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Research Article

Public Perception of Genetically Modified Organisms and the Implementation of Biosafety Measures in Kenya

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Genetically modified organisms (GMOs) are an important nexus of biotechnology, agriculture, and research. GMOs have gained popularity because of their potential to address global food insecurity. However, the widespread adoption of GMOs has sparked debates and controversies. This study collected data on the threats and effects of the GMO ban and the status of implementation of Biosafety Act and Cartagena Protocol on biosafety in Kenya. A cross-sectional survey was used with 216 participants sampled purposively and 16 key informants interviewed in a qualitative survey with triangulation of data from a scoping literature review. Fifty-seven percent of the respondents indicated GMOs and genetically modified (GM) foods are a solution to food security in Africa. A majority believe that the introduction of GMO technology and the use of GM food is beneficial (52.3%). Fifty-five percent of the respondents indicated that GM foods are safe. Most respondents (>90%) indicated that there is a low threat of GMO technology on the environment, human health, and animal health. The respondents (54.3%) agreed there is good adherence to the Cartagena Protocol. The correlation between awareness of the Cartagena Protocol on biosafety and views on whether there are adequate legal and regulatory frameworks was $r = 0.4$, indicating a weak but positive relationship between the two. Respondents who reported that the legal and regulatory frameworks were adequate were, therefore, likely ($r = 0.4$) to be aware of the Cartagena Protocol. There was a moderate positive correlation ($r = 0.67$) on views that GM food is a solution to food insecurity. Understandably, the relationship between GM food health concerns and GM food as safe was moderately negative ($r = -0.4591$). The findings are important in addressing gaps in the current GMO regulations and implementation aimed at increasing awareness of GMO technology as well as informing policy on biotechnology.

1. Introduction

The global triple threats of climate change, a burgeoning human population, and widespread biodiversity loss necessitate the need for environmentally friendly crops that are more resilient and more nutritious [1]. Consequently, food and nutrition insecurity continue to risk the lives and wellbeing of millions of people throughout the world today. Recent estimates show that globally about 702–828 million people were affected by hunger in 2021 [2]. Further, according to the Global Report on Food Crisis 2022 Mid-year update, up to 205 million people in 45 countries are predicted to endure acute food insecurity and require immediate assistance [3]. Food and nutrition insecurity has been linked to a growing population, conflict, and climate change, among other causes, with the majority of the burden affecting people, particularly in the Global South. Furthermore, the rising shocks, such as the recent COVID-19 outbreak, have disrupted food systems, exacerbating the continent's food and nutrition insecurity [1]. In 2021, about 278 million people living in Africa were affected by hunger [1, 3]. In Kenya, Food and nutrition insecurity is still a major challenge [4]. According to an update of the Kenya Food Security Steering Group's (KFSSG) 2021/2022 Short Rains IPC study, the number of food insecure persons in pastoral and marginal agricultural regions had increased from 3.1 million in February 2022 to over 4.1 million in May 2022 [5]. Climate variability and extremes continue to harm agricultural productivity across the country, creating vulnerability concerns to many people, the majority of whom are women who rely on agriculture for a living [2].

Globally, scientists have been searching for novel ways to boost agricultural productivity and ensure sustainable food security [6]. Further, Africa's development agenda 2063 has a focus on modern agriculture for increased productivity and production, which is one of the main concepts of the adoption of modern biotechnology [7]. Farmers have adopted different strategies, including improved seed varieties, mechanization, use of fertilizers and pesticides, information technology to mention but a few [8]. Similarly, genetically modified (GM) crops have been proposed as a potential strategy to promote sustainable food production [9]. However, controversies are being widely propelled by many challenges, such as lack of sufficient information, data, misconceptions, regulations, ignorance, and philosophical concerns, among others. In South Africa, for instance, GMO white maize was availed to nearly 4.6 million people annually as additional rations of food to the national population [10]. Moreover, the net welfare benefit of producing and consumption of GMO white maize in the country amounted to USD 695 million between 2001 and 2018 [11].

