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DRIVERS OF GENETICALLY MODIFIED MAIZE PRODUCTION AMONG RURAL FARMING HOUSEHOLDS IN NGQUSHWA LOCAL MUNICIPALITY, SOUTH AFRICA: A TRIPLE HURDLE APPROACH

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Abstract. Enhancing rural agricultural productivity using proven technologies such as genetically modified (GM) maize production has many advantages as a pathway to economic development and poverty reduction. However, despite the global rise in GM maize and potential benefits of GM technology, the production rates and yields of smallholder farmers remain very low for reasons that are poorly understood. With this background, the aim of this study was to investigate the drivers of genetically modified (GM) maize awareness, participation, and intensity of production at the household level. Data were collected from 400 randomly selected respondents from Ngqushwa Local Municipality using a semi-structured questionnaire. Through a triple hurdle model, the study revealed that GM maize awareness is negatively influenced by age and female gender and positively influenced by married status, employment and number of years in school. Conditional on awareness of GM maize varieties, both participation and intensity of participation in GM maize production are positively influenced by land size, female gender, group membership, income and ownership of arable land and negatively influenced by employment. The study recommends that priority should be given to these socio-economic and institutional (group membership) factors by targeting GM maize awareness campaigns using platforms more suited to female-headed, older, less educated and unemployed rural farming households. The study also recommends addressing income, secure land ownership and access to large areas of land.

Keywords: awareness, intensity, GM, households, participation, triple hurdle

INTRODUCTION

Agriculture is a major source of jobs in most developing countries, and it contributes a significant portion of their national income (Mmbando and Baiyegunhi, 2016). Agriculture's ability to contribute to economic growth, on the other hand, is heavily reliant on agricultural productivity (Ghimire et al., 2015). It has been argued that increasing agricultural productivity and thus improving the welfare of rural households in developing countries would remain a pipe dream if agricultural technology adoption remained poor (Ahmed and Anang, 2019). This means that finding mechanisms to ensure farmers' access to GM maize seed varieties while also improving the living standards of rural households would be crucial if production levels were to be increased and sustained (Oluwayemisi et al., 2017). Maize is vital to reducing hunger and improving food quality for low-income families and South Africa is one of the leading African countries for the growth of GM maize (Kolanisi et al., 2018). Since 2001, many private enterprise interventions and government programs have introduced GM maize to smallholder farmers in South Africa (Azadi et al., 2016). Since maize is Africa's most important staple crop, and for many smallholder farmers, stem borer damage is a major productivity issue, GM maize and its resistance to stem borer damage could have a significantly positive effect on farmers' and their families'

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livelihoods (Tadele, 2017). The creation and use of genetically modified maize increases demand, resulting in continuous socio-economic development; this includes increased incomes and decreased poverty, improved nutritional status and more job opportunities (Mwangi and Kariuki, 2015). As a result, the use of GM maize is encouraged in order to maintain agricultural productivity and food security and thereby keep up with the world's ever-growing population (Kadango et al., 2020). Although GM maize has been commercialised for more than two decades, its advantages and disadvantages are still being discussed, with topics ranging from the environment to health and socio-economic impacts (Huang et al., 2017). Many smallholder farmers in developing countries have struggled to use the improved GM maize technology and to realise the full potential of agricultural productivity (Ghimire et al., 2015). This is because of the economic risks posed by GM maize, such as increased costs, the genetically modified status that limits export opportunities and negative public opinion that has led to rejection (Naval and Dolojan, 2020). Therefore, rural farmers continue to face the challenge of an inadequate quantity of available GM maize seeds on small farms, and this causes the level of participation in GM maize production by farmers to remain low (Uduji and Okolo-Obasi, 2018). Therefore, this study analysed the determinants of genetically modified (GM) maize production at the household level in rural areas.

Specific objectives

1. To estimate factors that influence GM maize awareness among rural households.
2. To estimate factors influencing participation in GM maize production among rural households.
3. To estimate factors influencing the intensity of GM maize production among rural households.

Research questions

1. What are the factors that influence GM maize awareness among rural households?
2. What are the factors influencing participation in GM maize production among rural households?
3. What are the factors influencing the intensity of GM maize production among rural households?

THEORETICAL FRAMEWORK

The study uses the diffusion of innovation theory by Rogers (1995) and utility maximisation theory by Bentham (1970) to explain awareness, participation and intensity of production with respect to GM maize. The study assumes that the decision to produce GM maize varieties is a three-stage process whereby the farmer will first have to be aware of GM maize varieties before making the decision to participate or not to participate in their production (Yigezu et al., 2018). Conditional on this awareness, the farmer will then compare the innovation with the traditional technology and participate or use the technology if the utility from using the technology exceeds the current utility from the traditional technology (Borges et al., 2015). Further conditional on the decision to participate in GM maize production, the farmer allocates a certain area of land for the production of GM maize varieties, and all these stages are influenced by household attributes, which are social, economic and institutional (Ngcinela et al., 2019).

