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ARTICLE

Adoption of Genetically Modified Maize Technology in Ghana

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ABSTRACT

The paper investigates farmers' awareness of genetically modified maize technology, perceived challenges, willingness to adopt, and the factors influencing their decision. This research employs Binary Probit model and Kendall's constraint ranking technique for the analyses, based on cross-sectional data from 550 maize farmers across five regions in Ghana: Northern, Bono, Ashanti, Western, and Volta. The results demonstrate that 79% of the farmers are aware of GM maize, and 60% express willingness to adopt the technology. Key factors influencing their willingness to adopt genetically modified maize include age, farm size, experience, extension services, and input costs. The top three constraints farmers perceive are limited consumer demand for GM maize, high costs of planting materials, and concerns over the crop's potentially shorter lifespan. The study recommends intensifying GM maize awareness and benefits through workshops and educational initiatives. Additionally, direct sales channels for farmers should be promoted to boost their income. Furthermore, extension service delivery should be intensified with the needed logistics to enable them attend to the needs of farmers adequately, including the dissemination of GM crops. We also recommend that policymakers should develop channels through which farmers can sell their grains after harvesting so that they would be assured of a ready market for their GM produce.

Keywords: GMO Adoption; Perception; Probit Model; Constraints Kendall's Coefficient; Ghana

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1. Introduction

Globally, the estimated demand for cereals is about 2.5 billion metric tonnes, and it is expected to grow by about 382 metric tons annually between 2018 and 2028 [1]. Notable among widely consumed cereal is maize. It is estimated that global maize consumption is expected to grow by 1.1% annually, primarily due to increased feed demand [2]. Similarly, maize demand in Sub-Saharan Africa is projected to rise 2.3-fold over the next 30 years, which is influenced by demographic shifts and changes in dietary patterns [3]. Sub-Saharan African countries, including Ghana, tend to be most affected by such demand pressures and risk worsening the already food insecurity situation. For instance, Ghana has not been able to achieve its potential yield in maize, as it is only able to obtain about 2.0 mt/ha on average, against an achievable yield of about 6.0 mt/ha [4, 5]. Several factors are observed to account for the relatively wide gap between the actual and maximum yields possible. These include the persistent use of obsolete production technologies, such as planting materials like seeds, coupled with production inefficiencies [4]. Furthermore, initiatives and efforts to expand maize output have been skewed towards increasing land size rather than leveraging biotechnology to increase productivity. This is a development that could not be sustained, especially in the wake of increasing population and rapid urbanization, which creates a competing demand for land for both settlement and agricultural purposes. Domestic maize consumption is expected to reach 2.3 million metric tons by 2024 [6]. This calls for mitigation factors to be implemented to bridge the gap between supply and demand without compromising land for other purposes.

Maize is a key staple in nearly every Ghanaian household, featuring prominently in a wide range of dishes. It represents more than 50% of the country's total cereal production [7]. To increase maize yields, several projects and programs were implemented in the past five decades. These include the Ghana Grains Development Project (1979-1997) and the Food Crops Development Project (2000-2008), which were implemented and made significant contributions. In recent years, the Ghanaian government's initiatives to modernize the agricultural sector have prioritized maize as a vital food security crop, aligning with international and regional frameworks, such as the Comprehensive Africa Agriculture Development Programme (CAADP). For example, the Planting for Food and Jobs (PFJ) program focuses on providing improved seeds, fertilizers, extension deliveries, marketing support, and e-agriculture. Despite all these efforts, Ghana's maize production level is still one of the lowest volumes recorded globally [7]. Ghana's maize yield, which is currently estimated to be 2.66 metric tons per hectare, is relatively lower than the average maize yields in Africa and the Sub-Saharan as well [8]. In 2023, the actual maize yield recorded was 2.660MT/ha compared to the potential yield estimated at 6MT/ha [6].

With the fast-growing human population and expansion of settlements, vast parcels of land suitable for agricultural production are increasingly being converted into real estate development [8]. Furthermore, industrial demand for maize by the poultry sector is increasing and poses a threat to household demand for maize. Arable lands are also being destroyed through illegal mining activities and deforestation, which causes a decline in its supply for agricultural activities [9]. These developments represent problems of uncertainties hindering food security in Ghana.

Biotechnology is believed to have the potential to enhance food production in Africa and globally, addressing a major agricultural challenge [10]. While biotechnology has enabled the development of improved crop varieties with traits like drought tolerance and pest resistance [11], the adoption of genetically modified (GM) crops remains contentious, particularly in developing countries like Ghana. Existing research demonstrates the agronomic potential of GM technology to address food security challenges [12, 13]; however, significant gaps persist in understanding the barriers to farmer-level adoption in Ghanaian contexts.