Since the mid-1990s, genetically modified organisms (GMOs) and genetic engineering (GE) technology have been available [12, 13]. GMO is defined by the World Health Organization as organisms including plants, animals or microorganisms in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination" [14]. Likewise, the Food and Agriculture Organization of the United Nations and the European Commission have defined a GMO as a product "not occur naturally by mating and/or natural recombination" [15]. GMOs are products of modern biotechnology that involve the manipulation of the genetic material of organisms through GE procedures. Therefore, "GM foods" refer to foods produced from GM plants or animals [16]. The adoption of GMOs has been fraught with controversy, with anti-GMO activists raising concerns of the health and environmental risks [16–18]. While on the other side, the proponents arguing that it reduces the use of pesticides and increases crop yields [11, 19]. The technology has been slowly embraced in various regions of the world, with acreage under GM crops rising [8, 20]. In 2019, GM crops were grown in economically significant amounts in the United States at 71.5 million hectares, followed by Brazil (52.8 million hectares), Argentina (24 million hectares), Canada (12.5 million hectares), and India (11.9 million hectares) [8, 21, 22]. Soybean was the most adopted (50%), followed by maize (30%), cotton (13%), and canola (5%) [23]. Despite these global trends, the adoption of GM crops in Africa, including Kenya, has been slow due to the contradictory information on the health and safety of GM foods, lack of information, and negative views toward biotechnology, among others [24].

Additionally, adequate legal and regulatory frameworks must be present to increase a country's competence in agricultural biotechnology research and development and commercialization [25]. There are instruments of the biosafety framework that have been established to ensure an adequate level of protection in the handling and use of GMO products originating from modern biotechnology and are passed by parliament and implemented by a specified ministry [26]. In 2005, the Kenyan Parliament introduced the Biosafety Bill, which sought to regulate and oversee research on GMOs [27]. The bill was enforced in 2010, which led to the establishment of the National Biosafety Authority (NBA) [28]. The NBA was established by the Biosafety Act No. 2 of 2009 to exercise general supervision and control over the transfer, handling, and use of GMOs. However, a study by Séralini et al. [29] linking GM corn consumption to cancer in rats prompted Kenya's Minister of Public Health to call for a moratorium on GM crops without consultation with the NBA [30]. The ban remained in effect despite the withdrawal of the publication report [27]. As a result, the country's continuous development, marketing, and acceptance of GMO crops was hampered. In addition, the United States Department of Agriculture's Foreign Agricultural Service estimated that the prohibition might impact Kenya's capacity to meet public demand for maize [31] and also affect other countries considering GM policies [32]. In 2019, the cabinet approved the *Bt thuringiensis* cotton, which was later successfully released to farmers in 2020. Further, in October 2022, the import restriction on GM foods was removed in an effort to prevent the country's worst famine [28]. A recent study noted that 46% of the Kenyan population have limited knowledge about GMOs, and the majority showed concerns about the impact of GMOs on the environment, human health, and adverse effects on traditional farming practices, as well as the loss of biodiversity [33]. Therefore, there is a need for more studies on the health and environmental implications of GMOs to demystify concerns/fears about GM foods as well as reliable regulatory controls [34].

In accordance with Article 26 of the Cartagena Protocol on biosafety, the Kenyan Biosafety Act 2009 underlines the requirement for assessment of socioeconomic impacts before an application is approved. However, details on the assessment, analysis, and inclusion into biosafety decision-making have not been properly articulated [35, 36]. Sufficient details should be provided to ensure a fair and transparent biosafety regulatory system. This study was therefore designed to gather information and data on the effects and threats of the GMO ban and the status of implementation of the Biosafety Act and Cartagena Protocol on biosafety in Kenya.

2. Materials and Methods

A cross-sectional study design with a multidisciplinary and multisectoral participatory approach was used to collect data on perceptions of GMOs, threats, and effects of the GMO ban (2012–2022) and to give a situational analysis of the status of implementation of Biosafety Act and Cartagena Protocol on biosafety in structured survey interviews. The study also involved literature reviews, publications, desktop reviews, and interviews with identified stakeholders, among others, using appropriate data collection tools.

