S. Afr. J. Agric. Ext. Wawa, Zwane & Mmbengwa
Vol. 54 No. 1, 2026: 224-247
10.17159/2413-3221/2026/v54n1a21241 

# Factors Influencing Farmers' Adoption of Crop Biotechnology to Mitigate Climate Change: Case of Eastern Cape, South Africa

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***ABSTRACT***

*This study examined the adoption of crop biotechnology among smallholder farmers in the Eastern Cape as a strategy to mitigate the impacts of climate change, focusing on the barriers, socioeconomic factors, and current adoption status. Despite the increasing relevance of biotechnology in climate resilience, there is a lack of research on the specific challenges and drivers influencing its adoption in rural South Africa. The study aims to examine the barriers to biotechnology adoption, assess the socioeconomic factors influencing adoption, and highlight the status of crop biotechnology in climate change adaptation. A multi-stage sampling method was employed to conduct interviews with 350 smallholder maize farmers across three district municipalities in the Eastern Cape, with data collected through structured interviews. The Multinomial regression model and descriptive statistics were used in the analyses of the study. Key findings reveal that financial constraints, lack of knowledge, and limited access to climate information and credit are significant barriers, while education, income, and farm size have a positive influence on adoption. The study further recommends that targeted interventions be implemented to address these barriers, including financial, informational, and educational barriers, in order to enhance biotechnology adoption and improve the resilience and productivity of smallholder farmers in the face of climate change.*

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**Keywords:** Biotechnology Adoption, Climate Change, Smallholder Farmers, Maize Production, Eastern Cape.

## 1. INTRODUCTION AND BACKGROUND

South Africa faces significant challenges from climate change, which impacts critical sectors such as social welfare, infrastructure, and agriculture. Rising temperatures and altered rainfall patterns pose a threat to the country's ecosystems and economic stability. Extreme weather events have also become increasingly common. In KwaZulu-Natal and the Eastern Cape, the frequency and intensity of storms and flooding have escalated. These events are mainly driven by climate change and environmental mismanagement (Busayo *et al*., 2022; Gqalindaba *et al*., 2024). These climate variations result in severe rainfall and extreme temperatures. They pose considerable risks to low-lying coastal areas and contribute to flood disasters and sea level rise (Griggs & Reguero, 2021; Laino *et al*., 2023). Extreme temperatures have made socioeconomic challenges worse for families in coastal cities. Climate impacts in these regions are intensified by tropical cyclones, heavy rainfall, frequent coastal flooding, storm surges, and tidal shifts (Dube *et al*., 2022). Farmers are responding by adjusting planting schedules and diversifying crops to adapt to climate variability (Adlina & Oktari, 2024). Agroforestry and conservation agriculture are also gaining traction, enhancing resilience by promoting ecosystem health (Chauhan, 2024).

To combat these challenges, smallholder farmers are adopting agricultural biotechnology solutions. These solutions are vital for adapting productivity to climate change. Agricultural biotechnology increases crop yields and strengthens plants' resistance to pests and diseases. It can also reduce energy use (Andualem & Seid, 2021). Furthermore, agricultural biotechnology offers solutions for lowering the impact of climate change and mitigating its effects. South Africa is among the few African nations that have embraced biotechnology. It has adopted genetically modified (GM) crops, including cotton, soybeans, and maize. The South African government has supported GMOs for over a decade. It recognises their role in boosting productivity, especially in combating challenges such as stalk-boring insects, a major threat to maize production (Choudhary & Gaur, 2022). Despite these promising advances, some farmers remain wary of GMOs because of concerns about safety and market acceptance. This highlights the importance of education and support for adoption (Mutiga *et al*., 2023). By leveraging biotechnological tools and promoting awareness, South Africa aims to enhance its agricultural resilience in the face of climate challenges.

Farmers in the Eastern Cape, South Africa, are facing severe impacts from climate change. These include declining crop yields and agricultural productivity (Amoah & Simatele, 2021). While crop biotechnology offers a viable solution, its adoption remains low. Limited awareness, socioeconomic barriers, and cultural perception are key factors (Lemarié *et al.*, 2022). These challenges hinder farmers' ability to leverage biotechnology for climate resilience. Understanding these factors is crucial to promoting adoption and improving agricultural sustainability in the region. The objectives of the article are:

- To highlight the current status of crop biotechnology adoption as a strategy to mitigate climate change impacts in smallholder farming systems.
- To highlight the contribution of Agricultural Extension in the adoption of agricultural biotechnology.
- To investigate the barriers smallholder farmers face in adopting crop biotechnology, with a particular focus on the challenges that limit their ability to embrace climate-smart agricultural practices.
- To identify the socioeconomic factors influencing the adoption of crop biotechnology.