Diffusion of innovation theory

The key to adoption is that the individual perceives the idea, behaviour or product as new or innovative, and it is only through this perception that diffusion can occur (Dube and Gumbo, 2017). Diffusion is the process by which an innovation (such as GM maize) is communicated to members of a population over time through specific channels (Duniya, 2018). Rogers (1995) modelled the innovation-decision process that a person goes through when confronted with new technologies or ideas. The decision-making process for innovation is divided into five stages, namely knowledge, persuasion, decision, implementation and confirmation. Figure 1 presents the innovation-decision process theory.

1. Knowledge occurs when the individual learns about the existence of an innovation. This stage includes receiving information about the innovation through communication channels (Dube and Gumbo, 2017). Information about genetically modified maize is constantly communicated to individuals through various channels. This builds knowledge with respect to GM maize among smallholder farmers, which may trigger their willingness to participate in GM maize production in the future.

2. Persuasion occurs when the individual develops an attitude, either positive or negative, about the

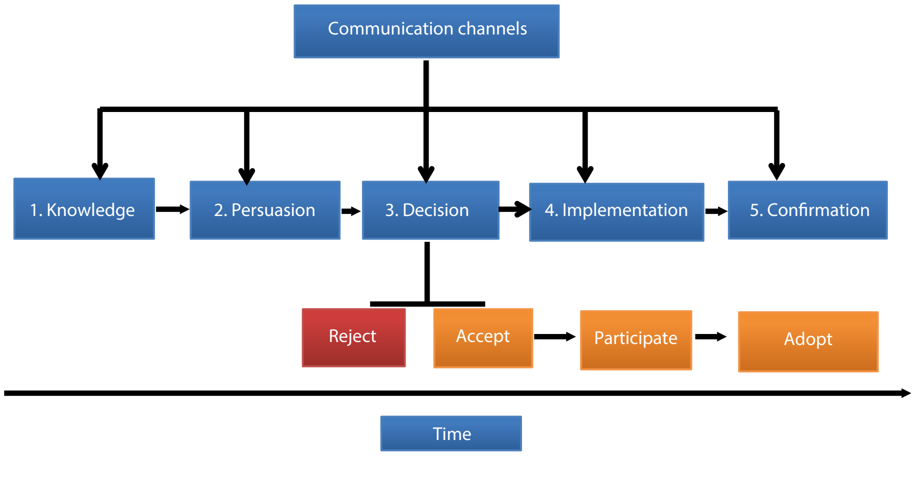

Fig. 1. Innovation-decision process theory
Source: modified from Rogers (2003); Dube and Gumbo (2017).

innovation through subjective evaluations of others such as colleagues and peers (Ugochukwu and Philips, 2018). Smallholder farmers also develop attitudes towards GM maize based on what they hear and see from their colleagues and peers. These instances of persuasion may trigger positive or negative attitudes towards GM maize among smallholder farmers capable of influencing future participation.

3. At the decision stage, the person decides to accept or reject the innovation. In this case, acceptance denotes maximum use of an innovation, while rejection denotes refusal to accept the innovation (Duniya, 2018). Knowledge gained by smallholder farmers in respect of GM maize and associated persuasion from peers has the potential to influence the decision stage of accepting or rejecting GM maize production. Thus, the decision to participate is not an event but a long process that would have started with knowledge acquisition and a series of acts of persuasion from peers.

4. At the implementation stage, mental information processing and decision-making stop, but behavioural change begins, and the innovation is implemented (Ugochukwu and Philips, 2018). For the convinced smallholder farmers, participation in GM maize production usually kicks in on a small scale to assess the associated risks and benefits at a small, manageable level.

5. At the confirmation stage, the adopter continues to evaluate the outcomes of their decision, and if the level of satisfaction is high enough, the adoption of the innovation will continue (Dube and Gumbo, 2017). Participation results (yields, costs, diseases, weeding benefits, market, production logistics) will be used by smallholder farmers to assess overall net benefits of GM maize over other varieties. If they are positive, adoption may follow, characterised by an increase in the scale of production.

Thus far, GM maize (new cultivar) production may be triggered by multiple factors that occur at different stages worth probing in a sequential hurdle process to avoid sample selection bias.

