sustainability

MDPI

Article

Factors Influencing the Willingness and Ability of Farmers to Adopt TELA Maize Seed in Alfred Nzo District, Eastern Cape, South Africa

Kwakhanya Gcaba [1,*], Mzuyanda Christian [2], Simon Letsoalo [1] and Dhanya Jagadeesh [1]

[1] Department of Agricultural Economics and Extension, North-West University, Private Bag X2046, Mmabatho 2735, South Africa; simon.letsoalo@nwu.ac.za (S.L.); dhanyajagadeesh2022@gmail.com (D.J.)

[2] School of Agricultural Sciences, University of Mpumalanga, Cnr R40 and D725, Mbombela 1200, South Africa; mzuyanda.christian@ump.ac.za

* Correspondence: kgcaba48@gmail.com

Abstract: In developing countries, drought is a major climatic challenge that has driven the development of drought-tolerant seed varieties aimed at improving yields and farm incomes; however, the adoption of drought-tolerant seeds, such as the TELA maize hybrid, remains low. This study explored the factors influencing the willingness and ability to adopt TELA maize seed and its potential production implications in Alfred Nzo District, Eastern Cape, South Africa. This study employed a multistage random sampling method to gather data from 120 smallholder maize farmers through a semi-structured questionnaire. Data were collected and analyzed using descriptive statistics and a probit regression model. The results showed that 65% of respondents were male, and 53% were married. Notably, 77% had low educational attainment, with the majority having completed only secondary school or less. Furthermore, 65% of respondents indicated that farming was primarily for livelihood purposes. This study found that limited access to credit and extension services were major obstacles to adopting TELA maize seed technology, compounded by skepticism towards innovation. The findings suggest that addressing these challenges requires the implementation of targeted gender equity programs, improving educational access, and enhancing financial support mechanisms. Additionally, strengthening cooperative engagement and extension services is crucial for promoting technology adoption. By fostering collaboration among stakeholders and providing adequate resources, this study highlights the potential for increased adoption of TELA maize seed, contributing to improved food security in rural households.

Keywords: willingness; ability; adopt; smallholder; TELA maize seed; smallholder farmers; Alfred Nzo District; Eastern Cape; South Africa

check for updates

Academic Editor: Roberto Mancinelli

Received: 2 December 2024
Revised: 20 January 2025
Accepted: 21 January 2025
Published: 24 January 2025

Citation: Gcaba, K.; Christian, M.; Letsoalo, S.; Jagadeesh, D. Factors Influencing the Willingness and Ability of Farmers to Adopt TELA Maize Seed in Alfred Nzo District, Eastern Cape, South Africa. *Sustainability* **2025**, *17*, 973. https://doi.org/10.3390/su17030973

1. Introduction

TELA maize seed hybrid technology has been engineered to introduce traits such as herbicide resistance and pest resilience [1]. The development of genetically modified seeds is referred to as a specific variety of maize seed that is designed for high performance and enhanced resistance to common maize diseases and pests; however, this technology offers a promising strategy for enhancing food security and alleviating poverty in developing countries, particularly in the context of maize production, where smallholder farmers often face low productivity levels. In regions such as Alfred Nzo within the Eastern Cape province, which faces challenges such as drought, soil degradation, and pests, the environmental resilience of TELA maize seed, including its drought tolerance and resistance to diseases, could make it an attractive option. Despite the potential benefits of this innovative technology, public skepticism regarding the safety of TELA maize seed has shaped policy discussions across many African nations, necessitating a more informed dialogue about their economic, environmental, and public health impacts. Farmers who face unpredictable weather patterns may be more willing to adopt technologies that help mitigate these risks; however, the seed's compatibility with local environmental conditions, such as soil health and fertility, will be a determining factor. If TELA maize seed requires specific soil conditions or additional inputs, farmers may hesitate, particularly if they lack the resources to manage such requirements.

In many developing regions, local food production is crucial for long-term food security and poverty reduction. While cooperative farming has shown success in enhancing productivity, access to innovative technologies such as TELA maize hybrid seeds remains limited. Collective action among smallholder farmers is essential for overcoming these barriers, as cooperation can facilitate resource acquisition and knowledge sharing. Manda et al. [2] emphasize that cooperative structures can improve understanding of collaborative practices that boost farm productivity.

The adoption of new agricultural technologies by smallholder farmers is influenced by a variety of factors that span individual, social, economic, and institutional dimensions. In general, the decision to adopt agricultural innovations, such as genetically modified seeds, is affected by quite a number of contributing factors ranging from farmers assessing technology based on perceived advantages, misinformation about a newly introduced technology, access to resources, social influence, and network, institutional and policy support.

In South Africa, the adoption of genetically modified (GM) crops, particularly GM maize varieties such as TELA, has gained attention because of their potential to improve food security and reduce dependency on chemical pesticides. TELA maize is a genetically modified maize developed to resist the stem borer pest, a significant threat to maize production in Africa.

The adoption of TELA maize seed in Alfred Nzo District is influenced by a multifaceted set of factors. Addressing the barriers to adoption, such as high seed costs, limited access to credit, and insufficient information, while enhancing the perceived benefits of the technology, can increase adoption rates. A comprehensive approach involving financial support, improved access to information, and community-level engagement can help farmers realize the potential of TELA maize seed, contributing to greater food security and agricultural sustainability in the region. Limited access to resources, lack of knowledge about TELA maize seed benefits, and persistent public skepticism hinder widespread adoption. This study aimed to bridge the gap by addressing the factors influencing the adoption of TELA maize seed hybrid technology by smallholder farmers in Alfred Nzo District. Through knowing which factors mostly delay adoption compared with traditional maize varieties, the research sought to unlock potential by encouraging the adoption of TELA maize seed hybrid technology by smallholder farmers in Alfred Nzo District Municipality.

