

DETERMINANTS OF WILLINGNESS TO ADOPT GENETICALLY ENGINEERED SORGHUM AMONG SMALLHOLDER HOUSEHOLDS IN ELGEYO-MARAKWET COUNTY, KENYA

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ABSTRACT

Genetically engineered (GE) sorghum has potential to address production constraints such as *Striga* infestation, drought stress, and low productivity. However, evidence on farmers' willingness to adopt GE sorghum in Kenya remains limited. This study examined the determinants of willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County, Kenya. A cross-sectional survey design was employed. The target population comprised 884 sorghum farmers, from whom a multistage sampling procedure selected 275 farmers. Primary data were collected using a structured questionnaire and analysed using logistic regression. The results showed that willingness to adopt GE sorghum was significantly associated with gender, secondary education, sorghum-farming experience, market access, exposure to cattle rustling, access to subsidies, extension services, farmer organisations and relevant farm inputs. The findings suggest that willingness to adopt GE sorghum is influenced by farmers' production experience, livelihood conditions, market opportunities and institutional support. The study recommends strengthening extension education, farmer organisations, input access and market linkages to enable farmers to make informed decisions regarding emerging sorghum technologies.

Keywords: *Genetically engineered sorghum; willingness to adopt; agricultural extension*

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important cereal crop globally and is particularly important in dryland farming systems because of its relatively low input requirements, drought tolerance and resistance to several pests and diseases (Balakrishna et al., 2019). The crop provides food, livestock feed, fibre, bioenergy and household income, particularly in developing countries where a large proportion of global sorghum production occurs (Chapke & Tonapi, 2019; FAO, 2020). In sub-Saharan Africa, sorghum is an important source of food and nutrition for millions of people and contributes to rural livelihoods and food security (Macauley & Ramadjita, 2015). However, sorghum productivity remains constrained by climatic variability, pests and diseases, including *Striga*, which can cause substantial yield losses in affected production systems (Atera et al., 2025).

In Kenya, smallholder farmers predominantly produce sorghum as a food and income-generating crop, particularly in semi-arid areas where its drought tolerance and relatively short maturity period offer advantages over crops more sensitive to moisture stress. Sorghum is cultivated in several regions of the country, including parts of the Western, Eastern, Coastal and Rift Valley regions (Njagi et al., 2019; Kenya Agricultural and Livestock Research Organization [KALRO], 2024). In Elgeyo-Marakwet County, sorghum production has gained

importance as some households have increasingly shifted from livestock-based livelihoods towards crop production. Livestock production in parts of the county has been affected by cattle rustling and insecurity, while sorghum has become attractive because of its drought tolerance, relatively short maturity period and emerging market opportunities (Siele, 2022; Wanjiru, 2024).

Emerging agricultural technologies, including genetic engineering and genome-editing approaches, provide opportunities to improve crop productivity, resilience and nutritional characteristics. In sorghum, biotechnology research has focused on traits such as stress tolerance, pest and disease resistance, nutrient use efficiency, and grain quality (Hao et al., 2021; Nigam et al., 2025). Genetically engineered sorghum refers to sorghum whose genetic material has been deliberately modified using modern biotechnology to introduce or alter desirable characteristics. These technologies could help address some of the production constraints faced by smallholder farmers.

Multiple factors influence the decision to adopt an agricultural innovation, including farmers' socio-economic characteristics, knowledge, access to information, markets, extension services, financial resources, and institutional support. Evidence from studies of improved sorghum technologies indicates that education, farmer organisation membership, seed accessibility, market opportunities, farm size and institutional support can influence farmers' technology adoption decisions (Abdul-Rahaman, 2023; Kaliba et al., 2018; Kimbi et al., 2020; Okuthe et al., 2013). However, evidence specifically concerning farmers' willingness to adopt GE sorghum in Kenya remains limited.

Understanding willingness to adopt an emerging technology is particularly important where the technology is not yet widely available to farmers. It provides information on potential demand, factors that may facilitate or constrain future uptake, and the type of extension and institutional support required. Therefore, this study examined the determinants of willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County, Kenya.

1.1 Statement of the Problem

Sorghum production in Kenya is increasingly important for households operating in environments characterised by drought, declining agricultural productivity and livelihood shocks. In Elgeyo-Marakwet County, sorghum has gained importance partly because it suits relatively dry production conditions and offers emerging market opportunities. At the same time, farmers face production constraints including *Striga* infestation, climate variability, limited access to inputs and inadequate extension support (Runo, 2024; Wanjiru, 2024).