2.1. Sampling Protocol and Data Collection. The sampling procedure employed in this study was a purposive sampling technique to identify stakeholders in GMO sector, including government, regulatory agencies, public sector, consumers, farmers, industry layers, academia, and NGOs, among others, value chain actors who could provide relevant GMO information. A total of 216 respondents were purposively selected to participate in the study. The data collection tool for the study included a structured survey questionnaire and checklist guides for key informant interview guides. The tools were used for in-depth survey interviews with the selected study respondents. Stakeholder mapping and analysis were conducted to identify key stakeholders with information and knowledge on GMOs in selected institutions and organizations from a pool of 1,000 potential participants. The stakeholder analysis was aimed at identifying the type of stakeholders with regard to GMOs, activities of each, threats, challenges, and opportunities, among others. The stakeholder consultations also engaged policy-makers, regulatory agencies, and government actors.

2.2. Desktop Review. A comprehensive desk review of relevant reports, publications, documents, and policies was reviewed with the aim to identify the current status of GMO use, perceptions, knowledge, and attitudes and map the industry's requirements; identify existing gaps to GMO use and adoption including threats and benefits of GMO technology; mapping the GMOs sector and identify potential opportunities for the NBA's future regulatory roles and oversight for better access; and to establish the factors inhibiting GMO use and adoption after the ban to inform policy. The primary sources for this review were electronic databases such as Springer, Elsevier, PubMed, Embase, and Web of Science. In addition, government reports for various ministries and organizations involved in issues of GMOs were reviewed. A number of broad search categories were targeted with relevant hits for this study, and the searches were based on the use of search terms, term truncation, and limiting to specific fields. Publications were searched with the search terms "genetically modified foods/GMOs"; safety and GMOs; environmental impact; GMO and biodiversity; biosafety and GMOs; biosecurity; GMO legal frameworks; GMO regulations; biosafety authorities; regulatory agencies in GMO; toxicities, or plant and human health effects among others were also considered in the review. All publication results, particularly abstracts, were stored using the literature data management software Zotero, which is effective in managing references, abstracts, and full-texts, including checking for duplicates.

2.3. Survey and In-Depth Interviews. A total number of 216 selected participants were determined as a sample size and engaged in in-depth interviews on the benefits and threats of GMOs using structured and validated questionnaires. The survey sought information on knowledge and awareness of GMO technology; perceptions on GMOs; the impact of GMOs, including the positive and negative benefits of adoption of GMOs, and human health, environment and safety issues; legal frameworks and regulations governing GMOs; ethical concerns on GMOs; roles of stakeholder in making decisions about policy issues related to GM foods among other categories.

2.4. Key Informant Interviews. Key stakeholders in the GMO sectors were interviewed on the benefits and threats of GMOs, among other knowledge, attitudes, and perceptions of GMO technology, applications, and safety issues to understand how laws, policies, rules, and regulations integration in the GMO sector with gender issues among others; and in which areas that NBA could focus on. A representative number of 16 stakeholders were interviewed. The sampling of the key informants was purposively done. GMO-based knowledge, perceptions, attitudes, and practices of the participants were sought through in-depth exploratory interviews.

2.5. Data Analysis and Reporting. All enrollment data documented gender and age in the event disaggregated analysis is possible. Data entry and cleaning were done through transcription of data from the review, in-depth interviews, and KIIs. Data analysis also involved coding and triangulating the data from the stakeholder consultative meetings with the literature review. The interview transcripts were transcribed verbatim, after deidentification, through Microsoft Word processing and cross-checked for accuracy and reliability against recordings. Transcripts were thematically organized at least twice using the data management tool NVivo version 12.0 (QSR International Version 12.0) qualitative analysis software. The qualitative data was coded inductively using coding principles to each GMO theme and cross-checked with all members of the research team to gain consensus, consistency, and result validity. Once the themes and associated subthemes were determined, a perspective theme mapping was created to illustrate the interrelationships between themes and subthemes. The data analysis was then done using ATLAS.ti and NVIVO. Secondary data analysis after mining was done using STATA (version 14.0). Data analysis included descriptive, bivariate, and multivariate analysis. The qualitative data from key informants was translated, and the transcripts were analyzed thematically using NVivo software. Pearson's Product moment correlation and chi-square were used to test the hypotheses.