## 2. THEORETICAL ASPECT OF ADOPTION

The adoption of crop biotechnology by smallholder farmers is a complex phenomenon driven by several interconnected factors. By adopting a systems thinking approach, these variables can be examined as components of a larger, interconnected ecosystem rather than separately (Sarkar *et al.*, 2024). This framework posits that the adoption process is influenced by three primary dimensions: individual farmer characteristics, socioeconomic factors, and environmental conditions, all of which interact dynamically within the agricultural system.

### 2.1. Individual Farmer Characteristics

The characteristics of smallholder farmers, such as education level, risk perception, and technological literacy, play a vital role in influencing their propensity to accept biotechnology. Farmers with higher educational attainment are more likely to recognise the benefits and risks associated with biotechnology breakthroughs (Harfouche *et al.*, 2021). Furthermore, according to Saleh *et al.* (2021), farmers' willingness to adopt new technologies is influenced by their perception of risk, as individuals who believe biotechnology will be advantageous are more likely to incorporate it into their farming methods.

### 2.2. Socioeconomic Factors

The socioeconomic context comprises access to resources, financial capital, and social networks. Smallholder farmers often face constraints such as limited access to credit, which can hinder their ability to invest in biotechnology. Farmers' views on the adoption of biotechnology are also greatly influenced by social networks and local norms. Implementation success can be enhanced by promoting collective adoption and facilitating knowledge transfer through peer and agricultural extension services (Beumer & Swart, 2021).

### 2.3. Environmental Conditions

The physical and regulatory elements of the agricultural environment contribute to the adoption of biotechnology. Factors such as soil fertility, climate variability, and pest pressures affect the perceived need and effectiveness of biotechnological solutions. Additionally, government policies and regulatory frameworks play a crucial role in shaping the adoption landscape. Policies that support biotechnology research, development, and dissemination can foster an environment conducive to smallholder farmers adopting these innovations (Yongabo, 2021; Feleke *et al*., 2021).

## 3. RESEARCH METHODOLOGY

The research methods used in the study are quantitative. The study utilised a multi-stage sampling method to select smallholder farmers in the Eastern Cape, explicitly targeting the districts of Alfred Nzo and Amathole, which have the largest populations of maize farmers, as these farmers were the largest group growing Genetically Modified (GM) maize, hence the motivation for this study to adopt GM maize. From these districts, two local municipalities were randomly selected, and a snowball sampling technique was used to identify individual maize farmers for participation. The initial target sample size was 400, calculated using the following probability sampling formula:

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

Where:

- n = sample size
- N = total population of maize-producing smallholder farmers in Eastern Cape (596,573 as per Stats SA, 2021)
- e = margin of error (0.05, representing a 95% confidence level)

Using the formula, the required sample size was determined to be 400. However, due to budget constraints, only 350 smallholder farmers were selected for the interview. The study ensured that participants were equally distributed across the three selected district municipalities and were fully informed about the study's objectives and confidentiality, thereby ensuring voluntary participation. The final sample represents a cross-section of maize-producing smallholder farmers in the region. The data collected through a survey questionnaire was encoded and recorded in Microsoft Excel. Primary data was collected using a questionnaire. Personal information (such as age, gender, level of education, and marital status) was required for this study, as well as general demographic data (income levels, household size). The study used descriptive statistics and a multinomial regression model.

### 3.1. Multinomial Regression Model (Analytical Framework)

The multinomial logit regression model (MNL) was employed to analyse the socioeconomic and environmental factors influencing the choice of biotechnological adoption by smallholder farmers in this study. Socioeconomic constraints can become significant factors that slow or hinder the mitigation of climate change and variability. Multinomial logit regression is used to analyse an individual's choice among a set of $J$ alternatives (Hoffman & Duncan, 1988; Damtew *et al.*, 2024). According to Bayaga (2010), multinomial logistic regression is used when the dependent variable has more than two nominal or unordered categories, in which dummy coding 3 of three independent variables is quite common. Furthermore, Shongwe *et al.* (2014) and Shongwe *et al.* (2021) argue that the MNL model for the choice of adaptation strategies specifies the relationship between the probability of choosing an adaptation option and the set of explanatory variables.