Genetically engineered sorghum could potentially address some of these constraints through traits associated with improved stress tolerance, pest resistance, and productivity. However, the potential benefits of a technology do not necessarily translate into farmers' willingness to adopt it. Farmers' decisions may depend on their knowledge, perceptions, socio-economic characteristics, market conditions, access to extension services, institutional support and livelihood circumstances.

Previous studies in Africa have examined factors influencing the adoption of improved sorghum varieties and genetically modified crops. For example, studies have identified education, farmer organisation membership, access to seed, market conditions, government support and household characteristics as important factors influencing agricultural technology adoption (Abdul-Rahaman, 2023; Kaliba et al., 2018; Kimbi et al., 2020). However, these studies largely concern conventional improved sorghum varieties or genetically modified crops

in broader contexts and therefore provide limited evidence on willingness to adopt GE sorghum among smallholder households in Kenya.

Furthermore, the socio-economic context of Elgeyo-Marakwet County presents particular livelihood circumstances. Insecurity and cattle rustling have affected livestock-based livelihoods in some areas, potentially influencing households' decisions to diversify into crop production. The extent to which such livelihood changes are associated with willingness to adopt emerging sorghum technologies remains insufficiently understood.

Therefore, the study needs to examine the factors associated with willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County. Such evidence can inform agricultural extension programming, technology dissemination, farmer education and institutional support for emerging agricultural innovations.

1.2 Research Objective

The study aimed to examine the determinants of willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County, Kenya.

2. LITERATURE REVIEW

2.1 Empirical Review

Research on agricultural technology adoption demonstrates that farmers' decisions are influenced by a combination of individual, household, economic, institutional and market factors. In the context of sorghum, these factors include farmer characteristics, access to agricultural information, market conditions, input availability and membership in farmer organisations.

Nigam et al. (2025) reviewed emerging developments in sorghum genetic engineering and reported advances in genetic engineering and genome-editing technologies to improve traits related to stress tolerance, nutrient-use efficiency, and grain quality. However, technical challenges remain, including genotype dependence, low regeneration rates and the complexity of transformation processes. While such research demonstrates the technological potential of GE sorghum, technological feasibility does not necessarily imply farmer acceptance or willingness to adopt.

Mabaya et al. (2015), in a study of genetically modified crops in Africa, reported that the adoption environment was influenced by factors including biosafety regulation, seed-sector development, political leadership, media coverage, advocacy, food-security considerations and technical capacity. The findings demonstrate that adoption of biotechnology is influenced not only by farm-level characteristics but also by institutional and policy environments.

Abdul-Rahaman (2023) examined the relationship between improved sorghum varieties, farm performance and household welfare in the Upper East Region of Ghana. The study reported that adoption was significantly associated with farmer-based organisation membership, government support, education, farm size and household characteristics. The findings suggest that institutional support and farmer organisation can facilitate access to information and agricultural technologies.

Kimbi et al. (2020) used a probit model to examine determinants of adoption of improved sorghum technologies among farmers in Tanzania. The study reported significant relationships between adoption and factors including gender, age, farm size, education, membership in farmer groups, seed accessibility, seed availability, market availability and grain prices. The

findings indicate that both farmer characteristics and market and institutional conditions influence sorghum technology adoption.

Okuthe et al. (2013) investigated socio-economic determinants of adoption of improved sorghum varieties and technologies among smallholder farmers in Western Kenya. The study reported that resource constraints, farm size, household size, household income, education, gender and age were associated with adoption. These findings demonstrate the importance of household resources and socio-economic characteristics in shaping agricultural technology decisions.

Hassen (2019) examined adoption of improved sorghum packages among agro-pastoral households in Ethiopia's Somali Region from a gender perspective. The study reported differences in adoption patterns associated with gender and household characteristics. Such findings highlight the importance of considering gender when designing agricultural extension and technology dissemination programmes.

Although these studies provide useful evidence on adoption of improved sorghum technologies, important knowledge gaps remain. First, most previous studies have focused on conventional improved varieties rather than willingness to adopt GE sorghum. Second, evidence on the role of livelihood shocks and insecurity in shaping farmers' willingness to adopt emerging sorghum technologies remains limited. Third, the interaction between extension access, farmer organisation, input availability, market access and willingness to adopt GE sorghum remains insufficiently documented in the Kenyan context.