Utility maximisation theory (UMT)

According to the utility maximisation theory (Bentham, 1970), a farmer compares the innovation to the conventional technology and adopts it if the expected utility from adopting outweighs the actual utility of the traditional technology (Borges et al., 2015). This study employed the utility maximisation theory to describe the responsiveness of farmers to GM maize production. A rational smallholder farmer is expected to switch from other maize varieties to GM maize if, and only if, the expected utility from GM maize is greater than that of other maize varieties as illustrated in equations 1 and 2 (Jaleta, 2013).

$$U_{i1}(X) = \beta_1 X_i + u_{i1} \text{ For participation} \quad (1)$$
$$U_{i0}(X) = \beta_0 X_i + u_{i0} \text{ For non-participation} \quad (2)$$

The i^{th} farmer will select the alternative adoption if $U_{i1} > U_{i0}$

The probability of participation is given by:

$P(1) = P(U_{i1} > U_{i0})$
$P(1) = P(\beta_1 X_i + \mu_{i1} > \beta_0 X_i + \mu_{i0})$
$P(1) = P(\mu_{i1}.\mu_{i0} < \beta_1 X_i.\beta_0 X_i)$
$P(1) = (\mu_i < \beta X_i)$
$P(1) = \varnothing(\beta X_i)$

Where:

U_{i1} – expected utility from producing GM maize
U_{i0} – utility derived from the use of other maize varieties
P (1) – probability of producing GM maize
$\beta_1 \ldots \beta_0$ – parameters to be estimated
X_i – independent variables
$\varnothing$ – cumulative distribution function of the standard normal distribution
μ_i – disturbance term

Sampling framework

The sampling framework is formulated from the above two theoretical frameworks. Figure 2 presents the triple hurdle model sampling framework. The three-stage decision process is conceptualised as follows: smallholder farmers may be aware or unaware of GM maize varieties on the market (1st hurdle). Conditional on their awareness, they then decide whether or not to participate in the production of GM maize (2nd hurdle). Conditional on their participation in GM maize production, they decide on the intensity of production (3rd hurdle).

Factors affecting each of the three hurdles are specified as a function of household characteristics (hc) and institutional (i) factors. These are broadly specified as illustrated in equations 3–5 (Kondo et al., 2019).

$$\text{GM Maize Awareness (GMA)} = (\text{hc, i}) \tag{3}$$
$$\text{GM Maize Participation (GMP)} = (\text{hc, i}) \tag{4}$$
$$\text{Intensity of GM Production (IGMP)} = (\text{hc, i}) \tag{5}$$

"GM Maize Awareness (GMA)" is a dichotomous indicator of whether a smallholder maize farmer is aware of GM maize varieties or not, conditional on a smallholder maize farmer being aware of GM maize varieties, and "GM Maize Participation (GMP)" is a dichotomous indicator of whether or not the maize farmer participates in GM maize production. Conditional on a smallholder maize farmer participating in GM maize production, "Intensity of GM production (IGMP)" is a truncated continuous non-zero integer reflecting the proportion of the total maize land area planted with GM maize.

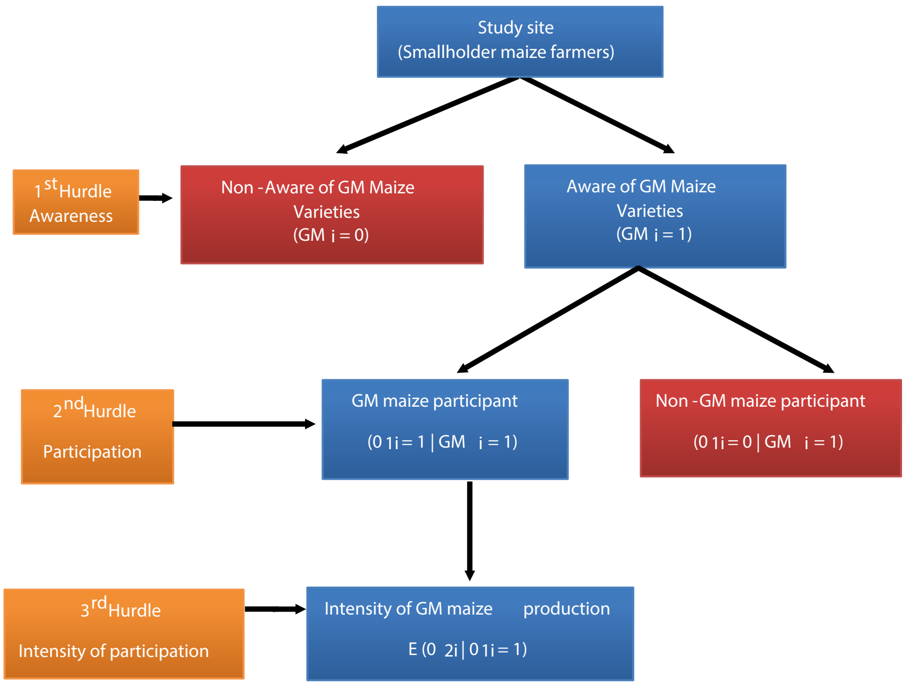

Fig. 2. Sampling framework
Source: modified from Kondo et al., 2019.