2. Theoretical Frameworks

The theoretical importance of this paper lies in its contribution to the understanding of technology adoption, particularly in the context of smallholder farmers in South Africa. By incorporating well-established theories such as Innovation Diffusion Theory (IDT) and the Theory of Planned Behavior (TPB), this paper enriches the theoretical landscape of agricultural technology adoption in a developing country context. The adoption of TELA maize seeds by smallholder farmers in Alfred Nzo District, Eastern Cape, can be effectively analysed using Innovation Diffusion Theory (IDT) and the Theory of Planned Behavior (TPB).

These theories offer complementary frameworks for understanding the factors that influence the decision-making process and adoption of agricultural innovations such as TELA maize seeds.

2.1. Theory of Planned Behavior

The Theory of Planned Behavior focuses on the factors that influence an individual's intention to engage in a behavior, such as adopting a new agricultural technology. TPB posits that three key factors shape behavioral intentions and, ultimately, behavior [3]. A farmer's attitude towards TELA maize will play a significant role in whether they decide to adopt it. If farmers view TELA maize positively (e.g., seeing it as beneficial for increasing crop yields or reducing the need for pesticides), they are more likely to adopt it. Negative attitudes, perhaps because of concerns about genetic modification, could hinder adoption [4]. The influence of social networks and community norms is crucial. If respected peers, local agricultural extension officers, or community leaders endorse the use of TELA maize, other farmers may feel socially pressured or encouraged to adopt it. Conversely, if there is skepticism or disapproval in the community, adoption could be limited. Farmers will assess their ability to adopt TELA maize based on factors such as access to seeds, affordability, and the perceived ease of using the new technology. If farmers feel that they have the resources (financial, technical, and knowledge-based) to adopt TELA maize successfully, their perceived behavioral control will be high, making adoption more likely [5].

2.2. Innovation Diffusion Theory

Innovation Diffusion Theory, developed by Rogers [6], focuses on how innovations (such as new technologies) are communicated and adopted across a social system. IDT identifies several factors that influence the adoption process, which is particularly useful for understanding the uptake of TELA maize seeds among smallholder farmers in Alfred Nzo District, Eastern Cape. Due to its relative advantages, TELA maize seeds are genetically modified to resist specific pests, improving yield and reducing crop losses. Smallholder farmers in the region may be more likely to adopt TELA maize if they perceive it as offering a clear advantage over traditional maize varieties, such as higher productivity and reduced pesticide costs; however, it depends on how well it fits with the farmers' existing practices, needs, values, and how easy it is to understand and use that particular technology. The other contributing factor to technology adoption is the possibility of demonstrating through trials the effectiveness of that particular technology and, last, observing the benefits of adopting TELA maize seed.

3. Conceptual Framework Evaluating the Adoption of TELA Maize Seed

Technology adoption amongst farmers is influenced by a number of factors that determine whether a farmer can develop a positive interest and willingness in the innovation or technology being introduced to them. Mabaya et al. [7] argued that the diffusion and adoption of a specific technology are influenced by the effectiveness of extension services and the manner in which information is disseminated and reaches farmers. Even so, appropriate extension methods cannot fully guarantee adoption as technology is capital-intensive.

The farmers carefully consider a wide range of criteria before deciding whether to use new technology; however, the uptake of better agricultural technology is the degree to which a potential adopter can test the technology on a modest scale before fully adopting is an indicator that is considered before adoption. The most important factor in the adoption decision-making process is the nature of the technology. If the technology is extremely complicated and challenging to use, farmers will not be drawn to use it. Furthermore, ref. [8] argued that technology is divisible and can address the farmer's needs, such as highyielding variety, fertilizer, herbicides, pesticides, and so forth. Farmers can consider testing the innovation on a small scale and will be willing to adopt, but if it is lumpy, small-scale trials are impossible, and the farmer may be more reluctant to adopt.

According to Chima and Rahman [9], the cost of adopting new technology in farming for improved maize production is very critical. In a study conducted by Martey et al. [6,10] on price determinants of maize production inputs such as hybrid maize seeds, fertilizer, and herbicides, the authors indicated that they require high capital. Several studies have reported that off-farm is the most important strategic system for solving credit constraints that act as a barrier to rural farmers in less developed countries. Dysfunctional rural economies and unprogressive governmental programs that do not meet the needs of the farmers also influence the production progress of these farmers.

Studies by Yokamo [8] and Wossen et al. [11] noted that by improving awareness of new technologies, smallholder farmers were found to strongly adopt technologies that they perceive or believe are useful and in line with their needs and are the ones who are easily adaptable and worth on their farm.

Moreover, the provision and linking of rural smallholder farmers to infrastructure and agricultural development were among the issues limiting and influencing technology adoption in developing countries [12]. Anang [13] noted that technology adoption by smallholder farmers is also tied up to government policies, which in many African countries become the most constraint; however, the policies are mostly imposed to promote or ban certain technologies, depending on their nature and their benefits. Arguably, these promoted or introduced technologies are reported to be easily adopted by farmers if training and research support are linked to farmers. Based on a study by Gao et al. [14], the provision of basic services such as water and proper roads play a part in influencing the attitude and behavior of farmers to adopt new technologies.