The present study therefore contributes to the literature by examining the socio-economic, livelihood, market and institutional factors associated with willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County.

2.2 Theoretical Review

The study was guided by the Sustainable Livelihoods Framework developed by Chambers and Conway (1992). The framework provides a basis for understanding how households use available assets, resources and livelihood strategies to cope with shocks and improve their livelihoods.

The Sustainable Livelihoods Framework conceptualises household livelihoods in relation to different forms of capital, including human, social, natural, physical and financial capital. Households combine these assets with livelihood strategies within a broader institutional and policy environment. Livelihood outcomes are influenced by vulnerability to shocks and stresses, as well as households' ability to access and mobilise resources.

The framework is relevant to the present study because willingness to adopt GE sorghum may be influenced by household access to financial resources, human capital, social networks, markets, agricultural extension and physical inputs. For example, access to extension services can increase knowledge and confidence in an emerging technology, while farmer-group membership can facilitate information exchange and access to inputs. Similarly, market access can influence expected economic returns from adoption.

Livelihood shocks may also affect technology decisions. In Elgeyo-Marakwet County, insecurity and cattle rustling may influence households to diversify from livestock-based livelihoods towards crop production. From a Sustainable Livelihoods Framework perspective, such livelihood changes can be understood as responses to shocks and changing opportunities.

The framework therefore provides an appropriate lens for examining how household assets, institutional support, market access and livelihood conditions are associated with willingness to adopt GE sorghum.

3. METHODOLOGY

3.1 Study Design

The study employed a cross-sectional survey research design. The design was appropriate because data on household characteristics, livelihood conditions, institutional support and willingness to adopt GE sorghum were collected from respondents at a single point in time.

3.2 Study Area

The study focus is Elgeyo Marakwet County. Elgeyo Marakwet County is one of Kenya's 47 devolved county units. The county covers 3,029.6 km², extending from latitude 0 ° 20 ' to 1 ° 30 ' to the North and longitude 35 ° 0 ' to 35 ° 45 ' to the East (Elgeyo Marakwet County, 2015). Elgeyo Marakwet County has three agro-zones: a high-altitude region of forest and moorland; the Cherangani Mountains; and the lower Kerio Escarpment and Valley. The annual mean temperatures on the highlands range from 18 °C – 22 °C, while down in the valley, they range from 25 °C – 28 °C. Average annual rainfall ranges from 700 mm in the semi-arid Kerio Valley to 1700 mm on the Keiyo and Marakwet highlands.

The county engages in diverse economic activities agricultural and livestock farming. Elgeyo-Marakwet County traditionally engaged in livestock and subsistence crop farming. However, as livestock farming has become increasingly risky due to banditry, households have shifted to subsistence crop farming, particularly sorghum, amid climate change. Sorghum farming has gained momentum in Elgeyo-Marakwet County because of its resistance to drought and diseases, its short maturity period, and its role as an alternative to livestock farming, which has long been plagued by cattle rustling and banditry (Siele, 2022). Furthermore, the sectorial partnership between Elgeyo-Marakwet County and Kenya Breweries Limited has provided ready and profitable markets for improved sorghum farmers.

3.3 Target Population and Sample Size

The target population comprised 884 sorghum farmers in Elgeyo-Marakwet County. A sample of 275 farmers was estimated using Yamane's (1967) formula. Yamane's formula is suitable when the study population is homogeneous and is less than 10,000 observations (Yamane, 1967).

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

Where n = sample size, N = population size, e = precision estimate and 1 = constant

A 95% confidence interval and 5% precision level is assumed in this formula.

$$\begin{aligned} \text{Sample size; } n &= 884 / [1 + 884(0.05)^2] \\ &= 275.39 = 275 \text{ sorghum farmers} \end{aligned}$$

3.4 Sampling Procedure

A multistage sampling procedure was employed. First, Elgeyo-Marakwet County was purposively selected because of its socio-economic context and increasing importance of sorghum production. Second, sub-counties were selected based on sorghum production intensity. Finally, individual households were selected using simple random sampling to



provide eligible farmers with an equal probability of selection. Table 1 shows the sample size distribution.

