The study further recommends that policymakers improve and expand agricultural extension programs, which will focus on training farmers in agronomic practices that will help in the use of GM (BT/HT) in the study area. Furthermore, extension practitioners in the Eastern Cape should target both experienced farmers and new farmers and make sure to emphasize the benefits of disease-resistant and herbicide-tolerant varieties.
- Based on the strong and statistically significant effect of GM seed adoption on productivity and farm returns, there is a clear and pressing need to expand and enhance access to GM maize seed varieties in the study area. Government and developmental agencies should ensure that they strengthen certified seed systems through supporting local seed development and distribution networks by partnering with the existing private seed enterprises. Furthermore, the extension practitioners in the study must ensure timely availability and access to affordable and high-quality seed, and this will result in more maize farmers benefiting from the GM technology.
- The study recommends the promotion of technology adoption programs, since GM adopters exhibited greater responsiveness to yield-enhancing inputs and had higher technical efficiency than their counterparts. This requires extension services to prioritise the scaling up of the adoption of GM technologies, especially the GM (HT/BT), which is resistant to both herbicides and diseases, including fertilisers and other production technologies. These programs should utilise on-farm demonstration plots, farmer-field schools, including hands-on training, which might encourage

the adoption and the proper use of inputs. Furthermore, extension practitioners should encourage the optimisation of inputs rather than land expansion. This can be implemented by ensuring that extension programs educate smallholder farmers on optimal input combinations and usage to ensure the maximisation of productivity per hectare instead of simply expanding the cultivated area.

8.3 The Limitations of the Study

This study was limited to only two districts of the Eastern Cape Province, which are the Chris Hani and OR Tambo Districts. Therefore, the findings of this study cannot be generalized to all other districts in the Eastern Cape Province. Time constraints were identified as one of the limitations, as the study was conducted at a single point in time and over a short period of time, which limited the observability of long-term effects. The study was conducted on smallholder maize farmers and was only conducted on maize farmers and excluded other commodities. Furthermore, the scale and scope of data collection were influenced by financial constraints, which may have influenced the depth and representativeness of the findings. Despite the abovementioned limitations, the researcher made every effort to ensure the reliability, including the validity of the study findings, through a proper sampling method, use of structured questionnaires, and the adoption of appropriate theories and econometric techniques.

8.4 Future Research Focus

While the current study provides significant empirical evidence on the positive impact of agricultural extension services on the technical efficiency of maize farmers, several areas need further investigation to deepen understanding and strengthen policy significance.

- Future studies could adopt a longitudinal approach, which will allow to collect long-term effects of agricultural extension services. The current study employed a cross-sectional approach, and this limited the ability to

observe changes over time, which would help establish stronger causal relationships. Therefore, a longitudinal approach will be important in tracking the temporal dynamics, assessing causal pathways, and assessing the long-term effects, which cannot be observed within a single time frame.

- Future studies could also look at examining the quality of agricultural extension services and their impact on shaping the technical efficiency and GM adoption by smallholder farmers. This would be important to check whether improvements in the quality of extension delivery led to a more sustained behavioural change and productivity gains among smallholder farmers, and not short-term effects.
- Future studies can also expand the geographical scope of the study and expand it and be conducted in other provinces to enhance the generalizability of findings.

Appendix I: Questionnaire
UNIVERSITY OF KWAZULU-NATAL

School of Agricultural, Earth and Environmental Sciences

College of Agriculture, Engineering and Science

SURVEY QUESTIONNAIRE



You are invited to participate in a research project being conducted by Athenkosi Ngqulana, a PhD student at the School of Agricultural, Earth and Environmental Sciences College of Agriculture, Engineering and Science at the University of KwaZulu Natal, Pietermaritzburg Campus. The purpose of this research is to find out the impact of agricultural extension services on technical efficiency of adopters and non-adopters of genetically modified maize in the Eastern Cape Province.

All information gathered for this study will be kept confidential and participation by all interviewees is voluntary.