Despite documented yield advantages of GM crops in experimental settings [14], real-world adoption rates remain low due to complex socio-cultural factors. European resistance to GM crops [15] and African consumers' concerns about safety [16] suggest that technical benefits alone cannot guarantee acceptance. In Ghana specifically, polarization persists between proponents who emphasize productivity gains Gakpo et al. [17] and critics who cite environmental and health uncertainties, with little empirical research examining how these competing narratives influence farmer decision-making.

Considering the recent developments, this paper examines farmers' awareness of GM maize, the perceived constraints they face, and the factors influencing their willingness to adopt GM maize technology. The rest of the paper adheres to these arrangements: Section two discusses GMO-related policy issues in Ghana; Section three highlights the methods employed in this study; Section four presents results and discussions; and Section five concludes and provides recommendations relevant for policy consideration.

GMO and Related Policy in Ghana

Genetically modified (GM) crops are the most widely used GMOs and were first commercialized in the mid-1990s. However, the decision to commercialize GMOs in any country is dependent on the political, regulatory, and legislative environment. Although the Food and Agricultural Organization provides information, advice, capacity-building assistance, and venues for interactions with its members regarding GMOs, it does not interfere with policies in relation to testing or the commercialization of GMOs in any country [18]. The legislative arm of the government of Ghana has sanctioned authoritative rule that makes it possible for the economy to ensure the commercialization of genetically modified crops (Act 831, 2011). The Ministry of Environment, Science, Technology, and Innovation introduced enabling legislation to the Parliament of Ghana for consideration and was approved on June 28, 2019, to allow for the introduction of genetically modified crops into the country. The legislation outlines the National Biosafety Authority's operational framework to ensure the safety of genetically modified (GM) foods. Adenle et al. [19] notes that the Plant Breeders' Bill, passed in 2013, supports the Biosafety Act and aims to establish a legal framework that fosters the development of new plant varieties and enhances food production in Ghana. Prior to the enactment of the Ghana Biosafety Law, the government's stance on biotechnology was influenced by other principles outlined in the National Science and Technology Policy (2017-2000), Ghana's constitution (Act 36, 41), and the Ghana Poverty Reduction Strategy (GPRS) documentation. The National Science and Technology Policy (2017-2000) emphasized the adoption of research and the application of new technologies, including safe biotechnology, which has the potential to increase agricultural yields and improve productivity. These efforts collectively served as a foundation for establishing a legal framework that would allow the country to choose the large-scale cultivation of GM crops and the sale of GMO products.

The government of Ghana is also committed to developing a new biotechnology program for the purposes of ensuring that the National Biosafety Authority proceeds in a way to create public awareness on issues related to genetically modified crops. This policy direction is targeted at policymakers, researchers, industry players, as well as farmers, based on the United Nations' Sustainable Development Goal 12. SDG 12 is concerned with the pressing need to alter the way agricultural produce is consumed, so that economic growth and sustainable improvement can be achieved in a manner that reduces, if not eliminates, ecological footprints. Furthermore, the SDG also advocates for the effective management of natural resources to provide for the basic needs of people, while the quality of the environment is not compromised. Accordingly, the Biosafety Act has realized a lot of successes in providing expertise for the safe and appropriate handling of GMOs through secured equipment for laboratory activities. The Environment, Science, Technology, and Innovation Ministry (MESTI) posits that biotechnology will go a long way in improving the crop sector in Ghana, despite the legal means to oppose and the display of dislike by anti-GMO entities, which call for an end to the introduction of GMOs in the country [20, 21]. MESTI has indicated that several Ghanaians may not be familiar with the GM technology, and this has led to widespread objections. This may be attributed to the fact that Ghana has not achieved maximum transparency regarding information on the commercialization of GMOs in the country [21]. The ministry, however, has noted that the government of Ghana bears with the public's concerns and will do well not to introduce any technology that may potentially be harmful to the health of the people.

In other developments, Ghana's Medium-Term National Development Policy Framework, specifically the Ghana Shared Growth and Development Agenda (GSGDA), along with the Food and Agriculture Sector Development Policy (FASDEP II), among other initiatives, promote the intensification of cultivation through the implementation of advanced technologies to enhance crop productivity. For instance, in the medium-term national development policy framework for GSGDA, significant emphasis has been placed on efforts to improve agricultural productivity and to enhance seed development for improved yields, among other things. The strategy aims to promote and adopt resilient, high-yielding crop varieties while giving the support for the production of certified seeds and enhanced cultivation materials for staple or industrial crops. The FASDEP II also encourages the use of biotechnology to improve productivity in the agricultural sector, and this can be seen in the document's last objective, which is the application of science and technology in agriculture development. This objective focuses on modernizing food and agriculture based on science and technology, which includes facilitating the passage of the biosafety bill that was passed in 2011. The purpose of this bill is to enhance food safety and facilitate the use of biotechnology tools in crop and livestock improvement research. Additionally, Ghana's Medium-Term Agriculture Sector Investment Plan (METASIP II), which was the implementation plan for FASDEP II, reflects the government's commitment to advancing seed and planting material development through biotechnology. This is reflected in its support for the growth and establishment of climate-resilient, high-yielding crops that are resistant to diseases and pests, all with a focus on ensuring the health and safety of consumers.