Moreover, Figure 1 illustrates that the adoption of TELA maize seeds enhances productivity, which in turn contributes to improved productivity and increased crop yields, bolstering food security. Conversely, the non-adoption of these seeds can lead to diminished production, resulting in lower productivity, reduced yields, and increased food insecurity.

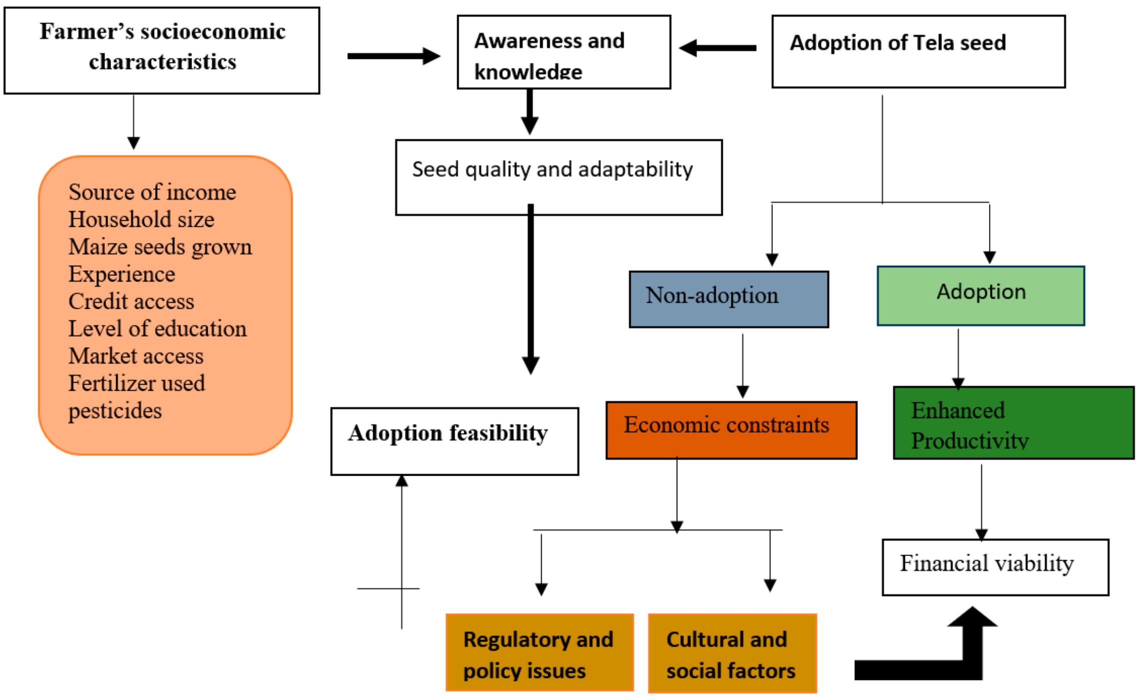

Figure 1. Conceptual Framework for adoption of Tela seeds by smallholder farmers. Source: Author's compilation, 2022.

Several socio-economic factors influence the decision to adopt TELA maize seeds. These factors include gender, marital status, education level, and occupation. Each of these aspects can affect farmers' willingness and ability to embrace new agricultural technologies.

In summary, the choice to adopt TELA maize seeds is not solely a matter of technology but is significantly shaped by socio-economic contexts and personal circumstances. Moreover, the productivity of TELA maize seeds translates into increased agricultural output depending on various characteristics and resources available to the farmers. Understanding these interconnected elements is crucial for promoting the effective use of Tela maize seeds and enhancing overall agricultural productivity and food security.

4. Methodology

4.1. Description of the Study Area

This study was carried out in South Africa, located at the Southern tip of the African continent. With an estimated land area of 1,220,000 km^2, South Africa shares borders with Zimbabwe, Namibia, and Botswana. The country is semiarid, characterized by a low average annual rainfall of 450 mm and a modest mean annual runoff of 8.6%. South Africa is divided into nine (9) provinces, with the Eastern Cape being one of them. Eastern Cape Province is the second largest province by surface area and is also considered the poorest of the nine provinces of South Africa. This study was specifically conducted in the Alfred Nzo District, which is one of the nine districts in the Eastern Cape. The district extends from the Drakensberg Mountains, bordering Lesotho to the North. To the east, it is bordered by the Sisonke District Municipality, while the O.R. Tambo District Municipality lies to the South [15]. Geographically, Alfred Nzo District lies at approximately 30°48′ S latitude and 29°22′ E longitude, placing it within the broader region of Southern Africa of the African continent. It has a total area of 10,731 km^2 and consists of seven major towns, with a total population of 936,462. The unemployment rate of the municipality is 77.58%. For their livelihoods, 36% of the population depends on social grants.

Agriculture is the primary economic activity in Alfred Nzo District; however, the district faces challenges in terms of economic development and agricultural expansion, as much of the farming is limited to traditional subsistence farming. Alfred Nzo District exhibits a climate that varies due to its diverse topography and altitude. The district is generally characterized by high rainfall and mild to warm temperatures, from 7 degrees in winter to 22 degrees in summer.

4.2. Research Design

A mixed research design in this study allowed for a richer, more nuanced exploration of the factors influencing smallholder farmers' adoption of TELA maize seeds. This comprehensive approach not only enhances the validity of the findings but also ensures that the research addresses the multifaceted nature of agricultural practices and decision-making. This study applied a cross-sectional research design where data were collected at one point on several variables, such as socio-economic and demographic factors influencing the willingness and ability to adopt TELA maize seeds.