To further describe the multinomial logit regression model, $P$ represents the probability that an individual chooses alternative $J$, and $Y$ is the polychotomic dependent variable, while $J$ denotes the number of unordered alternatives and $x$ represents the set of explanatory variables

(Hoffman & Duncan, 1988). In this study, the $Y$ represents the alternative adaptation trait to mitigate the effects of climate variability on crop production. Therefore, the set of explanatory variables includes the characteristics of the smallholder farmers who choose adaptation strategies. Additionally, the $P$ in this study presents the likelihood of the smallholder farmers being in each adaptation trait. Shongwe *et al.* (2014) argue that the MNL model for the choice of adaptation strategies specifies the relationship between the probability of choosing an adaptation option and the set of explanatory variables. Gbetibouo (2009) stated that the multinomial logit model analyses how the elements of $x$ would affect the response probabilities.

$$P\left(Y = \frac{j}{x}\right), j = 1,\ 2, \ldots J.$$

Also, the probability that a farmer $i$ will choose an adaptation alternative $j$ among the set of adaptation options could be defined as:

$$P\left(Y = \frac{1}{X}\right) = P(Uij > \frac{Uik}{X})$$

The above-defined probability equation is adopted from Armah *et al.* (2013), where $Uij$ and $Uik$ are the perceived utilities by farmer $i$ of adaptation options $j$ and $k$, respectively with $Xi$ being the vector of explanatory variables influencing the choice of the adaptation option. Since the probabilities must sum to unity, $P(Y = \frac{j}{X})$ would be determined once the probabilities for $j = 2, \ldots J$ are known. Furthermore, the adaptation strategies will be grouped into three categories, as farmers may have employed more than one strategy. The following multinomial logit model is adopted, as used by Armah *et al.* (2013) and Obayelu *et al.* (2014).

$$P\left(y = \frac{j}{x}\right) = exp\ exp\ (x\beta j)\ / \left[1 + \sum_{K=1}^{J} \quad (exp \times \beta j) + e, j = 1, \ldots J\right]$$

In the above MNL equation, $\beta j$ is the parameter to be estimated and $e$ is the error term. The parameter estimates of the multinomial logit regression only offer the direction of the effect of the independent variables on the dependent variable but do not represent the actual magnitude of change or probabilities (Deressa *et al.*, 2010; Armah *et al.,* 2013). Dependent and independent variables are shown in Table 1.

**TABLE 1: Dependent and Independent Variables for the Multinomial Regression Model**

| **Variables** | **Type of variables and description** |
|---|---|
| Dependent variables(Y)-Maize variety adopted. | Polychotomic variables |
| Bt maize (Insect resistant)<br>RR maize (Herbicide-tolerant)<br>Drought-TEGO (Drought-tolerant)<br>CAP 9001 maize (Disease resistant)<br>Non-genetically modified maize varieties (landrace) | |
| Independent variables (x):Socio-economic | |
| Age of the farmer | Discrete= Age of household head |
| Educational level | Discrete=Years |
| Marital status | Dummy-1=Married, 0 otherwise |
| Household size | Dummy-1=Yes, 0 otherwise |
| Land size | Discrete-Size |
| Gender | Dummy-1=Male, 0=Female |
| Reason for Farming | Dummy-1=Profit, 0= Subsistence |
| Source of Capital | Polychotomic variables |
| Farming years | Discrete= number of years |
| Household monthly income | Continuous |
| Farming Method | Polychotomic variables |
| Employment status | Polychotomic variables |
| Other Income Source | Polychotomic variables |

## 4. RESULTS AND DISCUSSION

### 4.1. Adoption of Crop Biotechnology to Adapt to Climate Change and Variability

Adaptation to climate change is imperative for the resilience of smallholder agriculture. The resilience of smallholder farmers to climate change can be directly linked to various adaptation strategies and their adaptive capacity, as documented in the literature (Ogundeji, 2022; Gebre *et al.*, 2023). According to Verma and Sudan (2021), farmers who respond to climate change through various adaptation measures are more likely to enhance agricultural productivity and improve their livelihoods. Adaptation to climate change contributes to improved household food security and, in general, farm household welfare. Adaptation strategies, such as improved crop varieties, are the adaptation strategies that farmers are adopting most frequently lately. According to the results of this study, approximately 96.9% of the respondents have adapted to climate change and its associated variability. The results showed that 76.6% of the respondents were familiar with crop biotechnology, which involved a variety of GM maize crops adopted to mitigate the effects of climate change.

#### *4.1.1. Maize Variety Adopted by Smallholder Farmers*

According to Ala-Kokko *et al*. (2021), genetically modified (GM) maize has significantly improved food security in South Africa, reduced environmental damage, and helped smallholder farmers achieve substantial gains in earnings over the past two decades. The respondents were asked about the maize varieties they had previously adopted and about the current maize variety they were using during the planting season. The maize variety they adopted from November 2023 to August 2024. This was done as it is essential when examining the adoption status of crop biotechnology for mitigating climate change.