2. Materials and Methods

2.1. Study Area and Sampling

This paper is based on primary data collected from maize farmers across five administrative regions of Ghana. These regions include Northern, Bono, Ashanti, Western, and Volta (**Figure 1**). Maize is grown in all regions of Ghana, both on large and small scales. The chosen regions are considered the leading maize producers, together contributing more than 80% of the country's total maize output[22].

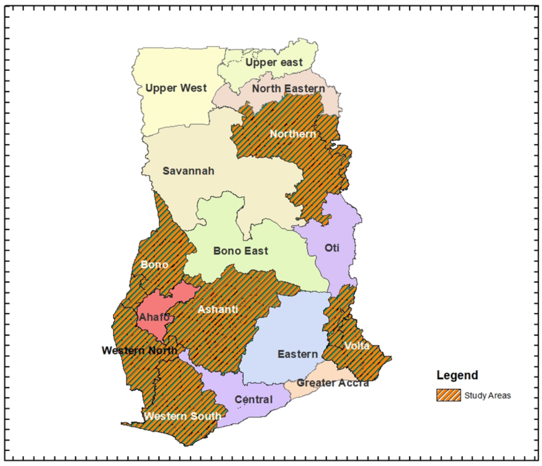

Figure 1. Administrative map of Ghana revealing the study regions.

The list of farmers selected for the study was sourced from the Food and Agriculture Ministry (MoFA), with support from district agricultural extension agents. A multi-stage sampling method, combining stratified and random sampling approaches, was adopted to select 603 farmers. However, the analysis focused only on commercial maize farmers, reducing the sample size to 550. The collected data encompassed socio-economic profiles, production details, awareness of GM crops, and factors influencing their decisions to grow GM maize. Data was gathered using a well-structured questionnaire, which was administered to respondents following a thorough pilot survey for validation.

2.2. Theoretical and Conceptual Framework

This paper is based on the Theory of Reasoned Action (TRA), developed by Fishbein et al.[23] and later improved by Nisson et al.,[24]. TRA explains how people decide to act, stating that behavior comes from intentions, which are shaped by attitudes and social pressures. According to TRA, a person's actual actions are best predicted by their intention to act. Intentions depend on two key factors: attitude toward the behavior and subjective norms. Attitude reflects how a person feels about a behavior, while subjective norms represent the social pressure they feel from others, such as friends, experts, or cultural expectations. TRA's dual focus on attitudes (individual perceptions of GM maize's benefits and risks) and subjective norms (social pressures, such as consumer acceptance) aligns perfectly with our key results, showing that adoption willingness is primarily influenced by informational and social factors rather than practical barriers. While the Theory of Planned Behavior adds perceived control and Diffusion of Innovation examines adoption patterns over time, TRA's streamlined approach better suits our cross-sectional study of intentional behavior, particularly given its established validity in GM food acceptance research where cultural values and social influence dominate economic considerations. TRA does not apply to behaviors that are quick, habitual, or done without thought because these do not involve a careful decision-making process [25]. This makes TRA useful for studying informed decisions, such as whether to buy genetically modified (GM) products, where people consider the risks and benefits. TRA highlights that knowledge and information shape attitudes, which influence intentions [23]. In the case of GM foods, research shows how information about the risks and benefits of such products affects people's views [26]. Also, people who encountered negative information about GM foods showed more dislike than those who did not [27]. On the other hand, consumers who received balanced, science-based information had lower rates of misunderstanding, supporting TRA's idea that informed attitudes guide behavior [28].