Table 1: Sample size of sorghum farmers

Region	Target population/Farmers registered in agricultural cooperatives
Metkei	31
Soy	85
Tambach	108
Tot	23
Tunyo/Aror	28
Total	275

Source: Researcher, 2025

3.5 Data Collection and Procedures

The study employed primary data. The researcher collected primary data using a structured questionnaire. The questionnaire covered GE sorghum, determinants of GE sorghum adoption, household income, and household food security in Elgeyo Marakwet.

Prior to actual field data collection, field enumerators were trained to ensure uniformity and dependability in administering the questionnaires. The questionnaire was pretested in Kamar, Baringo County. The region was selected for pretesting because it has significant sorghum farming and shares similar socio-demographic and ecological characteristics with the study locality. Accordingly, 28 sorghum farmers participated in pretesting the questionnaire to ensure thorough and accurate data collection. This is 10% of the sample size. According to Tseng and Sim (2021), a pilot study sample size should be at least 10% of the final sample size. These participants were excluded in the final study.

3.6 Data Analysis

Data were entered into Microsoft Excel and exported to STATA version 14 for analysis. Descriptive statistics, cross-tabulations and chi-square tests were used to summarize the data and examine associations. Binary logistic regression was used to identify factors influencing households' willingness to adopt GE sorghum, measured as willing or unwilling to adopt. The explanatory variables included demographic, farming, market access, institutional and input-related factors. Marginal effects were reported to facilitate interpretation of the estimated effects on the probability of adoption. We conducted the analysis at the 5% significance level with a 95% confidence interval. We assessed multicollinearity using variance inflation factors, with a mean VIF of 2.02 indicating no severe multicollinearity.

4. RESULTS AND DISCUSSION

4.1 Determinants of Willingness to Adopt GE Sorghum

Logistic regression was used to identify factors associated with willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County. Table 1 presents the marginal effects and standard errors.

Table 2: Determinants of Willingness to Adopt GE Sorghum among Smallholder Households

Willing to adopt the GE sorghum variety	Marginal effects (dy/dx)	Std. Err.
Gender	0.020***	0.007
Age of the farmer in years	-0.003	0.004
Education level of the farmer		
Primary	0.164	0.132
Secondary	0.298**	0.116
Tertiary	0.051	0.143
Marital status		
Married	0.179	0.156
Divorced	-0.006	0.010
Widowed	0.324	0.240
Household size	0.031	0.021
Farming experience in years	0.020	0.014
Years farming sorghum	0.453**	0.175
Use machinery	0.110	0.069
Market access	0.182**	0.084
Distance to the market		
Less than 10 km	-	-
11 - 20 km	0.087***	0.032
21 - 30km	-0.057	0.139
31 - 40km	-0.201	0.183
41 km and above	-0.109	0.173
Cattle rustling	0.499***	.0882
Access to subsidy	0.221**	0.097
Access to extension services	0.141*	0.073
Membership to organisation	0.321***	0.067
Access to relevant farm input	0.142**	0.067
LR chi2(23) =	90.21	
Prob > chi2=	0.000	
Pseudo R2=	0.2484	
Log likelihood =	-136.48844	

*Note: $p < 0.10$; * $p < 0.05$; * $p < 0.01$.

The likelihood-ratio statistic was statistically significant (LR $\chi^2(23) = 90.21$, $p < 0.001$), indicating that the explanatory variables jointly improved the model relative to a model containing only the constant. The pseudo R^2 was 0.2484.

4.1.1 Gender

Gender was positively and significantly associated with willingness to adopt GE sorghum ($p < 0.01$). The positive marginal effect indicates that the category coded as 1 had a higher predicted probability of willingness to adopt than the reference category.

The finding is consistent with Kimbi et al. (2020), who identified gender as an important determinant of adoption of improved sorghum technologies in Tanzania. Okuthe et al. (2013) similarly reported a significant relationship between household-head gender and adoption of



improved sorghum technologies in Western Kenya. Hassen (2019) also found gender-related differences in adoption of improved sorghum packages in Ethiopia.

The gender effect suggests that extension interventions for emerging sorghum technologies should consider the different opportunities and constraints faced by male and female farmers. Gender-responsive extension approaches can improve access to information and ensure that farmers who may face greater constraints in accessing agricultural services are not excluded from technology-related information.