4.3. Population, Sample Size, and Sampling Procedure

This study was conducted in Alfred Nzo District, chosen purposefully for its high density of smallholder maize farmers in the Eastern Cape. A multi-stratified random sampling method was employed to capture a representative sample of the district's diverse farming population. The population was first divided into strata based on distinct characteristics, including farm size and farming practices. Within each stratum, farmers were then randomly selected to achieve a total sample of 120. This approach ensured that the sample reflected a broad spectrum of socioeconomic conditions, enhancing this study's capacity to draw meaningful, unbiased conclusions applicable to all maize farmers in the district.

4.4. Method of Data Collection

This study utilized a structured approach to data collection involving both primary and secondary data sources. Farmers selected for interviews were visited prior to the actual data collection to communicate the purpose of this study and gather preliminary insights. This initial engagement helped build rapport and ensured that participants were informed and comfortable with the process. In addition, data collection tools were pre-tested on 12 farmers to assess their reliability and validity.

Primary data were collected through structured interviews with smallholder farmers in Alfred Nzo District. The interviews focused on various aspects of TELA maize adoption, including technical efficiency, challenges faced, and personal motivations. Relevant secondary data sources, such as agricultural reports and the academic literature, were also reviewed to complement and contextualize the findings from primary data.

4.5. Data Processing and Analysis

Once these data were collected, it was coded and captured in a spreadsheet using Microsoft Excel 365 (version 2409). These coded data were then exported to STATA (version 16) for further analysis. Various statistical tests and econometric models to identify the socioeconomic characteristics of farmers and factors influencing the adoption of TELA maize seed were conducted. The methods used for the data analysis are explained below.

4.5.1. Descriptive Statistics

This study employed a descriptive statistic to provide an overview of the respondents' socioeconomic characteristics. This section of this study aims to examine the socio-economic attributes, farming activities, and production systems of the sampled farmers. Tools for descriptive statistics included frequency tables for categorical variables and calculation of average mean, maximum, minimum, and standard deviation for continuous variables.

4.5.2. Probit Regression Model

The adoption of TELA maize seed hybrid technology by smallholder farmers is influenced by a variety of factors spanning demographic, socioeconomic, and technology-specific characteristics [16]. The factors influencing the adoption of Tela maize seed hybrid technology often draw on utility maximization theory. This theory suggests that individuals make decisions based on rational choices, aiming to maximize their satisfaction. This provides a theoretical framework to understand how and why farmers decide to adopt (1) or not adopt (0) Tela maize seed hybrid technology. The adoption function is defined as follows:

$$Y_i = \begin{cases} 1\ if\ u_i \geq 0 \\ 0\ if\ u_i < 0 \end{cases} \tag{1}$$

where Y_i represents a threshold assumed to be zero. A normal distribution of errors is assumed as follows:

$$P(Y=1) = \int_{-\infty}^{\beta' x} \varnothing(t)dt = \phi\ (\beta' x) \tag{2}$$

where a normal distribution is represented as ϕ, Y = 1 represents the adoption of Tela maize seed hybrid technology, x represents explanatory variables that are most likely to influence farmers' adoption of Tela maize seed hybrid technology. Moreover, marginal effects are estimated as follows:

$$\frac{\partial E\ (Y \mid \mathrm{x})}{\partial x} = \phi\ (\beta' x)\ \beta \tag{3}$$

Moreover, the marginal effects of dummy variables are presented as follows:

$$P(Y = 1 \mid X., \ d = 1) - P(Y = 1 \mid X., \ d = 0) \quad (4)$$

where x indicates the mean value of all continuous variables, the model estimating the adoption of Tela maize seed hybrid technology is given as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + \varepsilon \quad (5)$$

where:

Y = Dependent variables
β = Vector of parameters to be estimated
X = Set of explanatory variables (Independent variables)
ε = Error term

Table 1 provides a summary of the explanatory variables used in this study, detailing the type of measurement and outlining the proposed theoretical relationship between these variables and the dependent variable. Data for this study were collected between December 2023 and March 2024.

Table 1. The variables and measurement levels utilized in the probit regression model, along with the a priori expectations.

Variables	**Measuring Type**	**Expected Sign**
(Y) Adoption of TELA maize seed (Yes = 1 or No = 0)	Dependent variable	
Independent/explanatory variables (X)		
X_1 = Gender of farmer	Binary: Male = 0, Female = 1	+
X_2 = Age of farmer (years)	Continuous 1, 2, 3, 4, 5.	+/−
X_3 = Educational level (years)	Categorical: 1 = primary, 2 = secondary, 3 = tertiary, 4 = no formal education = 5	+
X_9 = Primary occupation	Categorical: 1 = Farmer, 2= Other businesses, 3 = Employed, 4 = Unemployed	−/+
X_4 = Household size	Categorical: 0–5 = 1, 6–10 = 2, 11–20 = 3	+
X_5 = Access to land	Binary: Yes = 1, No = 0	−
X_6 = Farm size (hectares)	Categorical: 0–4 Ha = 1, 5–19 Ha = 2, 20–49 Ha = 3, 50+ Ha = 4	−
X_7 = Access to maize training	Binary: 1 = Yes, No = 0	−
X_8 = Access to extension	Binary: 1 = Yes, 0 = No	−
X_9 = Access to credit	Binary: Yes = 1, No = 0, don't know = 2	−
X_{10} = Cooperative membership	Binary: Yes = 1, No = 0	+/−
X_{11} = Household annual income (ability)	Continuous	+/−
X_{12} = Willingness to adopt	Binary: Yes = 1, No = 0	+/−
X_{13} = Farmers' perception of risk	Categorical: risk-averse = 1, risk-neutral = 2, risk-preferer = 3	+

Source: Author's estimation, 2024.