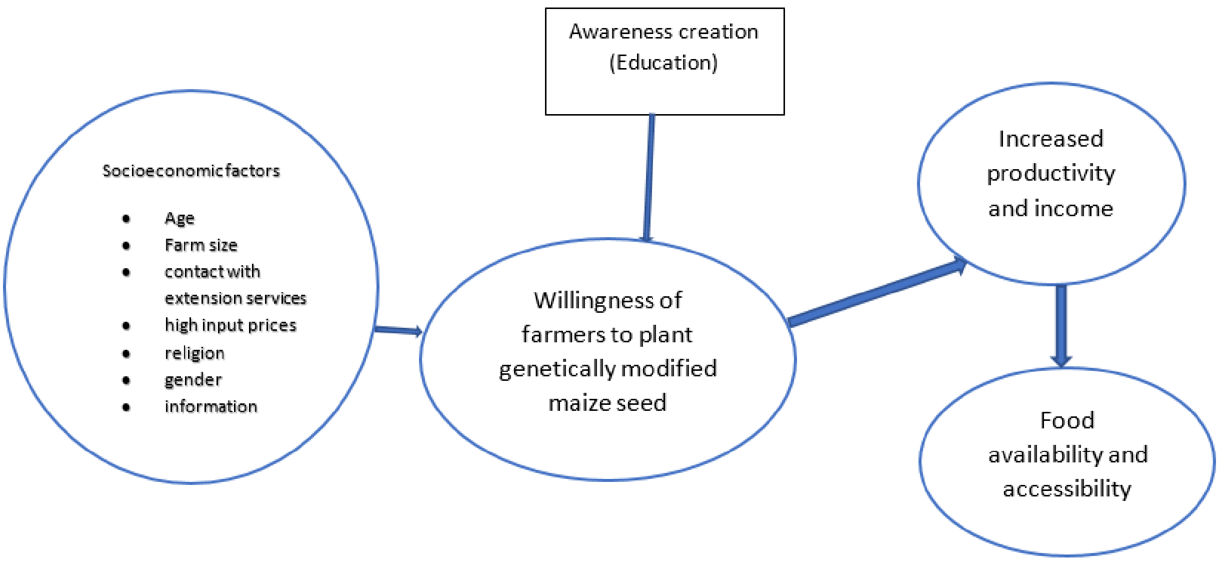

Figure 2. Conceptual framework.

The current study assumes that factors such as lack of education, misinformation, farm size, farmers' contact with extension service delivery, input prices, and other socioeconomic characteristics of farmers, including age and gender of primary decision maker of farm households, may influence their willingness to adopt farm technologies such as the use of genetically modified maize seeds for cultivation (**Figure 2**). For example, formal education is potentially perceived as preparing an individual to read and understand basic instructions, which can help erase some misconceptions and negative impressions about the adoption of genetically modified crops by farmers. Additionally, farmers' contact with agricultural extension service providers is important, as they receive good agronomic practices and innovative technologies that are practically demonstrated to them, enhancing their farming activities.

2.3. Statistical and Econometric Estimations

The paper employs descriptive statistics in terms of percentages to analyze the farmers who indicated their awareness of genetically modified maize seeds in the study area [Equation (1)].

$$\text{Percentage of farmers aware of GM maize seeds} = A/N \times 100 \quad (1)$$

Where A represents the number of farmers/respondents who are aware of GM maize seeds, and N denotes the total number of farmers interviewed.

The binary probit model is subsequently employed to analyze the factors influencing farmers' decisions to adopt genetically modified maize, as used in studies such as Anang[29], Ngcinela et al.[30], and Sravanth[31]. The use of probability choice models, such as the binary probit model, in adoption studies is often preferred over conventional linear regression models because they offer an alternative that addresses the weaknesses of linear regression models. For instance, the probit model provides parameter estimates that are asymptotically consistent and efficient, and it is specified in Equation (2).

$$P_i - prob[Y_i = 1 \mid X] = \int_{-\infty}^{X_i^o\beta} (2\pi)^{-1/2} \exp\left(-t^2/_2\right) dt = \phi(X_i^o\beta) \quad (2)$$

Where P_i is the likelihood of a farmer adopting a genetically modified maize technology, ϕ is the cumulative distribution of a standard normal random variable. $Y_i = 1$ is the noted response for the ith observation. $Y_i = 1$ refers to the likelihood of a farmer to adopt whilst $Y_i = 0$ stands for a maize producer who is not willing to adopt; and X_i are the vector of explanatory variables.

The marginal effect related to X_i on the probability $prob[Y_i = 1|X]$, keeping other factors fixed is expressed as Equation (3).

$$\frac{\partial(y_i = 1|x_i)}{\partial x_i} = \varphi(x_i\beta)\beta \quad (3)$$

Where x_i is the likelihood density function of a standard normal factor.

The marginal effects of a dummy variable Ω of a farmer who is willing to adopt GM maize technology are derived by Equation (4).

$$\Omega = \phi(\bar{X}\beta, d = 1) - \phi(\bar{X}\beta, d = 0) \quad (4)$$

Where d is a dummy variable.

The decision to adopt model (2) can be expanded as Equation (5).

$$\phi^{-1} = \sum_{j=0}^{j-n} \beta_j x_{ij} = \phi(\delta + \beta_1 x_{1i} + \beta_2 x_{2i} +, \ldots, +\beta_{ij} x_{ij}) + \varepsilon_i \quad (5)$$

Where δ and β_j's represent a constant term and parameter estimates respectively; and ε_i is the error term.

2.4. Empirical Model Specification and Definition of Variables

As discussed in the conceptual framework, the willingness of a farmer to adopt genetically modified maize is assumed to be influenced by the following factors, as shown in **Table 1**.

The explicit Probit model for this paper is specified in Equation (6).

$$P_i = \delta + \beta_1 Age_i + \beta_2 Gen_i + \beta_3 Inf_i + \beta_4 Ext_i + \beta_5 Fmz_i + \beta_6 Inp_i + \beta_7 Exp_i + \beta_8 Rsk_i + \beta_9 Edu_i \quad (6)$$

Table 1. Determining factors of GM maize technology adoption.