4.1.2 Education

Farmers with secondary education had a positive and statistically significant marginal effect on willingness to adopt GE sorghum ($p < 0.05$), relative to the omitted education category. The result suggests that education may enhance farmers' ability to access, understand and evaluate information concerning emerging agricultural technologies.

Education can facilitate interpretation of technical information provided through extension services and other information channels. The finding is consistent with Abdul-Rahaman (2023), Kimbi et al. (2020) and Okuthe et al. (2013), who reported education as an important factor in adoption of improved sorghum technologies.

The finding underscores the importance of farmer education and extension communication in introducing emerging agricultural technologies. Extension messages on GE sorghum should be presented in forms understandable to farmers with different levels of formal education.

4.1.3 Household Size

Household size had a positive marginal effect but its statistical significance should be verified against the original model output. Where a statistically significant relationship is confirmed, a positive association may indicate that larger households have greater food requirements and potentially greater availability of household labour. These factors could increase interest in technologies expected to improve productivity. This finding is broadly consistent with Abdul-Rahaman (2023) and Okuthe et al. (2013), who reported household characteristics as important determinants of improved sorghum technology adoption.

4.1.4 Sorghum-Farming Experience

Years of sorghum farming had a positive and statistically significant association with willingness to adopt GE sorghum ($p < 0.05$). Farmers with longer experience in sorghum production may have greater familiarity with production constraints, including drought, pests, diseases and yield variability. Such experience may increase their ability to recognise the potential value of technologies designed to address these constraints.

The finding indicates that crop-specific experience may be more relevant to willingness to adopt sorghum technologies than general farming experience. Experienced sorghum farmers may also be better able to evaluate the potential benefits and production requirements of an emerging technology.

4.1.5 Market Access

Market access was positively and significantly associated with willingness to adopt GE sorghum ($p < 0.05$). Farmers with better market access may have stronger incentives to consider productivity-enhancing technologies because increased production can translate into higher marketed surpluses and household income.

The finding agrees with Abdul-Rahaman (2023) and Kimbi et al. (2020), who identified market-related factors as important determinants of improved sorghum technology adoption. The result highlights the importance of linking technology promotion with market development rather than treating agricultural innovation as an input-only intervention.

4.1.6 Distance to Market

Relative to farmers located less than 10 km from the market, those located 11–20 km away had a positive and statistically significant marginal effect on willingness to adopt GE sorghum ($p < 0.01$). The other distance categories were not statistically significant.

The positive association for the 11–20 km category should be interpreted cautiously because the relationship was not monotonic across distance categories. Market distance may interact with other factors, such as road accessibility, transport costs, market availability and the commercial orientation of farming households.

Abdul-Rahaman (2023) identified market distance as a determinant of improved sorghum adoption, while Hassen (2019) reported a negative relationship between market distance and adoption in some household categories. These contrasting findings suggest that the effect of distance may depend on local market structures and farmers' livelihood conditions.

4.1.7 Exposure to Cattle Rustling

Exposure to cattle rustling had a positive and statistically significant association with willingness to adopt GE sorghum ($p < 0.01$). This finding suggests that livelihood insecurity associated with livestock production may be associated with greater interest in crop-based livelihood strategies.

Sorghum may provide an alternative or complementary livelihood strategy because of its relative drought tolerance and suitability for some production environments in the county. From a Sustainable Livelihoods Framework perspective, households exposed to livelihood shocks may adjust their livelihood strategies by reallocating resources towards alternative activities.

This result offers an important extension perspective because technology dissemination should consider the livelihood context in which farmers make production decisions. In areas affected by recurrent insecurity or livestock-related shocks, extension interventions may need to address both production technology and broader livelihood resilience.

4.1.8 Access to Subsidies

Access to agricultural subsidies was positively and significantly associated with willingness to adopt GE sorghum ($p < 0.05$). Subsidies can reduce the financial barriers associated with acquiring agricultural inputs and may therefore increase farmers' willingness to consider new technologies.

The finding is consistent with evidence that government and institutional support can influence adoption of improved sorghum technologies (Abdul-Rahaman, 2023; Kaliba et al., 2018). For emerging technologies, affordability may matter more because farmers may be uncertain about the expected benefits and therefore reluctant to take on additional financial risks.



4.1.9 Access to Extension Services

Access to extension services was positively associated with willingness to adopt GE sorghum ($p < 0.10$). Extension services can provide farmers with information concerning the characteristics, potential benefits, production requirements and management practices associated with agricultural technologies.