The results from the last planting season showed that respondents reported the following varieties: 41.43% planted Bt maize, 29.57% planted drought-resistant maize, 11.71% non-GM/Landrace maize, 10.57% RR maize, and 9.14% Cap009 maize. This aligns with findings from Ala-Kokko *et al*. (2021) and Muzhinji and Ntuli (2021), which highlight that GM maize has contributed to improvements in food security, increased farmer incomes, and reduced environmental damage in South Africa.

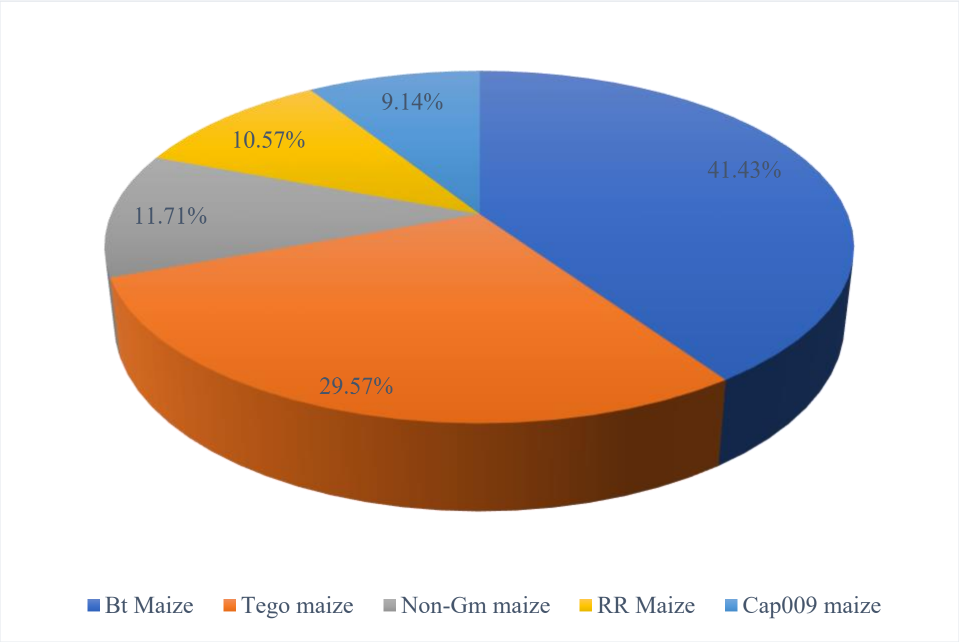


**FIGURE 1: Showing Currently Adopted Maize Varieties by the Respondents**

The study examined the adoption of various maize varieties among smallholder farmers, with a focus on their use in past planting seasons. Results showed that Bt maize, with its pest resistance, was the most widely adopted variety, used by 46.28% of respondents (n = 350). This was followed by drought-resistant maize, adopted by 34.29% (n = 350), highlighting the importance of crops that can withstand climate variability. Non-GM maize and RR maize were also adopted, at 32.29% and 29.14% (n = 350), respectively, suggesting that farmers are balancing biotechnology with traditional practices. These findings reflect a growing trend among smallholder farmers to select maize varieties that help address critical climate challenges, such as pests and drought. The high adoption of Bt and drought-resistant varieties suggests that farmers recognise the need for resilient crops to cope with the increasing unpredictability of weather patterns associated with climate change.

The results also emphasise the potential of crop biotechnology in climate change adaptation. By adopting genetically modified (GM) and drought-tolerant varieties, farmers can enhance their resilience to climate stressors, including insect infestations and water scarcity. However, this also highlights the importance of providing access to affordable and sustainable seed varieties, ensuring that all farmers, regardless of their economic status, can benefit from these innovations. As climate change continues to impact agricultural productivity, the adoption of climate-resilient crops will be crucial in ensuring food security for smallholder farmers. The maize varieties are shown in Figure 2.