MATERIALS AND METHODS

Study area

The study was carried out in Ngqushwa Local Municipality in the Eastern Cape Province of South Africa. Ngqushwa is located in the west of the Amathole district and is made up of two towns, Peddie and Hamburg, as well as a portion of the King Williams Town villages. It is one of six local municipalities in the Amathole District Municipality and consists of 108 villages (Stats SA, 2016). Ngqushwa local municipality has an estimated population of 69,200 households, and the key economic sectors are agriculture and tourism (Stats SA, 2016).

Data and empirical model used

The study followed a cross-sectional research design to gather information from 400 randomly selected households from the study site. The sample was stratified into two groups: (a) households producing GM maize (households exclusively producing GM maize and those that mix GM and non-GM maize varieties) and (b) households producing any other maize varieties that are not GM. The study used a semi-structured questionnaire as the main tool to collect primary data. A household head was used as the primary respondent.

Following Yamane (1967) the sample size was calculated as illustrated in Equation 1:

$$n = \frac{N}{1 + N(e)^2} \tag{6}$$

Where: n – is the sample size, N – is the population size, and e – is the level of precision.

$$n = \frac{69200}{1 + 69200(0.05)^2} = 398 \approx 400 \text{ households}$$

A minimum sample size of 398 was required, which was rounded up to 400. From the sampling frame, 400 households producing maize were randomly selected for "in-person interviews" (Category A: GM maize producers = 78 households. Category B: non-GM maize producers = 322 households).

A triple hurdle approach

A triple hurdle model was employed in this study to determine the factors influencing awareness, participation, and intensity of production with respect to GM maize varieties. The triple hurdle model has three separate stochastic decision choices that should be analysed simultaneously but divided into sequential hurdles (Chi, 2018). Several previous studies modelling sequential hurdles have also used double or triple hurdle models depending on the number of hurdles under consideration (Gebremedhin et al., 2017; Duniya, 2018; Tabe-Ojong et al., 2018; Ngcinela et al., 2019).

Given the sequential hurdles likely to be faced by respondents in the process of producing GM maize, the study adopted a triple hurdle model as guided by the literature. The respondents faced the following hurdles: (a) awareness, (b) participation in GM maize production and (c) intensity of participation in GM maize production. The first hurdle analysed factors that influence awareness (probit regression). Using a subset of the first sample, the second hurdle analysed factors that influence the decision to participate in GM maize production (probit regression). Lastly, using a subset of the second sample, the third hurdle analysed factors that influence the extent of participation as measured by area under GM maize production (tobit regression).

First hurdle: Awareness of GM maize

Based on the initial sample of those producing and not producing GM maize, a Probit model was used to estimate factors that influence awareness of GM maize varieties among rural farmers, as illustrated in equation 7 (Green, 2003).

$$Y_i^* = \alpha Z'_i + \mu_i \tag{7}$$

Where: Y_i^* – is the latent variable that takes the value 1 if a farmer is aware of GM maize seed, and 0 if not. Z – is the vector of farmers' characteristics, α is the vector of parameters and μ_i – is an error term, specified as illustrated in equation 8.

$$Y_{i1} = \alpha_0 + \alpha_{i1}Z_{i1} + \alpha_{i2}Z_{i2} + \alpha_{i3}Z_{i3} + \dots \alpha_n Z_n + \mu_i \tag{8}$$

Second hurdle: Participation decision

Focusing on a subset of those aware of GM maize, a Probit model was employed which involved whether a farmer decides to produce GM maize or not, specified as illustrated in equation 9 (Greene, 2003).

$$Y_i^* = \alpha Z'_i + \mu_i \tag{9}$$

Where: Y = 1 if a farmer decides to participate in GM maize production and Y = 0 otherwise. α_0 – is a constant term, α_1 to α_n – are coefficients of independent variables,

Z_1 to Z_n – are independent variables and μ_i is an error term, specified as illustrated in equation 10.

$$Y_{i2} = \alpha_0 + \alpha_{i1}Z_{i1} + \alpha_{i2}Z_{i2} + \alpha_{i3}Z_{i3} + \dots \alpha_n Z_n + \mu_i \quad (10)$$

Third hurdle: Intensity of production

Focusing on a subset of those producing GM maize, a Tobit regression model was employed to analyse the factors influencing production intensity as illustrated in equation 11 following Tobin (1958).

$$Y_i^* = \delta Q_i + v_i \quad (11)$$

Where: δ_0 is a constant term, δ_1 to δ_n are coefficients of independent variables Q_1 and v_i is the error term, specified as illustrated in equation 12.

$$Y_{i3} = \delta_0 + \delta_{i1}Q_{i1} + \delta_{i2}Q_{i2} + \delta_{i3}Q_{i3} + \dots \delta_n Q_n + v_i \quad (12)$$