5. Results and Discussion

5.1. Reliability, Validity and Trustworthiness

According to Jebb et al. [17], the reliability, validity, and trustworthiness of a data collection tool are essential measures of effectiveness and quality. Prior to conducting an analysis of quantitative data, the researchers evaluated the reliability, validity, and trustworthiness of the questionnaire. Reliability refers to the consistency, stability, and dependability of the measurement results, implying the degree of trustworthiness in data collected by the questionnaire. Typically, Cronbach's Alpha coefficient is used to assess the reliability of these data, with values ranging from 0 to 1. A value closer to 1 shows stronger reliability, while a value closer to 0 suggests weaker reliability. In this study, the authors obtained a reliability value of 0.6, indicating good reliability.

Regarding validity, the authors defined it as the method that assesses the accuracy of the content. The Kaizer–Meyer–Olkin test is commonly used to measure validity, with values ranging from 0 and 1. Values closer to 1 indicate a strong correlation, while values closer to 0 suggest otherwise. In this study, the KMO value was 0.65, implying good validity.

Additionally, the questionnaire was pre-tested by handing out a sample of 10 questionnaires to maize farmers in the Alfred Nzo District, who were evaluated on their responses to the research questions. The questionnaire's content validity was determined using the designed questionnaires and responses. Content validity and reliability were considered with the goal of determining whether the wording of the questions is understandable and achievable and that they are arranged appropriately.

5.2. Demographics and Socio-Economic Characteristics of Smallholder Farmers

Understanding the socio-economic characteristics of the respondents is crucial as it plays a major role in influencing rural household's attitudes towards the adoption of Tela maize seed technology [18]. Socio-economic characteristics track economic progress and social change and generally describe households' state of well-being, whereas demographic characteristics study a population based on factors such as age, gender, educational level, marital status, and occupation. Tables 2 and 3 present the summary statistics of demographics and socio-economic characteristics of farmers.

Table 2. Demographics and socio-economic characteristics of farmers (continuous variables).

Variable	Description	Average Mean	Min	Max	Std.Dev
Age	Non-adopters	57.88	29	82	14.46
	Adopters	56.88	30	82	11.93
	Combined	57.53	29	82	13.58
Farm size	Non-adopters	1.29	4	1	0.58
	Adopters	1.43	4	1	0.58
	Combined	1.34	4	1	0.95
Household size	Non-adopters	1.94	1	3	0.67
	Adopters	2.05	1	3	0.76
	Combined	1.98	1	3	0.70
Farming experience	Non-adopters	2.90	1	5	0.93
	Adopters	2.95	2	5	0.99
	Combined	2.92	1	5	0.95

Table 2. *Cont.*

Variable	Description	Average Mean		Min		Max		Std.Dev
Farming experience	In other businesses	4	5.13	8	19.05	12	10.00	
	Unemployed	11	14.10	9	21.43	20	16.67	
	Employed	4	5.13	5	11.90	9	7.50	

Abbreviations: Max, Min, and SD; maximum, minimum, and standard deviation. Sources: Findings, 2023.

Table 3. Demographics and socio-economic characteristics of farmers (categorical variables).

Variable	Description	Non-Adopters (N = 78)		Adopters (N = 42)		Overall Sample (N = 120)		Chi-Square
		N	%	N	%	N	%	
Gender	Male	51	65.38	27	64.29	78	65	0.014
	Female	27	34.62	15	35.71	42	35	
Marital Status	Single	20	25.64	8	19.05	28	23.33	4.72
	Married	41	52.56	23	54.76	64	53.33	
	Divorced	1	1.28	2	4.76	3	2.50	
	Widowed	16	20.54	9	21.43	25	20.84	
Education level	Primary	12	15.38	6	14.29	18	15.00	3.85
	Secondary	35	44.87	20	47.62	55	45.83	
	Tertiary	12	15.38	11	26.19	23	19.17	
	No formal education	19	24.36	5	11.90	24	20.00	
Primary occupation	Farmer	59	75.64	20	47.62	79	65.83	11.10
	In other businesses	4	5.13	8	19.05	12	10.00	
	Unemployed	11	14.10	9	21.43	20	16.67	
	Employed	4	5.13	5	11.90	9	7.50	

Sources: Findings, 2023.

According to Christian et al. [19], gender is an important variable in decision-making within a household. In this study, there were more male-headed households than female-headed households. As presented in Table 3, overall, 65% were male-headed households, while 35% were female-headed. These observations are in line with those of Kibirige et al. [20], who noted that men dominate farming in the region, with women largely confined to household duties.

Table 2 shows that the minimum age of farming household heads was 29 years old, while the maximum age was 82 years old, with the mean average age for the overall sample being 57.53. This means that age distribution among farmers was fairly old, indicating an effect on the adoption of new technologies or practices, with younger farmers potentially being more open to change. Similarly, a study by Odile and Tung [21] found that the average household age was 50 years, with a notable old population of farmers.

The results in Table 2 indicate that the average farm size among the sampled farms is 1.34 hectares. This means that, on average, farms are slightly larger than 1 hectare but smaller than 1.5 hectares. The maximum farm size recorded is 4 hectares, with the minimum size of 1 hectare, indicating smaller-sized farms. In contrast, a study by Chete [22] suggested that farm size is a key determinant of technology adoption. More hectares of farming land with good financing capital tend to be able to invest in improved seeds, while farms with fewer hectares were more reliant on traditional seeds and practices.