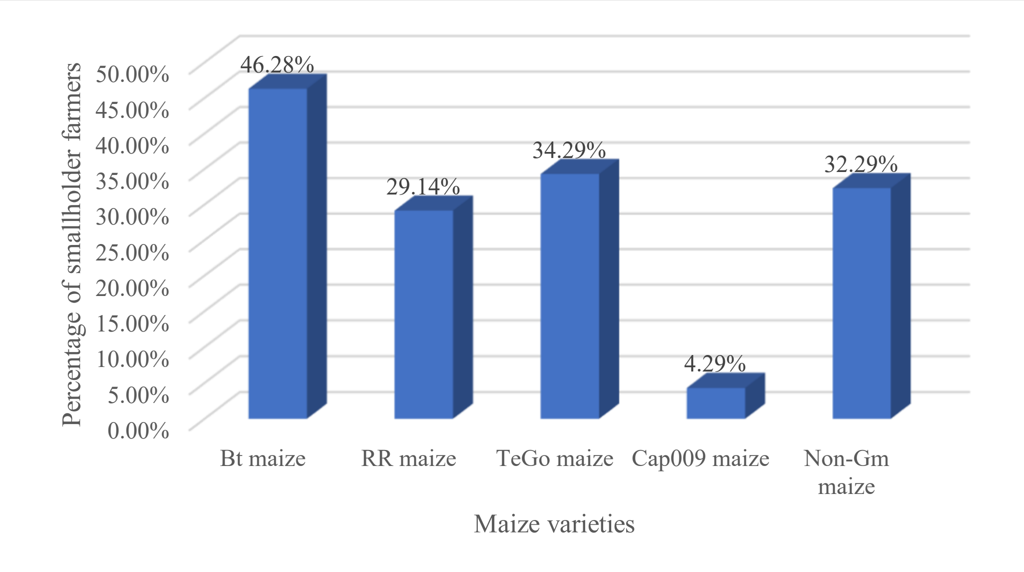


**FIGURE 2: Showing the Maize Varieties Adopted in Past Planting Seasons**

The study found that 59.14% of respondents had no issues with paying for GM seeds, indicating a positive attitude toward the adoption of genetically modified crops. However, 19.14% of respondents reported that GM seeds were not affordable for them, highlighting a significant barrier to wider adoption. A small portion (2%) of farmers were uncertain about their willingness to pay for GM seeds, suggesting some indecision or lack of information. The respondents who had previously and currently bought GM maize seeds were then asked how they paid for the seeds. Forty percent (n=350) of the overall sample reported using loans, 60% personal savings, 17.71% (n=350) received support from the government, and 12.51% (n=350) used other means. These results offer a glimmer of hope, as previous studies have reported that farmers in the Eastern Cape are not willing to pay for their farming services and are dependent on government support (Loki, 2022; Ruzhani & Mushunje, 2022). However, a willingness and desire to do something do not always mean the ability to do so. These respondents face challenges in accessing credit facilities, which also hinders their advancement in farming. When observing the respondents who are more inclined to adopt GM maize. Smallholder farmers are still sceptical about adopting advanced crop varieties and still face barriers in the adoption of new technology, including biotechnology

### 4.2. Contribution of Agriculture Extension in the Adoption of Agricultural Biotechnology

Agricultural extension is crucial in providing small-scale farmers with the knowledge and resources they need to adopt agricultural biotechnology and mitigate the effects of climate change (Wahyuni, 2025). The findings demonstrate that extension services serve as a vital link between research and agriculture by raising awareness about climate change, offering technical assistance, and providing training. More than half of the farmers (58.9%) reported participating in extension services, and many stated that they had observed improvements in their farming methods, such as using higher-quality seeds and managing climate variability more effectively. Farmers have found it crucial to adapt to climate change with the aid of technical assistance, which includes soil analysis (39.4%), training (50.9%), crop insurance advice (29.1%), and the dissemination of climate information (50.9%) to face difficulties such as increasing temperatures, drought, and changes in precipitation patterns.

However, there are still notable failings. The effectiveness of services is hampered by the scarcity of extension officers, inconsistent contact (59%), and inadequate specialised training. Additionally, government incentives such as seed distribution, mechanisation assistance, and soil testing are not being provided to farmers regularly, with the majority of respondents stating that they received little or no assistance. These gaps undermine farmers' ability to embrace climate-smart strategies and biotechnology.

### 4.3. Barrier to Adoption of Agricultural Biotechnology

Solutions to reduce the yield gap must meet the requirements of smallholder farmers. According to Alemu (2020) and Kabisa *et al*. (2020), biotechnology in agriculture provides some solutions. However, there are several obstacles in the way of creating, implementing, and embracing biotechnology, as with any other technology. When examining the barriers to the adoption of crop biotechnology, the results indicated that a lack of adequate finances (92%) is the leading cause of slow adoption or use of GM varieties accessible to their financial brackets, with no consideration of the solutions offered. This is consistent with Alemu and Grebitus (2020), Kabisa *et al* (2020), Alemu (2020), Langyintuo (2020), and Kedisso *et al*. (2022), who identify financing as a major barrier to the uptake of biotechnology and who assert that access to credit and financial support is vital for the uptake of biotechnology.