By signing below: I indicate that I have read and understood the information above and agree to participate in the research study and give my consent for the researcher to collect and use my data for the purpose of this study

Signature _____ Date: _____

General information:

Questionnaire Number	
District Name	
Village Name	
Date of Interview	

Instructions:

Please tick the appropriate Box

SECTION A

DEMOGRAPHIC CHARACTERISTICS OF THE FARMER

Household Head Gender	0 = Male		1= Female		3= Other			
Household Head Age (actual years)	.....							
Educational Level	0 = No Formal		1 = Primary		2 = Secondary		3 = Tertiary	
Number of years spent at school (actual years)	.....							
Marital Status	0 = Married		1 = Single		2 = Divorced		3 = Widowed	
Household Size (actual number)	……..							
Number of children	……..							
Employment Status	0 = Employed		1 = Self Employed		2 = Unemployed		3 = Retired	
Secondary income generating activity	Civil service		Hawker		Other …….			
Average Household Monthly Income (Rands)	.....							

Sources of Income (*Please tick)*	Farming		Salaries and Wages		Retirement pension		Remittances		Other
	Yes	No	Yes	No	Yes	No	Yes	No	…….
Do you have access to land?	Yes		No						
If yes, what type of land do you have access to?	Own land		Leased		Communal land		Other …….		
How much land do you have access to?	……								
Do you have access to credits?	Yes		No						
If yes, how much did you receive?	……								

Who is the source of credits (*Please tick Yes/No)*	Government agencies		Commercial Banks		Cooperatives		Relatives		Money landers		Other
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	……
Indicate the purpose of the credits?	Purchase seeds		Pay labour		hire tractor		Purchase fertilizer		Other (specify)		
	Yes	No	Yes	No	Yes	No	Yes	No	……..		
What is the distance to the credits source? (km)	Less than 10Km		10 Km		Greater than 10km						
	Yes	No	Yes	No	Yes	No					
If no what makes you not to access the credits? *(Please tick Yes/No)*	Don't have a collateral		Not eligible		No facilities Available		Other ……..				
	Yes	No	Yes	No	Yes	No					

Do you have access to infrastructure in your farm?	Yes		No									
If yes, what type of infrastructure do you have access to? *(Please tick Yes/No)*	Irrigation systems		Roads and transportation		Storage facilities		Other ……...					
	Yes	No	Yes	No	Yes	No						
Which additional farming enterprises are you undertaking now?	……											

SECTION B: The adoption intensity of GM seeds by maize farmers in Eastern Cape Province

Do you adopt GM maize seeds in your farm?	Yes		No									
If yes, mention the type of GM maize seed adopted	……											
If yes, list the reasons why you use GM maize seeds *(Please tick Yes/No)*	Pest resistance		Herbicide tolerance		Drought tolerance		Improved yield		Other ……			
	Yes	No	Yes	No	Yes	No	Yes	No				
How long have you been adopting GM maize seeds	……											
How much land is devoted to GM seeds?	……											
Were you influenced to adopt GM seeds by any of the following? *(Please tick Yes/No)*	Neighbors		family members		Community leaders'		Social media		Other ……			
	Yes	No	Yes	No	Yes	No	Yes	No				
Have you influenced any of the following to adopt GM? *(Yes/No)*	Neighbors		family members		Community leaders'		Social media		Other ……			
	Yes	No	Yes	No	Yes	No	Yes	No				
How do you usually receive the GM maize seeds information? *(Please tick Yes/No)*	Radio		Newspaper		Mobile Phones		Other ……..					
	Yes	No	Yes	No	Yes	No						
If no, what has affected you in accessing information on GM seeds? (*Please tick Yes/No)*	Limited access to internet and technology		Language barriers		Lack or limited extension services		Limited literacy		Other ……			
	Yes	No	Yes	No	Yes	No	Yes	No				