Variable	Description	Measure	*apriori* Expectation
Age (X_1)	Age of the farmer	Years	+/−
Gender (X_2)	Gender of the farmer	Dummy 1 = male; 0 = otherwise	+/−
Information (X_3)	Information on GM maize technology available to respondents	Dummy 1 = informed farmer; 0 = otherwise	+

Table 1. *Cont.*

Variable	Description	Measure	*apriori* Expectation
Extension contact (X_4)	Primary decision maker benefited from extension service	Dummy 1 = contact with extension service provider; 0 = otherwise	+
Farm size (X_5)	Total of all plots planted to maize by the respondent in the study period	Hectares (Ha)	+
Input price (X_6)	Price of GM maize seed	Ghana Cedis (GHS)	−
Experience (X_7)	The number of years of cultivating maize	Years	+/−
Risk Perception (X_8)	Farmers' risk perception about GM seeds	Dummy 1 = perceived to be risky; 0 = otherwise	+
Education (X_9)	Primary decision makers years of formal education	Years	+

2.5. Perceived Constraints to Farmers' Willingness to Plant GM Maize Seeds

Kendall's coefficient of concordance (W) and a chi-square test were used to examine the constraints that hinder farmers' adoption of genetically modified maize seeds. The coefficient (W) measures agreement involving individuals who are evaluating or ranking a band of subjects [32]. It is used to evaluate the extent to which respondents in a study provide consistent rankings on various issues. This method of analyzing farmers' perceived constraints is preferred over other measures, such as Garrett's ranking technique, due to its statistical and interpretational preferences. Moreover, in contrast to tests that rely on the standard Pearson correlation coefficient, which assumes normal distribution and matches two sets of outcomes at a time, Kendall's (W) does not assume a specific probability distribution and can accommodate any number of distinct outcomes. Kendall's (W) is calculated using Equation (7).

$$W = \frac{12(S)}{M^2(n)(n^2) - mT} \tag{7}$$

Where n represents the number of objects, m denotes variables of interest, T is the rectification factor, and S denotes the sum of squared statistic calculated on the row sums of ranks, R_i [Equation (8)].

$$S = \sum_{i=1}^{n} (R_i - R)^2 \tag{8}$$

Where R is the average of the R_i values, which is initially calculated from the row-marginal sums of the ranks (R_i) assigned to the objects.

T is defined for tied ranks, as shown in Equation (9).

$$T = \sum_{k=1}^{g} (t_k^3 - t_k)^2 \tag{9}$$

Where t_k represents the number of connected ranks in each k of g groups of ties. T is zero when there are no tied values.

In the absence of tied values, the Equation (10) simplifies as below.

$$W = \frac{12(S)}{M^2(n)(n^2 - 1)} \tag{10}$$

Where W is the outcome of the variance of the row sums of ranks (R_i), scaled by the maximum possible variance, which occurs when all variables are in complete agreement. Therefore,

$$0 \leq W \leq 1$$

When W is 1 it represents perfect agreement between the rankings and when it is 0 it denotes a perfect disagreement between the rankings [31]. The paper uses the Friedman's chi-square statistic to investigate the significance of the derived W. The chi-square statistic is calculated using Equation (11).

$$X^2 = m(n - 1)W \tag{11}$$

3. Results and Discussion

3.1. Socioeconomic Characteristics of Respondents

The average age of the farmers is estimated to be 46 years, indicating that the majority of maize farmers are within the middle age bracket. As shown in **Table 2**, the minimum age of farmers interviewed is reported to be 20 years, and the maximum is 81 years. However, based on the African Youth Charter and the United Nations definition of who a youth is, the paper categorizes ages as less than or equal to 35 years, which is about 30%, whilst 70% of the respondents are estimated to be more than 35 years of age. The implication is that the majority of the youth in the study area are not actively involved in farming activities, which corroborates the findings of Pelzon et al.,[33] that the youth are not interested in agriculture because of their relative less access to technical and financial support.

Table 2. Descriptive statistics of socioeconomic variables.

Variable	Mean	Minimum	Maximum	Standard Deviation
Age (years)	46	20	81	15
Gender	Percentage			
Males	68			
Females	32			
Education (years)				
Educated	48			
Uneducated	52			
Awareness of GM maize seed				
Aware	79			
Not aware	21			
Willingness to plant GM maize seed				
Willing	60			
Not willing	40			

The majority (68%) of farmers interviewed are males, with the remaining 32% being females (**Table 2**). This agreed with the assertion by Kuwornu et al.[34] that there are more male maize farmers in the study area compared to female farmers. In a typical traditional setting in Ghana, males own more productive assets, such as agricultural lands, compared to their female counterparts. Regarding the educational attainment of farmers, 48% of respondents have at least one year of formal education, while the remaining 52% indicated that they have had no formal education. This is consistent with Kuwornu et al.[34], who attributed this to the lack of educational facilities in rural communities and the fact that people of school-going age must trek several miles every day to access school.