Furthermore, while GM maize adoption is relatively high, other crop varieties, including non-GM maize, are still widely used, signalling hesitance or resistance to biotechnology in some farming communities. This suggests that factors such as access to knowledge, affordability, and trust in the technology continue to be significant barriers to full adoption. The respondents reported a lack of knowledge as a barrier to their adoption, with 60.57% of the farmers responding that they need more knowledge in the aspect of new crop varieties. A percentage of 39.43% of respondents are well-informed and connected to information sources, whose knowledge was not a barrier for them.

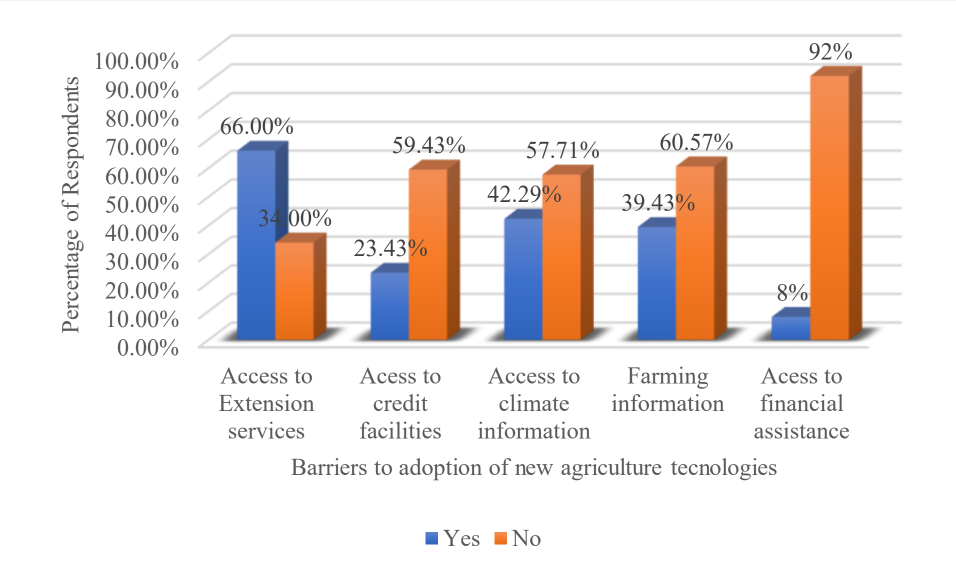


**FIGURE 3: Challenges Faced by Smallholders in Their General Farming Practices**

To enhance agricultural resilience and production in the face of climate change, smallholder farmers implementing crop biotechnology must have access to accurate climatic information. Farmers can use this knowledge to make informed decisions about biotechnology applications that mitigate negative effects by understanding climatic trends. When asked about their level of climate-informedness, 57.71% of respondents reported being climate-informed and having access to climate information, while 42.29% reported having no access to climate information.

Fifty-eight percent may seem like a significant percentage, but 42.29% is still a larger number of smallholder farmers with no access to climate information, which can alter the goal of climate resilience and self-reliance among smallholder farmers in Rural areas. This can put a stumbling block to food security. This gap in access to critical information could undermine efforts to improve resilience through biotechnology, as farmers may struggle to align their crop choices with current climatic conditions. This lack of access is particularly concerning in rural areas, where the infrastructure for disseminating information is often limited. As noted by Hallegatte (2016) and Schattman *et al*. (2021), the effectiveness of GM crop adoption in mitigating climate impacts is significantly reduced when climate-informed decision-making is not employed.

Access to credit is crucial for smallholder farmers to adopt green biotechnology, as it alleviates financial constraints and enables investment in innovative agricultural practices; however, looking at the results, a high percentage of 59,43% of the respondents reported they had no access to credit, which stems as a barrier to their adoption of crop biotechnology. Only 23.43% of the population had access to credit, and this was not a major barrier. Access to credit is crucial for smallholder farmers to adopt crop biotechnology, as it enables them to invest in advanced seed varieties, technology, and infrastructure needed to mitigate the impacts of climate change. Financial support enables farmers to afford genetically modified (GM) crops or drought-resistant varieties that enhance yield and resilience against climate-related stressors, thereby fostering sustainable agricultural practices in the face of environmental uncertainty.