What do you think can be done to solve this problem of not accessing GM maize information?	…….									
How has GM seed adoption affected your maize yields?	Improve yields		Reduced yields		Other …….					
Will you continue planting the GM maize?	Yes		No							
If yes, why?	……									
If not adopted, have you ever considered using GM maize seeds in your farm?	Yes		No							
What are the primary reasons for your decision not to adopt GM maize? *(Please tick Yes/No)*	Lack of access to information		Technological factors		High costs		Biosafety concerns		Other ……	
	Yes	No	Yes	No	Yes	No	Yes	No		
Which additional farming enterprises are you undertaking now?	Vegetables		Livestock		Fruits					
	Yes	No	Yes	No	Yes	No				
Do you practice dry land or irrigation maize production	Yes		No							
What is your main reason for farming? (*Please tick Yes/No)*	Earn income		Household consumption		Tradition		Other ……..			
	Yes	No	Yes	No	Yes	No				
How many years have you been farming maize? (actual number)	……									
What skills do you possess on maize production? *(Please tic Yes/Nok)*	Planting and crop management		Soil preparation and conservation		Fertilizer and pest management		Harvesting and postharvest handling		Other ……..	
	Yes	No	Yes	No	Yes	No	Yes	No		
What type of soils are found in your farm?	Clay		Sandy		Loam		Other (specify) ……			
Which farming implements do you use *(Please tick Yes/No)*	Hoes		Ox-drawn plough		Tractor		Planter		Other (specify ……	
	Yes	No	Yes	No	Yes	No	Yes	No		
Are you a member of a farm organization?	Yes		No							

If yes, mention the name of the farm organization	…….								
What is the main purpose of joining the organization group? *(Please tick Yes/No)*	Easy access to credit		Collective transportation of commodities		Group selling of produce		Easy access to input		Other (Specify) ……
	Yes	No	Yes	No	Yes	No	Yes	No	
If no, what is the main reason of not joining an organization?	……...								
Do you have access to markets?	Yes		No						
If yes, what kind of markets do you have access to? *(Please tick Yes/No)*	Farm gates		Cooperative markets		Retail Markets		Other ……		
	Yes	No	Yes	No	Yes	No			
How far is your farm to the markets?	……...								
Indicate your level of risk preference attitude towards GM maize seeds adoption.	Very Unwilling to Take Risks	Somewhat Unwilling to Take Risks	Neutral	Somewhat Willing to Take Risks	Very Willing to Take Risks				
If adopted GM seeds, how compatible are they with your existing farming practices?	Very compatible		Somewhat compatible		Not very compatible		Not at all compatible		
If adopted, how complex are GM seeds to use?	Very easy to use		Somewhat easy to use		Neutral		Somewhat difficult to use		Very difficult to use
If adopted, how observable are the benefits of GM seeds?	Very observable		Somewhat observable		Not very observable		Not at all observable		
If adopted, where you able to trial GM seeds before adopting?	Yes		No		Maybe				
If adopted, what is the relative advantage of GM seeds compared to non-GM seeds?	Much better		Somewhat better		About the same		Somewhat worse		Much worse

SECTION C: The technical efficiency level, production and Profitability of the farmers

What is the quantity of seeds used in your farm (actual KGs)	…….			
How did you obtain the maize seeds?	Government	Local seed shop	Cooperative	Other ……

(Please tick Yes/No)	Yes	No	Yes	No	Yes	No	
How much is the costs of seeds in kilograms?	……						
What type of fertilizer did you use per hectare? (if applicable)	Organic fertilizer (animal dung)		Chemical fertilizers		Both (Mixture)		