Intensity of GM maize production was calculated as the ratio of the area under GM maize to the total area under maize as illustrated in equation 13 following Duniya (2018).

$$Y_{i3} = \frac{\text{Area planted with GM maize (ha)}}{\text{Total area devoted to maize production (ha)}} \times 100 \quad (13)$$

RESULTS AND DISCUSSION

Descriptive results

The results show that the majority of the sampled households were females (59.75%) with males constituting 40.25%. Information on the marital status of the sampled household heads from the study area was as follows: 48.50% were single, 40.25% were married, 7.50% were widowed and 3.75% were divorced household heads. In regard to employment status, 0.50% of the surveyed households were fulltime farmers, 5% were part-time farmers, 23.5% were pensioners, 27% were formally employed and 44% were unemployed.

With reference to household size, results indicate that the mean household head age was 50 years. The mean number of years in formal education was 10, which means that on average sampled respondents spent 10 years in formal education. The mean for household size was five family members, as detailed in Table 1. With reference to access to extension, results reveal that 74.25% of the respondents had no access to extension

Table 1. Descriptive statistics of sampled households

Categorical variables	Frequency (N = 400)	Percentage (%)		
Gender				
Male	161	40.25		
Female	239	59.75		
Marital status				
Single	239	59.75		
Married	161	40.25		
Employment status				
Fulltime farmer	2	0.5		
Part–time farmer	20	5		
Pensioner	94	23.50		
Formally employed	108	27		
Unemployed	176	44		
Household income				
<500	33	8.25		
500–1000	53	13.25		
1000–2000	134	33.5		
2001–5000	97	24.25		
5001–10000	63	15.75		
10001–20000	17	4.25		
>20000	3	0.75		
Access to extension				
Yes	103	25.75		
No	297	74.25		
Access to own arable land				
Yes	316	79		
No	84	21		
Access to formal credit				
Yes	16	4.01		
No	383	95.55		
Membership to farming organisation				
Yes	39	9.75		
No	361	90.25		
Type of farming system				
Crop	171	42.75		
Livestock	4	1		
Mixed farming	225	56.25		
Continuous variables	Mean	Std. dev.	Min	Max
Age	50	14.15	20	95
Years of formal education	10	3.43	0	18
Household size	5	2.91	1	17

Source: ?

services. The results further indicate that the majority of the respondents had access to arable land (79%). Descriptive statistics also show that the majority had no access to formal credit (95.55%). With reference to membership of a farming organisation, the findings show that the majority of respondents were not members of any local farming organisation (90.25%). Lastly, three farming systems were noted from the study area as follows: mixed farming (56.25%) and mono farming (crop production 42.75% and livestock production 1%).

Drivers of GM maize awareness, participation and intensity of production

The triple hurdle model results for drivers of GM maize awareness, participation and intensity of production are summarised in Table 2. Schooling years was used as an exclusion variable (tool) capable of explaining awareness, participation and intensity of participation. Against this background, and for the purposes of testing for conditionally uncorrelated errors between stages, the Inverse Mills Ratio (IMR) was generated on the probability of being aware of GM maize and included in the second stage as an independent variable (Burke et al., 2015). The same procedure was repeated in stage two and the generated IMR was included in stage three as an independent variable. Results reveal that IMRs in the second and third stages were statistically significant (Stage 2: Participation in GM production: $\beta = -5.450$: p-value = 0.0000; Stage 3: Intensity of GM production: $\beta = -25.673$: p-value = 0.0000). This suggests that the Inverse Mills Ratio has a significant influence in explaining participation in GM production and intensity of GM production (Burke *et al.,* 2015). Sample selection bias between stages of estimation was therefore detected, and IMR should be included for the estimates of the triple hurdle model (Burke et al., 2015), as illustrated in Table 2.

Drivers of awareness of GM maize varieties among rural farming households

Age: The results show that age negatively influences awareness of GM maize varieties from the study area. The marginal effects show that a unit increase in the age of the household head decreases the likelihood of GM maize awareness by 1.3% holding other variables constant. These findings suggest that younger household heads are more likely to be aware of GM maize than older household heads, mainly because young rural farming households are more exposed to digital information and are more flexible when exposed to new ideas than their older counterparts (Oluwayemisi et al., 2017), especially in this era when a lot of farming information has migrated online. Previous studies also noted that age negatively influences awareness mainly because as farmers grow older, there is an increase in risk aversion and a decreased interest in exploring new farming technologies (Mwangi and Kariuki, 2015).

Schooling years: Years of schooling show a positive effect on GM maize varieties awareness. The marginal effects show that a unit increase in the household head's years of schooling increases the chances of GM maize awareness by 5.3% holding other independent variables constant. Educated rural farming households are more likely to be aware of GM maize varieties due to their open-mindedness, access to more information, and understanding of the benefits of using new technologies. Previous studies also noted that years of schooling positively influence awareness and this could be because of access to information and awareness brought about by education (Kadafur et al., 2020).