Access to agricultural extension services is also crucial for smallholder farmers to effectively adopt green biotechnology and other technologies. These services facilitate the dissemination of knowledge and innovations, enabling farmers to make informed decisions about new technologies. A percentage of 66.3% of respondents reported having access to agricultural extension services; however, some reported this for different reasons. These include livestock production and other activities. They reported that they were not part of the maize-producing farmers' groups. A percentage of 33,7% of the farmers reported that access to agricultural extension was a barrier for them. This finding is supported by Shankar *et al*. (2018) and Maulu *et al*. (2021), who note that access to extension services and educational programs is critical for overcoming knowledge gaps. However, even when extension services are available, they are often limited in reach, with some farmers not having access due to geographic or logistical challenges.

### 4.4. Socioeconomic Factors Influencing the Adoption of Crop Biotechnology

#### *4.4.1. Multinomial Model Results*

The multinomial regression model was used to analyse factors influencing smallholder farmers' adoption of various maize varieties, particularly genetically modified (GM) crops. The model fitting criteria show that the -2 Log Likelihood statistic decreased from 993.289 in the intercept-only model to 873.770 in the final model, with a Chi-Square of 119.519 (df = 60, $p < .001$). This significant reduction indicates that the inclusion of predictor variables meaningfully improves the model's ability to predict maize adoption categories compared to a model with only the intercept.

The goodness-of-fit tests, including the Pearson and Deviance chi-square tests, both display high p-values (Pearson: .245, Deviance: 1.000), suggesting that the model fits the data well and that the observed frequencies in each category are consistent with those predicted by the model. However, the pseudo-R-square values Cox and Snell (.291), Nagelkerke (.308), and McFadden (.120) indicate a moderate amount of explained variance. These values highlight the model's effectiveness, but also suggest that additional, unexplained factors influence maize adoption decisions that are not currently included in the model. A key focus of the analysis is identifying significant predictors of maize adoption levels. The likelihood ratio tests reveal that several predictors are statistically significant, specifically age ($p = .036$), employment status ($p = .005$), education level ($p < .001$), monthly income ($p = .013$), other source of income ($p = .033$), and years farming ($p =.020$).

#### *4.4.2. Education Level*

The education level, with the highest Chi-Square value (21.852), emerges as a particularly influential predictor, suggesting that increased education is strongly correlated with maize variety adoption decisions. This implies that farmers with higher educational attainment are more likely to adopt new or GM maize varieties. The parameter estimates give further insight into the direction and magnitude of these relationships. Education level shows a particularly strong effect across multiple adoption levels. For example, in category 2, education has a positive coefficient of $B = 1.610$ ($p < .001$), with an Exp(B) of 5.001, indicating that farmers with higher levels of education are five times more likely to adopt this maize type than those with lower levels of education.

This result highlights the critical influence of educational attainment in shaping farmers' openness to genetically modified or advanced crop varieties, likely due to increased knowledge about the benefits of GM technology and a reduction in misconceptions or fears about GM crops. This trend aligns with the literature, which suggests that educated farmers are more open to adopting innovative agricultural technologies due to a better understanding and fewer misconceptions about biotechnology (Asfaw *et al*., 2021; Mulugeta *et al*., 2024). In the study, education has a particularly strong correlation with the adoption of GM crops, as evidenced by the high Chi-square value for education level in the regression analysis.

### *4.4.3. Age of Farmers*

Age consistently shows a negative coefficient across adoption levels, meaning younger farmers are more likely than older ones to adopt various maize varieties. This trend is especially notable in adoption category 2, where age has a coefficient of -0.066 (p = .003), indicating that younger farmers have a significantly higher likelihood of adopting this maize type. These findings suggest that younger farmers may be more open to innovations, potentially due to greater familiarity with or openness to agricultural technologies.

### *4.4.4. Employment Status*

Employment status is another important predictor. In the adoption category 0, employment status has a positive coefficient (B = 0.676, p = .034), indicating that farmers with stable employment are more likely to adopt specific maize varieties than those without employment. This finding highlights the importance of economic stability in influencing adoption decisions, as employed farmers may have greater financial security to invest in GM seeds. This finding is consistent with that of Teye and Quarshie (2022), who argue that access to financial resources plays a crucial role in enabling farmers to invest in new technologies. Employment provides the necessary economic stability to absorb the costs associated with GM seeds, which may be prohibitive for farmers without stable incomes. Conversely, farmers with lower monthly incomes or those without employment face challenges in adopting GM maize, as they prioritise cost-effective agricultural practices.