According to **Table 2**, the paper revealed that 79% of the farmers interviewed indicated they were aware of genetically modified maize technology through various means, including radio or television programs, colleagues, agriculture extension service officers, and farmer workshops. In a study examining farmers' understanding and views on genetically modified crops (GM) crops, Zakaria et al.,[35] found that many leaders in farmer-based organizations (FBOs) in the Northern region of Ghana are aware of the genetically modified crops, with nearly two-thirds (64%) possessing a substantial understanding of the technology. These leaders ultimately pass on their technical knowledge to member farmers, helping to improve their agricultural practices. Zakaria et al.,[36] attributed the high level of awareness among farmers to the steady advances in the commercialization of genetically modified (GM) crops despite growing opposition. The steady progress involves the dissemination of radio and television messages on safety concerns, including health and environmental issues related to GM crops Ogwu et al.[37]. Therefore, widespread communication about the benefits of high-yielding, disease-resistant, and nutritionally enhanced crops achievable through GM biotechnology is crucial for increasing awareness among both farmers and consumers about GM crops [11].

The paper further found that the majority (60%) of farmers indicated their willingness to adopt the genetically modified maize, whilst the remaining 40% are not due to varied views including environmental issues, health concerns of consumers, as well as input prices. In related research, Adenle et al. [19] highlighted that several farmers are willing to cultivate genetically modified maize seeds mainly because of the perceived benefits they stand to gain in terms of yield, rather than necessarily understanding the concept of genetically modified technology. Barrows et al. [35] also observed that genetically engineered crops have the potential to enhance crop response to climate change while increasing the nutrient density of staple foods. The segment of respondents (40%) who are hesitant to adopt the technology believe that GM seeds from multinational corporations could undermine their independence and endanger their livelihoods. In a study examining the factors influencing the acceptance of genetically modified food crops in Ghana, Ogwu et al. [37] recommended increased and active engagement with all stakeholders to establish appropriate legislation, regulations, policies, and collaborative knowledge-building processes to support the adoption of GM crops.

3.2. Determinants of Farmers' Willingness to Plant GM Maize Seeds

The paper's diagnostic analysis of the binary probit model reveals key characteristics, such as a Prob > chi2 = 0.006 with a p-value of 0.000, indicating that the explanatory variables collectively explain farmers' willingness to plant GM maize seeds in the study area. While it is important to emphasize farmers' willingness to adopt new technology, the paper also delves into the factors that may influence their decision to adopt GM maize. This exploration is valuable for both research and policy development, particularly in addressing issues related to food availability and accessibility. The study identifies several significant determinants of farmers' willingness to plant genetically modified maize, including age, information on GM technology, extension contact, farm size, input prices, experience, and education (**Table 3**). These findings align with those of previous studies [19, 34, 38–42]. However, the influence of gender and farmers' risk perception regarding GM seeds on their willingness to adopt the technology was found to be positive but insignificant. Although these variables did not emerge as significant predictors in this study, their inclusion ensures a more comprehensive analysis and future research may further explore their roles across different socioeconomic and gender-based contexts.

Table 3. Binary probit regression results.

Variable	Marginal Effect	P>|z|
Age	−0.012	0.001***
Gender	0.157	0.042
Information	0.346	0.003***
Extension contact	0.213	0.002***
Farm size	0.063	0.048**
Input prices	−0.246	0.006***
Experience	0.011	0.077*
Risk involved	0.180	0.328
Education	0.008	0.018**
Prob > chi2	0.006	0.000***

Note: ***, ** and * represent 1%, 5% and 10% level of significance, respectively.

We observed a negative relationship between age and farmers' willingness to plant genetically modified maize, suggesting that the likelihood of older farmers adopting GM maize decreases as their age increases. This trend may be partly attributed to more conservative nature of older farmers, who tend to prefer sticking with traditional technologies they are familiar with. Additionally, their asset base may have diminished, making it difficult for them to invest in new or improved technologies, which often come at a higher cost compared to traditional methods. This finding aligns with similar studies [38, 39, 41, 43]. The paper revealed a positive and significant relationship between the information farmers receive about GM maize technology and their willingness to adopt it. Clear and detailed information about the potential benefits of a technology is likely to encourage its adoption. GM maize offers several advantages, including resilience to harsh climatic conditions, high yields, resistance to diseases and pests, and a shorter time to maturity. Biotechnology can offer health and safety benefits and may be environmentally friendly [44]. It is important for all stakeholders to effectively communicate the positive attributes of GM maize, including its economic benefits, to both farmers and consumers, thereby promoting acceptance.