Gender: The results also show that gender influences awareness of GM maize varieties. The marginal effects reveal that a unit change from being a male headed household to being a female headed household decreases the likelihood of GM maize awareness by 13.5% holding other independent variables constant. This implies that females are less likely to be aware of GM maize varieties than males from the study site. These findings support those of Mwangi and Kariuki (2015), which showed that male-headed households are more likely to be aware of GM maize varieties than households headed by females. Males are more likely to have access to information in most rural cultures because they are treated as household heads networked to multiple local groups where farming information is normally discussed.

Marital status: The results show that marital status influences awareness of GM maize varieties. Marginal effects show that the likelihood of GM maize awareness will increase by 5.5% per every unit change from being single to being married holding other independent variables constant. These findings suggest that married household heads are more likely to be aware of GM maize varieties because married rural farming households have families depending on them and for that reason they are often looking for ways to make money and increase food availability to meet the needs of their

Table 2. Results of the triple hurdle estimation

Variables	1st hurdle (Dep variable: awareness)		2nd hurdle (Dep variable: participation)		3rd hurdle (Dep variable: intensity of participation)	
	Probit regression	Marginal effects	Probit regression	Marginal effects	Tobit regression	Marginal effects
Age	–0.041 (0.000) ***	–0.013 (0.000)	0.026 (0.169)	0.003 (0.142)	1.465 (0.117)	1.465 (0.117)
Schooling years	0.163 (0.044)**	0.053 (0.047)	–	–	–	–
Household size	0.094 (0.598)	0.030 (0.598)	–0.172 (0.434)	–0.023 (0.443)	–6.592 (0.515)	–6.592 (0.515)
Farm size	0.406 (0.238)	0.131 (0.238)	1.281 (0.003)***	0.174 (0.017)	44.851 (0.015)**	44.851 (0.015)
Gender	–0.419 (0.009)***	–0.135 (0.009)	0.628 (0.004)***	0.085 (0.004)	31.027 (0.003)***	31.027 (0.003)
Formal credit	–0.041 (0.906)	0.013 (0.906)	0.3894 (0.330)	0.053 (0.339)	22.904 (0.106)	22.904 (0.106)
Informal credit	0.099 (0.674)	0.032 (0.674)	–0.245 (0.367)	–0.033 (0.362)	–12.855 (0.321)	–12.855 (0.321)
Group membership	–0.006 (0.983)	–0.002 (0.983)	0.790 (0.003)***	0.107 (0.008)	34.940 (0.003)***	34.940 (0.003)
Arable land	–0.165 (0.336)	–0.053 (0.337)	0.777 (0.001)***	0.105 (0.000)	42.133 (0.000)***	42.133 (0.000)
Marital status	0.170 (0.083)*	0.055 (0.086)	–0.156 (0.336)	–0.021 (0.325)	–6.258 (0.450)	–6.258 (0.450)
Employment status	0.247 (0.004)***	0.079 (0.004)	–0.338 (0.065)*	–0.046 (0.050)	–18.922 (0.030)**	–18.922 (0.030)
Household income	–0.006 (0.927)	–0.002 (0.927)	0.210 (0.008)***	0.028 (0.015)	8.154 (0.026)**	8.154 (0.026)
Extension services	0.279 (0.239)	0.090 (0.240)	–0.390 (0.164)	–0.053 (0.168)	–20.448 (0.135)	–20.448 (0.135)
IMR	–	–	–4.059 (0.000)***	–0.550 (0.000)	–213.343 (0.000)***	–213.343 (0.000)
_cons	0.886 (0.291)	–	–1.233 (0.155)	–	–49.449 (0.210)	–
Pseudo R^2 = 0.2518 Wald Chi^2 (14) = 103.41 Prob > Chi^2= 0.0000 No. of Obs = 400			*Pseudo* R^2 = 0.3400 Wald Chi2 (14) = 89.65 Prob > Chi2 = 0.0000 No. of Obs = 400		*Pseudo* R^2 = 0.1124 F(13, 387)= 13.54 Prob > F = 0.0000 No. of Obs = 400 Uncensored = 78 Left censored = 322	

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; p-values in parentheses.

families (Mutenje et al., 2016). Previous studies also noted that married people have a higher probability of knowing and being aware of GM maize varieties and their benefits than those who are not married (Ahmed and Anang, 2019).