### *4.4.5. Farm Size*

Farm size also plays a significant role in determining adoption levels. In category 3, farm size has a positive coefficient (B = 0.385, p = 0.011), indicating that larger farms are more likely to adopt specific types of GM maize. This aligns with the notion that larger farms, which often benefit from economies of scale, may be better equipped to absorb the costs associated with GM seed technology and may also have greater access to resources to support new crop varieties. Monthly income and other income sources are also significant predictors. This supports the findings of Zewde (2020) and Kedisso *et al*. (2023), who suggest that farm size directly influences the ability of farmers to adopt and implement high-cost technologies, such as GM crops. However, smallholder farmers with limited land may struggle to adopt GM maize due to the upfront costs, despite potential long-term benefits.

#### *4.4.6. Farmer's Diverse Income*

Farmers with diverse income streams ($p = .033$ in likelihood ratio tests) are more likely to adopt GM varieties, possibly due to increased financial flexibility that enables them to invest in newer or more resilient maize types. However, income effects vary slightly across adoption levels, reflecting that different financial structures may influence adoption in unique ways. Notably, in category 3, monthly income has a negative coefficient of -0.594 ($p = .020$), which could indicate that lower-income farmers in this group may prioritise cost-effective crops over GM varieties or that the cost of GM seeds may be a limiting factor.

#### *4.4.7. Years of Farming Experience*

Years of farming experience (Years F) also shows significance ($p = 0.020$ in likelihood ratio tests), particularly at adoption level 1, where it has a negative association with adoption ($B = -0.068$, $p = 0.008$). This suggests that farmers with less farming experience may be more inclined to adopt GM varieties, possibly because they may be more adaptable to new practices or less entrenched in traditional farming methods. The acceptance of genetically modified (GM) crops and farming experience has a complex relationship; some research indicates that farmers with less expertise may be more likely to embrace GM crops. In the context of GM acceptance, Mueller and Flachs (2022) stated that this pattern is observed, with less experienced farmers possibly being less devoted to conventional methods or more flexible in adopting new ones. The simplicity of farming methods and the potential for greater production improvements associated with genetically modified crops are two reasons for this trend.

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#### *4.4.8. Farming Method*

The influence of farming methods is evident in adoption category 3, where farming methods have a negative impact on adoption (B = -1.152, p = .077). Although this effect is not statistically significant across all categories, it suggests that specific farming practices may affect openness to GM maize. In line with the findings of Tobaben and Kwade's 2024 study, farmers' perceptions of the hazards associated with adopting GM technology significantly influence their attitudes towards it. The association between perceived advantages and adoption readiness is mediated by negative views rooted in health and environmental dangers (Tobaben & Kwade, 2024). According to Patil & Padaria (2018) and Sendhil *et al*. (2022), this is similar to the finding that farmers' willingness to adopt Bt-brinjal was negatively impacted by socioeconomic and health risk perceptions, suggesting that risk perception is a critical factor in adoption decisions.

## 5. CONCLUSION AND RECOMMENDATIONS

### 5.1. Conclusion

In conclusion, smallholder farmers in the Eastern Cape are increasingly adopting crop biotechnology, with Bt maize and drought-tolerant varieties being the most favoured since they are resistant to climate stress and pests. Despite affordability, lack of credit, and little government assistance remaining significant challenges, the majority of farmers indicated a willingness to pay for GM seeds. Despite the crucial role that agricultural extension services play in providing training, technical advice, and climate data, their effectiveness is hindered by a shortage of extension officers, inadequate specialised support and sporadic contact. Due to these gaps, farmers' capacity to adopt biotechnology for climate change adaptation is limited.

Additionally, socioeconomic variables influence adoption choices. Older farmers with limited resources are still hesitant to use GM types, while younger, more educated farmers with steady incomes and larger farms are more likely to do so. Additionally, adoption is slowed by insufficient access to climate data and knowledge gaps. In general, biotechnology has a clear capacity to enhance resilience, increase productivity, and promote food security among smallholder farmers. However, maximising its impact necessitates addressing financial limitations, increasing extension support, and ensuring consistent government incentives to foster a conducive environment for broader and more equitable uptake.

### 5.2. Recommendations

It is recommended that policymakers and development agencies should focus on improving access to credit, providing targeted educational programs, and enhancing information dissemination systems to support smallholder farmers in adopting GM crops and other climate-smart technologies. Extension services should educate farmers about the benefits of GM varieties to promote food security.

## 6. ACKNOWLEDGEMENTS

Special gratitude to my supervisors, Prof. EM Zwane and Prof. M.V. Mmbengwa from the School of Agriculture and Environmental Science, University of Limpopo, for their supervision and feedback throughout the research.

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