In line with the subsequent discussion, the paper found a positive relationship between farmers' contact with extension service personnel and their willingness to plant GM maize seeds. This finding is consistent with the study by Kuwornu et al. [34]. It can be explained in the sense that agricultural extension agents offer advisory services on best agricultural practices, including pest and disease management. Therefore, regular interaction with extension services can enhance farmers' knowledge of their farming activities, which is crucial for improving productivity and may also serve as an incentive to adopt advanced technologies. Farm size also exhibits a positive relationship with the willingness of farmers to plant GM maize seeds, and this is consistent with Garming et al. [42]. This result shows that the farmers with relatively large land holdings of maize are likely to plant GM maize seeds. Large farms may be associated with commercial operations and are inclined to adopt productivity-enhancing technologies that can increase their level of profits. Input price is found to have a negative relationship with farmers' willingness to plant genetically modified maize. This outcome agrees with a priori expectation and is consistent with the finding of Adenle et al. [19]. The high cost of planting materials is a significant barrier to farmers adopting GM technology in the study area. Establishing additional research centers and equipping them with biotechnology facilities could significantly contribute to reducing the cost of GM planting materials.

The number of years a farmer has spent cultivating maize was found to be positively related to their willingness to plant GM maize seeds, a result consistent with Fernandez-Cornejo's [40]. Each additional year of maize farming experience increases the likelihood that farmers will adopt GM maize seeds. Experienced farmers are likely to have explored various maize technologies and seed varieties, notably improved ones, alongside their traditional varieties, which may lead them to be more open to biotechnology and willing to adopt it. However, experienced farmers must maintain consistency in adopting new technologies as they grow older. Education is found to correlate positively with famers' willingness to plant GM maize. This suggests that obtaining higher education increases the likelihood of maize farmers in the study area adopting the technology. Ngcinela et al. [30] revealed in their paper on determinants of genetically modified (GM) maize adoption in South Africa that improvement in the level of education enhances the adoption of GM maize by about 4%. Idrisa et al. [45] demonstrated that educated farmers are better positioned to access, digest, and properly interrogate information relevant to acceptance of a new technology. One graduate farmer from the survey mentioned that he will always choose the GM maize seed over the conventional seed due to its higher protein content and greater resistance to armyworm infestation.

3.3. Farmers' Perceived Constraints to the Adoption of the GM Maize Seeds

The results of farmers' rankings on their perceived constraints to the adoption of GM maize technology are presented in **Table 4**. The Kendall's Coefficient of Concordance (W) obtained is 0.484. This means that there is about a 48% level of agreement between the ranks. The paper identified the most pressing constraint with a mean rank of 2.31 to be fear of consumers' unwillingness to buy GM maize after harvest, perhaps due to relatively low knowledge about GM crops and the public debate on the crops [46]. Adenle et al. [19] concluded that consumer preference for conventional crop varieties is a significant factor to consider as they claim that the local varieties are easy to cook and taste better than improved varieties.

The second constraint, with a mean rank of 2.55, is how expensive farmers perceive planting materials for

GM maize would be. They assumed that planting materials for GM maize would be expensive; hence, they would rather not plant them. Adenle et al.[19] also noted that genetically modified crops would be expensive and that the cost of GM technology may be unaffordable for smallholder farmers. Farmers also assumed that there is a chance of GM maize having a shorter lifespan than the local maize varieties well known to them. A development they perceive will lead to a loss of their investment. This was also ranked the third most pressing constraint to farmers' willingness to adopt GM maize technology, with a mean rank of 3.24.

Furthermore, the risk of the patent was found to be the fourth most pressing constraint to farmers' willingness to adopt the GM maize technology, with a mean rank of 3.41. This is the risk of going to the same company or organization for the seeds of GM maize since stocks from the harvested produce in the previous crop season cannot be replanted. Farmers perceived that such companies or organizations can increase prices for their benefit which may disadvantage them, especially in terms of cost. Typically, such companies are multinational seed companies that are well-organized and well-resourced to meet the development requirements for GM products, aiming for profit gains[11]. The risk of losing everything when the crop does not do well was also considered a constraint to farmers' willingness to adopt the GM maize technology. Perceived crop failure constraint had a mean rank of 4.80 and was ranked the 5th most pressing constraint. Farmers were also concerned about losing indigenous traits of maize when they started planting GM maize seeds. Some farmers agreed that the indigenous maize traits can never be lost and would always be around, whilst some disagreed. This was the 6th most pressing constraint and had a mean rank of 5.58.

Table 4. Ranked perceived constraints to adoption of GM maize seeds.