Employment status: Employment also has a positive influence on awareness of GM maize varieties from the study area. The marginal effects indicate that a unit change of employment status (from being unemployed to being employed) increases the likelihood of being aware of GM maize varieties by 7.9% *ceteris paribus*. This implies that employed rural farming household heads are more likely to be aware of GM maize varieties than their unemployed counterparts because of exposure and access to more information through social networks. A study by Ali and Rahut (2018) also found that employment positively influences awareness because it drives the willingness of farmers to know more about GM maize as higher income from off-farm work influences their ability to purchase GM seeds.

Drivers of participation in GM maize production among rural farming households

Gender: The results indicate that conditional on being aware of GM maize varieties, gender influences participation in GM maize production. As indicated by the marginal effects, a unit change of gender status (from being a male to a female-headed household) increases the likelihood of GM maize production by 8.5% holding other predictor variables constant. This suggests that females are more likely to produce GM maize than males because in most households women take care of the children and, therefore, are more likely to engage in food production (staple food crops) so as to meet the food needs of the household while men tend to cultivate cash crops. The elimination of manual weeding that is possible with GM maize varieties because of their ability to accommodate non-selective herbicides will further appeal to females given that most weeding activities in rural areas are handled by females (Gouse et al., 2016).

Land size: Conditional on being aware of GM maize varieties, land size positively influences GM maize participation among rural farming households. The marginal effects show that a unit increase in land size increases the likelihood of GM maize production by 17.4% *ceteris paribus*. These findings suggest that the more land rural farming households have access to, the more they are likely to participate in GM maize production. Large farm sizes provide space for farmers to try new risk crop varieties without replacing their old varieties, especially for GM maize that requires mandatory isolation from other maize varieties (Kadafur et al., 2017). These results support previous conclusions by Danso-Abbeam et al. (2017), who argue that the probability of farmers producing GM maize is higher in households with larger farm sizes than those with smaller farm sizes.

Income: The results show that conditional on being aware of GM maize varieties, household income positively influences GM maize participation. Marginal effects reveal that a unit increase in the income of the household head increases the likelihood of GM maize production by 2.9% *ceteris paribus*. Income enhances the capacity of rural farming households to purchase GM maize seed, which is relatively expensive (R138.33/kg), including the fertilizers and irrigation necessary for the optimum productivity of GM maize. Rural farming households with low income will be limited in their participation in GM maize production because of seed cost, the fertilizers required and supplementary irrigation in conditions of low natural rainfall typical of most rural areas. This is against a background where GM maize was bred for high-potential agro-ecological areas (Raman, 2017). These results reinforce the findings of Mmbando and Baiyegunhi (2016), who argue that households with higher incomes can afford to invest in improved maize varieties such as GM maize because their adoption is dependent on cash availability.

Association membership: Belonging to a local farming group has a positive influence on participation in GM maize production conditional on awareness of GM maize varieties. The marginal effects indicate that a unit change in membership status at a local farming group (non-member to member) will increase the likelihood of participating in GM maize production by 10.7% *ceteris paribus*. This implies that farmers belonging to a local farming group are more likely to participate in GM maize production. Local farming groups provide social capital to members, who have more opportunities to network and educate one another. Higher interactions among members of a community group increase the chances of broadening awareness of new technologies and their benefits and thus encourage participation. This is consistent with the findings of Mwangi and Kariuki (2015), which indicate that farmers who were more involved in community-based organisations were more likely to participate in social learning about technology, increasing their chances of using and possibly adopting the technologies.

Employment status: Employment has a negative influence on participation in GM maize production. As indicated by the marginal effects, a unit change of employment status from unemployed to employed decreases the likelihood of participation in GM maize production by 4.6% holding other predictor variables constant. These findings reveal that unemployed rural farming households are more likely to participate in GM maize production, conditional on awareness of GM maize varieties, than their employed counterparts do. Several factors, like time availability and the potential of GM maize as a food and income source, explain the revealed negative effect. These findings are consistent with a previous study by Mutenje et al. (2016), which found that GM maize varieties have the potential to increase crop production, improve household food security and thereby raise the incomes of poor unemployed households.

Access to own arable land: Having access to arable land positively influences participation in GM maize production. The marginal effects reveal that a unit increase in arable land ownership increases the likelihood of participating in GM maize production by 10.5% *ceteris paribus*. Conditional on awareness of GM maize varieties, rural farming households who own arable land are more likely to participate in GM maize production than those without access to their own arable land. Arable land ownership presents rural farming households with the flexibility to try new crop varieties – a risk that those leasing or without access to their own arable land may not be willing to take. These findings are consistent with earlier research by Zeng et al. (2018) which highlight that land ownership encourages adoption of GM maize, but lack of land ownership prevents it.