The results in Table 2 indicate that the average household size is 1.98 individuals, which is slightly less than 2. This suggests that many households are small, likely consisting of one or two members. The minimum household size is one, indicating that there are single-person households, while the maximum of three suggests that larger households are relatively rare.

The results indicate that the average farming experience among respondents is 2.92 years, suggesting that most farmers in this group have relatively limited experience, generally just under three years (Table 2). The minimum of 1 year implies that some farmers are quite new to farming, while the maximum of 5 years shows that a few individuals have more substantial experience.

This study found that the majority (53.3%) of farmers were married (Table 3). The stability of married households can enhance decision-making processes and foster a supportive environment for adopting new technologies.

Farmers were asked about educational attainments, measured using the number of years spent at school. Table 3 shows a troubling trend, with only 15% having primary education, 46% secondary, 19% tertiary, and 20% with no formal education. This aligns with findings by Uematsu and Mishra [23] on the generally low educational levels of rural farmers in South Africa and Jain [24], who highlight the correlation between education and poverty. Low education levels can limit farmers' understanding and application of advanced agricultural techniques.

A striking 75.64% of farmers engaged primarily in farming are non-adopters of new technologies (Table 3). Conversely, those in other businesses (19.65% adoption) seem more open to innovation, potentially due to greater financial stability and resource availability. The high rate of non-adoption among farmers may reflect resistance or lack of awareness regarding new technologies. Farmers engaged in diverse income-generating activities might possess the flexibility and resources needed to explore new practices, whereas full-time farmers could be constrained by traditional practices and limited access to innovation.

5.3. Factors Influencing Adoption of TELA Maize Seed

The adoption of TELA maize seed is essential for enhancing agricultural productivity and ensuring food security. Understanding the factors that influence farmers' decisions to adopt this innovation is crucial for promoting sustainable maize production. Table 4 presents results from the probit regression model on the factors influencing the adoption of TELA maize seed.

Table 4. Factors influencing adoption of TELA seed by smallholder maize farmers.

Non-Adopter/Adopter	Coefficient	Standard Error	Z	$p > \|z\|$	[95% Conf. Interval]	
Constant	1.298887	1.347211	0.96	0.335	−1.341598	3.939372
Gender	1463718	0.2778348	0.53	0.598	−0.3981744	0.6909181
Age	0.004325	0.010696	0.40	0.686	−0.0166387	0.0252888
Level of education	−0.2012804	0.1458171	−1.38	0.167	−0.4870767	0.0845158
Primary occupation	0.2236672	0.0967373	2.31	0.021 **	0.0340655	0.4132689
Household size	0.004364	0.2152355	0.02	0.984	−0.4174898	0.4262177
Access to land	−0.0871814	0.4766179	−0.18	0.855	−1.021335	0.8469726

Table 4. *Cont.*

Non-Adopter/Adopter	Coefficient	Standard Error	Z	$p > \lvert z \rvert$	[95% Conf. Interval]	
Farm size	0.0498339	0.2295235	0.22	0.828	−0.400024	0.4996917
Access to training	−0.221537	0.2879055	−0.77	0.442	−0.7858214	0.3427475
Access to extension and advisory services	−0.5903429	0.2884007	−2.05	0.041 **	−1.155598	−0.0250878
Access to credit	−0.553661	0.2364052	−2.34	0.019 **	−1.017007	−0.0903153
Cooperative membership status	0.3798155	0.3282004	1.16	0.247	−0.2634455	1.023077
Probit Regression Information						
Number of observations = 120	LR $chi^2(11) = 21.87$			Prob > $chi^2 = 0.0254$		
Log-likelihood = −66.75681			Pseudo $R^2 = 0.1408$			

Note: ** $p < 0.05$ means significance at 5% levels of significance. Source: Probit model results, 2023.

Gender and age are both statistically insignificant predictors of adoption likelihood at $p > 0.05$. Although each has a slight positive coefficient, the lack of significance implies that these factors do not substantially influence the adoption decisions of the farmers; however, these findings are contrary to a study by Mdoda et al. [25], that male farmers are more receptive to newly introduced innovation than female farmers. According to Christian et al.'s study [26], age was seen as a factor that significantly contributes to decision-making of putting innovation into practice, as indicated that as household heads keep increasing on a yearly basis, the chances of technology adoption decrease gradually. In many societies, farming is traditionally seen as a male-dominated activity. Men are often the primary decision-makers when it comes to adopting new agricultural practices and technologies. Their role in the public sphere shows a higher receptiveness to innovation and farming technology. Moreover, socioeconomic factors, access to resources, risk appetite, and cultural norms all play significant roles in shaping the willingness and ability of farmers to embrace new agricultural technologies.

The level of education shows a non-significant, slightly negative effect on adoption. This could indicate that higher education levels might be associated with a more critical assessment of the adoption decision, possibly leading to hesitation; however, given the lack of statistical significance, education does not appear to affect adoption meaningfully, meaning adoption outreach efforts could focus on individuals with varied educational backgrounds.

As a statistically significant predictor at $p = 0.021$, primary occupation positively influences adoption likelihood. This indicates that individuals whose primary occupation is farming are more inclined towards adoption. A study by Gcaba et al. [27], found those who are into other businesses are more likely to adopt new technologies, among others, as affordability is high for them.

Household Size has a negligible, non-significant effect on adoption. This finding suggests that household size does not have any influence on the adoption of new technologies; however, similar to a study by Christian et al. [26], in smaller households, adoption was less likely to occur, whereas larger households might adopt new technologies for labor or resource-sharing reasons only.