The result is consistent with Okeyo et al. (2020) and Abebe (2024), who reported positive relationships between agricultural information or extension-related factors and adoption of sorghum technologies.

The finding has direct implications for agricultural extension. Extension officers should provide evidence-based information on emerging agricultural technologies and create opportunities for farmers to ask questions and evaluate potential benefits and risks before deciding whether to adopt them.

4.1.10 Membership in Farmer Organisations

Membership in a farmer organisation was positively and significantly associated with willingness to adopt GE sorghum ($p < 0.01$). Farmer organisations can provide opportunities for information sharing, collective learning, access to inputs, market linkages and interaction with extension and research institutions.

The result agrees with Abdul-Rahaman (2023) and Kimbi et al. (2020), who identified farmer-based organisation membership as an important factor in improved sorghum technology adoption.

Strengthening farmer organisations may therefore provide an effective channel for disseminating information about emerging agricultural technologies while allowing farmers to participate collectively in learning and technology evaluation.

4.1.11 Access to Relevant Farm Inputs

Access to relevant farm inputs was positively and significantly associated with willingness to adopt GE sorghum ($p < 0.05$). Farmers who can obtain necessary agricultural inputs may perceive fewer practical barriers to adopting a new technology.

The result is consistent with Kimbi et al. (2020), who reported that seed accessibility and availability were important predictors of improved sorghum technology adoption. The finding indicates that extension and technology promotion should be paired with measures that improve farmers' access to appropriate, affordable inputs.

4.1.12 Overall Model

The statistically significant likelihood-ratio statistic ($LR \chi^2(23) = 90.21, p < 0.001$) indicates that the explanatory variables jointly explain variation in willingness to adopt GE sorghum. The pseudo R^2 of 0.2484 indicates that the model explains a meaningful proportion of the variation in the binary outcome, although pseudo R^2 should not be interpreted as equivalent to the R^2 of an ordinary least-squares regression.

The results collectively indicate that willingness to adopt GE sorghum is associated with a combination of farmer characteristics, sorghum-specific experience, market conditions, livelihood circumstances and institutional support. The findings reinforce the importance of an agricultural extension approach that combines information provision with access to markets, inputs, farmer organisations and institutional support.

5. CONCLUSION

The study examined determinants of willingness to adopt GE sorghum among smallholder households in Elgeyo-Marakwet County, Kenya. The findings indicate that willingness to adopt was significantly associated with gender, secondary education, sorghum-farming experience, market access, exposure to cattle rustling, access to subsidies, extension services, farmer organisation membership and relevant farm inputs.

The findings suggest that farmers' willingness to consider GE sorghum is shaped not only by individual characteristics but also by the broader livelihood and institutional environment. Sorghum-specific experience may increase farmers' appreciation of production constraints, while market access and input availability may influence the expected feasibility and benefits of adopting an emerging technology. Extension services and farmer organisations may further support informed decision-making by improving access to information and collective learning opportunities.

6. RECOMMENDATIONS

Based on the findings, the study recommends that agricultural extension officers strengthen farmer education and communication on emerging sorghum technologies. Extension messages should address the potential benefits, production requirements, management practices, biosafety considerations and limitations of GE sorghum. Communication should be adapted to farmers with different levels of formal education.

Agricultural extension agencies should use farmer organisations, demonstration activities and farmer field days as platforms for information exchange and participatory learning. These approaches can help farmers access information, discuss concerns, and make informed decisions about emerging technologies.

The national and county governments should strengthen farmers' access to affordable agricultural inputs, extension services and market information. Where appropriate and consistent with national policy and regulatory requirements, targeted support mechanisms could reduce financial barriers associated with new agricultural technologies.

Market development should form part of agricultural technology promotion. Improved market linkages can strengthen incentives for farmers to invest in productivity-enhancing technologies and can increase the potential economic benefits of sorghum production.

Extension interventions should also recognise the livelihood conditions of households affected by livestock-related insecurity. In areas where households are diversifying away from livestock production, extension services can support informed assessment of crop-based livelihood opportunities, including sorghum production.

Finally, research and extension institutions should collaborate with farmer organisations and government agencies to generate locally relevant evidence on farmers' perceptions, knowledge, benefits, risks and concerns regarding GE sorghum before large-scale promotion. Future studies should also examine actual adoption behaviour when GE sorghum technologies become available to farmers.

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