Drivers of intensity of GM maize production among rural farming households

Gender: Conditional on awareness of GM maize varieties and participation in GM maize production, results show that gender influences the intensity of GM maize production. The marginal effects indicate that a unit change in gender status from male to female increases the likelihood of allocating more land to GM maize production (intensity of GM production) by 31.027 units holding other independent variables constant. This implies that female-headed households that are aware of and producing GM maize are more likely to allocate more land to GM maize production than male headed households. This is probably because males are normally involved in multiple livelihood activities including off-farm work that may limit their time for increased GM maize production compared to female headed households. Sinyolo (2019) has also noted that male farmers dedicate less land to improved maize varieties (for subsistence purposes) than female farmers because men prioritise cash crops while women prioritise staples such as maize.

Land size: Land size shows a positive relationship with intensity of GM maize production conditional on awareness of and participation in GM maize production. Marginal effects show that a unit increase in the land size increases the likelihood of more intensive GM maize production by 44.851 units *ceteris paribus*. These results imply that intensive GM maize production is more likely to be practised by rural farming households with larger areas of farmland than households with smaller holdings. Larger farms allow farmers to expand GM maize production without substituting other crops, a luxury that may not exist for households with smaller farm sizes. These results support findings by Mohammed et al. (2019), who found that farm size had a positive correlation with intensity of production. Studies by Mwangi and Kariuki (2015) also noted that a larger farm allows farmers to produce beyond their household food consumption needs. This suggests that farmers with larger farms are better able to produce and sell surpluses to the market, enabling them to allocate more land to GM maize production.

Income: Household income positively influences the intensity of GM maize production. Marginal effects reveal that a unit increase in income increases the likelihood of more intensive GM maize production by 8.154 units *ceteris paribus*. These results imply that as household income increases for rural farming households who are aware of GM maize varieties, and as they participate in GM maize production, the intensity of GM maize production increases because of the ability to purchase GM maize seed and fertiliser as well as installation of supplementary irrigation. The positive association can be explained by greater capital availability, which can be used to buy more hectares of land, seed and associated inputs (Akinbode and Bamire, 2015).

Association membership: Membership of a local farming group positively influences intensity of GM maize production conditional on awareness of and participation in GM maize production. The marginal effects show that a unit change in membership status to a local farming group status from being a non-member to a member increases the likelihood of intensity of GM maize production by 34.940 units holding other independent variables constant. This implies that rural farming households that are aware of and producing GM maize and are also members of a local farming group are more likely to intensify their GM maize production than non-members. Farmer group membership connects farmers to information sources, boosting their ability to analyse risks and advantages, take advantage of new developments and devote resources to such initiatives. Ghimire and Huang (2015) discovered that membership of farmer organizations had a substantial impact on the intensity of participation in GM maize production.

Employment status: Results reveal that employment has a negative influence on participation in GM maize production. A unit change in employment status from unemployed to employed decreases the likelihood of allocating more land to GM production by 18.922 units *ceteris paribus*. Aware and GM maize-producing farming households who are formally employed are less likely to intensify their GM maize production because formal employment reduces the amount of time that formally employed farmers spend on farming activities, reducing their willingness to invest in new crop varieties and expand the area under production. Previous research by Gebre et al. (2019), and Mwangi and Kariuki (2015) indicates that off-farm work by farmers may hinder their adoption of new technologies by lowering the quantity of household labour allocated to farming enterprises.

Access to own arable land: Access to arable land positively influences the intensity of GM maize production. The marginal effects reveal that a unit increase in arable land increases the likelihood of allocating more land to GM maize production by 42.133 units *ceteris paribus*. Conditional on awareness of and participation in GM maize production, rural farming households who own arable land are more likely to intensify GM maize production than those that depend on hired land because of the risk-averse behaviour associated with non-land owners. Kondo et al. (2019) have noted that farmers who own their own land do not share the output with anyone and hence have the freedom to use their land as they see fit. They may be able to boost production because they have no obligation to compensate any landowners in cash or in kind.

CONCLUSION AND RECOMMENDATIONS

This paper aimed to understand the drivers of genetically modified (GM) maize awareness, participation, and intensity of production at the household level using the example of Ngqushwa Local Municipality in South Africa. The study concludes that GM maize awareness is negatively influenced by age and female gender and positively influenced by married status, employment and number of years in school. Both participation and intensity of participation in GM maize production are positively influenced by land size, female gender, group membership and ownership of arable land and negatively influenced by employment and income.

The following recommendations are suggested:

GM maize awareness may be promoted by GM maize awareness campaigns using platforms popular with female-headed, older, less educated and unemployed rural farming households.

GM maize participation may be promoted by addressing land property rights to accommodate women as well as issues of land size and ownership conditional on awareness.

Conditional on participation in GM maize production, intensification may be promoted by addressing land size and land ownership given the isolation regulations associated with GM maize.

Efforts to increase income-generating activities (like off-farm income) will also promote intensification conditional on awareness of and participation in GM maize production.

Lastly, promotion of social networks will also promote intensification of GM maize production for those producing GM maize as they share experiences and information.

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