Access to land and farm size exhibit non-significant effects on adoption, with access to land showing a slightly negative coefficient and farm size a slightly positive one. The non-significance of these variables implies that land resources alone do not impact adoption likelihood. This could reflect the fact that, in some cases, the need for adoption is not tied to land quantity but to the perceived benefits or utility of the adoption itself. Hence, land availability and farm size may not be direct barriers or motivators.

Access to training has a non-significant, negative effect on adoption, suggesting that training availability does not meaningfully impact adoption decisions; however, this points to a potential gap in the training approach, suggesting that training programs need to be more tailored and specific to influence adoption positively.

This variable is significant at p = 0.041 and negatively associated with adoption likelihood. This finding implies that if advisory services are intended to promote adoption, they may need to refocus their messaging to better balance the benefits and risks associated with adoption [28].

Access to credit is also a significant predictor at p = 0.019, showing a negative relationship with adoption likelihood. Credit access is often expected to enable individuals to invest in new practices or technologies; however, a few explanations might clarify this outcome. Individuals with access to credit may prioritize other, more pressing financial needs, or the type of credit available might not support adoption-related expenses directly.

Cooperative membership has a positive coefficient, but it is statistically insignificant, indicating that cooperative membership alone does not significantly impact adoption likelihood. Cooperatives often serve as platforms for knowledge sharing and resource pooling, which could encourage adoption [29].

6. Conclusions and Policy Recommendation

The findings underscore the need for multifaceted approaches to enhance technology adoption among farmers. Addressing gender disparities, improving educational access, supporting various household structures, and engaging resistant farmers through targeted interventions will be essential for fostering an environment conducive to agricultural innovation and development in Alfred Nzo District Municipality.

The results of the stochastic frontier model reveal critical insights into the factors affecting technical efficiency among maize farmers. Addressing financial constraints, improving access to credit, and fostering technology adoption are essential for enhancing productivity. Additionally, strategies to engage cooperatives, provide effective extension services, and improve market access will be crucial in promoting sustainable maize production among smallholder farmers.

To enhance technology adoption among maize farmers in Alfred Nzo District Municipality, a multifaceted approach is essential. This should begin with targeted gender equity programs that empower women farmers through training and resources, fostering their participation in agricultural decision-making. Additionally, improving educational access is crucial; practical agricultural literacy programs can equip all farmers with the necessary skills to adopt modern farming technologies. Support for diverse household structures, particularly through community-based groups, can ensure that varying needs are met and resources are effectively shared. By accelerating adoption through these actions, TELA maize can significantly boost food security, enhance productivity, and improve the livelihoods of smallholder farmers, particularly those in regions vulnerable to climate change and drought. The strengthening of policies related to seed access, financing, market access, and farmer empowerment will ensure the long-term success and sustainability of this initiative.

Moreover, addressing financial constraints is vital. Establishing microfinance initiatives tailored for smallholder farmers can enhance access to credit for purchasing essential inputs such as TELA seeds and fertilizers. Engaging cooperatives in a way that revitalizes their membership and incorporates younger, tech-savvy individuals can further boost efficiency. Strengthening extension services to provide relevant support and improving market access through better infrastructure and organized buyer connections will be key to promoting sustainable maize production. By implementing these strategies collaboratively among stakeholders, the region can create an environment conducive to agricultural innovation and growth.

Author Contributions: Conceptualization, K.G. and M.C.; Data collection, K.G.; Writing, revising, and editing of the final paper, M.C., K.G., S.L. and D.J.; Funding acquisition, K.G. and M.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research work received no external funding.

Institutional Review Board Statement: The research was conducted as part of an MSc study approved by the Ethic Research Committee (FNASREC) of the North-West University (NWU-01207-23-A9).

Informed Consent Statement: The research collected data from the farmers in Alfred Nzo District Municipality. The respondents signed an informed consent and approval to conduct research in the study areas was granted by the office of the District Mayor.

Data Availability Statement: All data and materials used in this study are available upon request from the authors.

Acknowledgments: The authors are very grateful to the Department of Rural Development and Agrarian Reform (DRDAR) and private agricultural organizations for assisting in identifying farmers who were affected by climate change in the study area. Most importantly, we thank the smallholder farmers in the project areas for their time and willingness to provide data. The enumerators are also recognized for their sacrifice in self-administering the questionnaires and in ensuring that farmers are assisted in translating and breaking down questions for respondents.

Conflicts of Interest: The authors declare that there are no financial or non-financial competing interests. The authors declare no conflict of interest.