(Please tick yes/No)						
	Yes	No	Yes	No	Yes	No
What quantities of fertilizer did you apply?	……					
what is price of fertilizer per hectare?	……					
Do you apply any pesticides and herbicides in your farm?	Yes		No			
If yes, what quantities of pesticides and herbicides did you use per hectare? (litres)	……					
How much is the price of herbicides and pesticides?	……					
Do you have access to labour?	Yes		No			
If yes, what kind of labour do you have access to? (*Please tick Yes/No)*	Family labour		Hired labour		Community labour exchange	Other ……
	Yes	No	Yes	No	Yes	No
What amount of labour did you use? (actual number) for each type						
What is the total amount of labour did you use? (actual number)	…….....					
How much is the price of labour for man-day?	……					
If no, how do you compensate for labour?	……..					
Do you use any oxen-draught power in your farm?	Yes		No			
If yes, is the oxen-draught owned or hired?	Owned		Hired			
If hired, how much for oxendraught power?	……					
Do you use any tractor in your farm?	Yes		No			
If yes, is the tractor owned or hired?	Owned		Hired			

If, hired how much did you pay for the tractor?	……				
How much is your total maize output per year? (kgs)	……				
How much maize was sold?	……				
How much was received from maize sales?	……				
Did you experience any natural hazard(s) (eg drought) during production season?	Yes		No		
If yes specify	……..				
Do you have any problem in obtaining inputs for your farm?	Yes		No		
If yes, state the problem	……				
Do you access to transport your produce to the market	Yes		No		
If yes, is the transport hired or own transport	Own		Hired		
How much is the cost of transport for your produce?	……				
If no, how do you compensate transport for your produce?	……				
How would you rate your technical efficiency levels?	Very inefficient		Inefficient		Neutral		Efficient		Highly Efficient	

SECTION D: The effect of agricultural extension services on the technical efficiency of maize farmers

Have you ever received agricultural extension services specifically related to maize farming in the past 2 years?	Yes		No		
If yes, how frequently do you interact with agricultural extension agents?	Daily	Weekly	Monthly	Quarterly	Yearly
If yes, who usually offer the services?	Government		Private		Community organization	
For how long have you been getting the extension services?	……				

What kind of services do you receive regarding your maize? *(Please tick Yes/No)*	Technical advice on maize cultivation		Training/ workshops on modern techniques of what?		Access to improved maize seeds		Farm management		Other ……
	Yes	No	Yes	No	Yes	No	Yes	No	
What are the AEX sources of information? *(Please tick Yes/No)*	Field visits		Mobile phones and SMS services		Radio and TV programs		Other ……		
	Yes	No	Yes	No	Yes	No			
To what extent do you implement recommendation suggested by extension agents?	Always		Often		Sometimes		Rarely		Never
What farming practices have you adopted because of agricultural extension advice? (Check all that apply) *(Please tick Yes/No)*	Improved crop varieties		Better soil management techniques		Enhanced pest and disease control methods		Improved water management practices		Other (specify) ……..
	Yes	No	Yes	No	Yes	No	Yes	No	
How would you rate the quality of agricultural extension services you received?	Very poor		Poor		Neutral		Good		Excellent
What can be done to improve the extension services?	……								
If you have never received extension services, what might be the reason? *(Please tick Yes/No)*	Lack of resources		Limited extension Personell		Cost constraints		Remote location		Other ……
	Yes	No	Yes	No	Yes	No	Yes	No	
What would you suggest solving the problem of not receiving the extension services?	……..								

THE END THANK YOU! NDIYABULELA!

Appendix II: Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

04 November 2024

Athenkosi Ngqulana (224195341)
School of Agri Earth & Env Sc
Pietermaritzburg Campus

Dear A Ngqulana,

Protocol reference number: HSSREC/00007889/2024
Project title: Impact of agricultural extension services on technical efficiency of adopters and non-adopters of genetically modified maize in the Eastern Cape Province
Degree: PhD

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 18 October 2024 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

Incidents of adverse events and serious adverse events (AEs and SAEs) should be reported in writing to HSSREC, the study sponsors, and any regulatory authority (where appropriate), within 7 working days of the occurrence for local sites and 14 days for all other South African sites.

This approval is valid until 04 November 2025.
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

HSSREC is registered with the South African National Health Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

Professor Dipane Hlalele (Chair)
/nng