Perceived Constraint	Mean Ranks	Rank
Fear of consumers unwillingness to buy maize after harvest	2.31	1st
Expensive planting materials	2.55	2nd
Risk of shorter lifespan of GM maize	3.24	3rd
Risk of patent	3.41	4th
Crop failure	4.80	5th
Loss of indigenous traits of maize	5.58	6th

4. Conclusion and Recommendations

This paper examines farmers' willingness to adopt genetically modified (GM) maize technology in Ghana, a critical step toward addressing food security challenges and boosting agricultural productivity in the face of climate change and pest pressures. Specifically, the study explores the proportion of farmers aware of GM maize technology, identifies and ranks the perceived barriers to their willingness to plant GM maize, and investigates the factors influencing their decision to adopt the technology. The research is based on cross-sectional data from 550 commercial maize farmers across five regions of Ghana: the Northern, Bono, Ashanti, Western, and Volta regions. These regions were selected to capture diverse agroecological and socio-economic conditions, ensuring the findings are representative of Ghana's maize-growing areas. The findings reveal that while most farmers are aware of GM maize technology, only a smaller percentage of them express willingness to adopt it. This gap highlights the need for targeted interventions to bridge knowledge and trust deficits. Additionally, the study suggests that older farmers are less likely to plant GM maize seeds than their younger counterparts, possibly due to their strong preference for traditional maize varieties that have been passed down through generations. This divide suggests that youth-focused agricultural programs could be pivotal in promoting the uptake of GM technology.

Farmers with relatively larger farm sizes are found to be more willing to adopt the GM maize technology compared to smallholders, likely due to their greater capacity to absorb risks and invest in new technologies. Similarly, farmers with more years of experience in maize farming show a higher willingness to adopt GM maize, possibly because their expertise allows them to evaluate potential benefits more critically. The study also found that farmers who benefited from extension services were more willing to plant GM maize than those who had no contact with extension services, underscoring the role of reliable information channels in fostering acceptance. In other words, information reaching farmers about new technologies through extension services is considered crucial for their willingness to adopt new technologies. Input price is also found to be an important factor influencing farmers' willingness to adopt GM maize technology. Specifically, the high cost of inputs negatively affected farmers' willingness to plant GM maize, a challenge that could be mitigated through subsidy programs or partnerships with seed companies.

Regarding perceived constraints, farmers ranked consumer resistance to GM foods as the most pressing barrier, reflecting global debates about GM safety and labeling. The high cost of planting materials and concerns about the shorter lifespan of GM maize followed as significant deterrents. Notably, fears of patent risks and loss of indigenous traits reveal more profound anxieties about corporate control and cultural erosion, which policymakers must address transparently.

Based on these findings, the paper recommends that relevant stakeholders, such as the Ministry of Food and Agriculture, in collaboration with their pertinent counterparts, should put in place measures such as designing and implementing programs like farmer business schools (FBS) and workshops to educate farmers on GM maize technology. Since a certain proportion of the farmers interviewed are not aware of the GM maize technology, creating a cognizance to farmers would be a significant way to make them know that the GM maize technology exists with many benefits, including improvement in agricultural productivity.

Targeted policies are required to ensure the price stabilization of genetically modified maize seeds, thereby enabling affordability for smallholder farmers. Additionally, government programs that target youth participation in agriculture should be intensified whilst introducing them to GM technology. Extension service delivery should be intensified with the needed logistics to enable them to attend to the needs of farmers adequately, including the dissemination of GM engineering. Policymakers should develop channels through which farmers can sell their grains after harvesting so that farmers would be assured of a ready market for their GM produce.

Lastly, more research is needed to answer the remaining questions. For example, future studies should examine the long-term effects of growing GM maize on local communities and the environment, including its impacts on biodiversity, soil health, and farmers' livelihoods over several growing seasons. Additionally, researchers should investigate how the production of GM crop affects consumer health and market dynamics, including price changes and trade patterns, to inform policymaking. Comparing different regions in Africa could help identify specific challenges to adopting GM crops. Qualitative research focusing on cultural views and ethical concerns would also deepen our understanding of the resistance to GM technologies.

Author Contributions

Conceptualization, E.E.O. and P.B.O.; Methodology, E.E.O. and T.T.K.; Data analysis, T.T.K., D.A.O. and M.H.N.; writing and original draft preparation, E.E.O., T.T.K. and P.B.O.; writing-reviews and editing, E.E.O., T.T.K. and P.B.O. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Before data collection began, ethical approval was granted by the seminar committee of the Department of Agricultural Economics at the University of Ghana following the presentation of the thesis proposal. Consent was also obtained from all the communities involved prior to the commencement of fieldwork. All aspects of informed consent, anonymity, and confidentiality were carefully addressed. Participants were approached individually, and verbal informed consent was obtained from all those included in the study. Well-trained enumerators thoroughly explained the research objectives, confidentiality procedures, potential risks and benefits, and the participant's right to withdraw from the survey at any time. Anyone who chose to opt out of the research was excluded and never coerced into participating in the fieldwork. All participants were reassured that their responses would be linked to unique codes for identification purposes only.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data is available upon request.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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