References

1. Mulungu, K.; Ng'ombe, J.N. Climate change impacts on sustainable maize production in Sub-Saharan Africa: A Review. In *Maize: Production and Use*; IntechOpen: London, UK, 2019; pp. 47–58.
2. Manda, J.; Gardebroek, C.; Kuntashula, E.; Alene, A.D. Impact of improved maize varieties on food security in eastern Zambia: A doubly robust analysis. *Rev. Dev. Econ.* **2018**, *22*, 1709–1728. [CrossRef]
3. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [CrossRef]
4. Ajzen, I. Perceived behavioral control, self-efficacy, locus of control, and the theory of planned behavior. *J. Appl. Soc. Psychol.* **2002**, *32*, 665–683. [CrossRef]
5. Bandura, A. Self-efficacy: The exercise of control. *J. Cogn. Psychother.* **1997**, *13*, 158–166. [CrossRef]
6. Rogers, E.M. *Diffusion of Innovations*, 5th ed.; Free Press: New York, NY, USA, 2003.
7. Mabaya, E.; Fulton, J.; Simiyu-Wafukho, S.; Nang'ayo, F. Factors Influencing Adoption of Genetically Modified Crops In Africa. *Dev. S. Afr.* **2015**, *32*, 577–591. [CrossRef]
8. Yokamo, S. Adoption of improved agricultural technologies in developing countries: Literature review. *Int. J. Food Sci. Agric.* **2020**, *4*, 183–190. [CrossRef]
9. Rahman, S.; Daniel, C. Determinants of modern technology adoption in multiple food crops in Nigeria: A multivariate probit approach. *Int. J. Agric. Manag.* **2015**, *4*, 100–109.
10. Martey, E.; Etwire, P.M.; Kuwornu, J.K. Economic impacts of smallholder farmers' adoption of drought-tolerant maize varieties. *Land Use Policy* **2020**, *94*, 104524. [CrossRef]
11. Wossen, T.; Abdoulaye, T.; Alene, A.; Haile, M.G.; Feleke, S.; Olanrewaju, A.; Manyong, V. Impacts of extension access and cooperative membership on technology adoption and household welfare. *J. Rural Stud.* **2017**, *54*, 223–233. [CrossRef]
12. Fadeyi, O.A.; Ariyawardana, A.; Aziz, A.A. Factors influencing technology adoption among smallholder farmers: A systematic review in Africa. *J. Agric. Rural Dev. Trop. Subtrop.* **2022**, *123*, 13–30. [CrossRef]
13. Anang, B.T. Farm Technology Adoption By Smallholder Farmers in Ghana. *Rev. Agric. Appl. Econ. (RAAE)* **2018**, *21*, 41–47. [CrossRef]
14. Gao, Y.; Zhao, D.; Yu, L.; Yang, H. Influence of a new agricultural technology extension mode on farmers' technology adoption behavior in China. *J. Rural Stud.* **2020**, *76*, 173–183. [CrossRef]
15. Municipalities of South Africa, Alfred Nzo District Muncipality (DC44). Available online: https://municipalities.co.za/map/101/alfred-nzo-district-municipality (accessed on 20 January 2025).

16. Gaya, H.; Tegbaru, A.; Bamire, A.; Abdoulaye, T.; Kehinde, A. Gender differentials and adoption of drought tolerant maize varieties among farmers in Northern Nigeria. *Eur. J. Bus. Manag.* **2017**, *9*, 81–87.
17. Jebb, A.T.; Ng, V.; Tay, L. A Review of Key Likert Scale Development Advances: 1995–2019. *Front. Psychol.* **2021**, *12*, 637547. [CrossRef]
18. Agbugba, I.; Christian, M.; Obi, A. Economic analysis of smallholder maize farmers: Implications for public extension services in Eastern Cape. *S. Afr. J. Agric. Ext.* **2020**, *48*, 50–63. [CrossRef]
19. Christian, M.; Obi, A.; Zantsi, S.; Mdoda, L.; Jiba, P. The role of cooperatives in improving smallholder participation in agri-food value chains: A case study of one local municipality in Eastern Cape, South Africa. *Sustainability* **2024**, *16*, 2241. [CrossRef]
20. Kibirige, D.; Obi, A. Agricultural efficiency of smallholder farmers in Eastern Cape province of South Africa. *Int. J. Econ. Com. Manag.* **2015**, *3*, 269–289.
21. Odile, J.; Lim, T. Drought-tolerant GM maize as a climate-smart measure in South Africa: Promises, perils and precaution. *S. Afr. J. Environ. Law Policy* **2018**, *24*, 119–154. Available online: https://hdl.handle.net/10520/EJC-1a709ef39f (accessed on 20 January 2025).
22. Chete, O.B. Factors influencing adoption of improved maize seed varieties among smallholder farmers in Kaduna State, Nigeria. *J. Agric. Ext. Rural Dev.* **2021**, *13*, 107–114.
23. Uematsu, H.; Mishra, A.K. Can education be a barrier to technology adoption? In Proceedings of the Agricultural & Applied Economics Association 2010 AAEA, CAES, & WAEA Joint Annual Meeting, Denver, CO, USA, 25–27 July 2010.
24. Jain, P. Impact of Demographic Factors: Technology Adoption In Agriculture. *SCMS J. Indian Manag.* **2017**, *14*, 93–102.
25. Mdoda, L.; Tshotsho, A.; Nontu, Y. Adoption of mass media for agricultural purposes by smallholder farmers in the eastern cape province of South Africa. *S. Afr. J. Agric. Ext.* **2022**, *50*, 117–136.
26. Christian, M.; Obi, A.; Agbugba, I.K. Adoption of irrigation technology to combat household food insecurity in the resource-constrained farming systems of the Eastern Cape Province, South Africa. *S. Afr. J. Agric. Ext.* **2019**, *47*, 94–104. [CrossRef]
27. Gcaba, K.; Christian, M.; Usapfa, L. 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. *S. Afr. J. Agric. Ext.* **2024**, *52*, 148–165. [CrossRef]
28. Jiba, P.; Obi, A.; Mdoda, L.; Mzuyanda, C. The impact of smallholder irrigation scheme on household welfare in farm-managed irrigation scheme communities in the Eastern Cape province, South Africa. *S. Afr. J. Agric. Ext.* **2024**, *52*, 48–72. [CrossRef]
29. Christian, M.; Luvhengo, U.; Khobai, H.; Agbugba, I.K. Reviewing land access livelihood diversification strategies and factors influencing wellbeing of rural households in Mnquma, Eastern Cape: Implications to extension agents. *S. Afr. J. Agric. Ext.* **2020**, *48*, 113–125. [CrossRef]