3. Results

3.1. Sociodemographics Characteristics of the Respondents. Out of the 216 respondents interviewed, 34.7% were female and 65.3% were male, with 60% aged 18–30 and 31–40 years. Over 120 respondents had postgraduate education and 73 tertiary education, among other levels of education. The majority of the respondents were salaried employees (68%), mid-level managers (34%), senior managers (33%), self-employed (31%), and CEO/top of organizations (17%) among others (31%). In addition, most of the respondents represented mainly the private/industry (27.3%), academia (25.9%), NGO/INGO (9.3%), national government (7.4%), farmer/farmer organization (8.3%), county government (5.6%), research institute (6.0%), parastatal (5.1%), consumer organization (0.9%) among others (4.2%). Table 1 shows the demographic characteristics of the respondents in the baseline study.

3.2. GMO Knowledge. All the respondents (100%) were aware of the GMO technology. The respondents indicated

Table 1: Demographic characteristics of the respondents in the baseline survey.

Respondents characteristics	Description	Freq.	Distribution of survey responses ($N = 216$)	
Age	18–30	61	28.2%	Mean = 2.425926
	31–40	60	27.8%	SD = 1.232911
	41–50	54	25.0%	—
	51–60	25	11.6%	—
	61–70	15	6.9%	—
	Above 70	1	0.5%	—
Gender	Female	75	34.7%	Mean = 1.652778
	Male	141	65.3%	SD = .477193
Level of education	Postgraduate (masters/PhD)	121	56.0%	Mean = 2.185185
	Secondary education	8	3.7%	SD = 1.40198
	Tertiary education (diploma)	13	6.0%	—
	Tertiary education (degree)	74	34.3%	—
Type of organization	National Government	16	7.4%	Mean = 3.60386
	County Government	12	5.6%	SD = 2.049765
	Academia	56	25.9%	—
	Research Institute	13	6.0%	—
	NGO/INGO	20	9.3%	—
	Private/industry	59	27.3%	—
	Parastatal	11	5.1%	—
	Farmer/farmer organization	18	8.3%	—
	Consumer organization	2	0.9%	—
	Other	9	4.2%	—

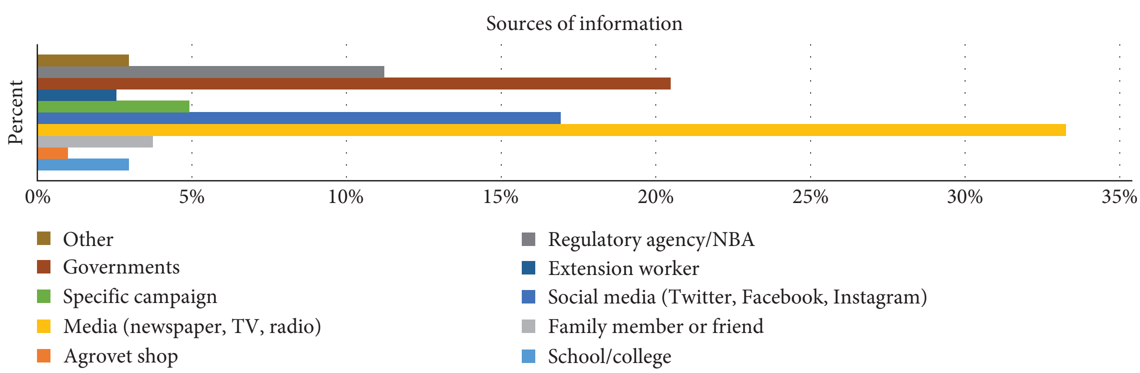

Figure 1: Major sources of information of GMOs in Kenya.

that their sources of information of GMOs were media like newspaper, TV, radio (33%), governments (20%), social media like Twitter, Facebook, Instagram (17%), regulatory agency/NBA (11%), specific campaigns (5%), family member or friend (4%), school/college (3%), extension worker (3%), Agrovet shop (1%) among other sources (3%). Figure 1 shows the sources of information identified in the study.

Most respondents (91.7%) indicated that some of the foods consumed in Kenya are GM foods, mainly imported foods, including maize/corn, soybean, tomato, potato, banana, soybeans, cassava, apples, mango, oils, common beans, spices, among others. The majority of the respondents ranked GMOs of high importance toward increasing the agricultural productivity of staple foods (Figure 2). The respondents were able to rank the importance on a scale of 1–10, with 1–3 (no importance), 4–6 (moderate importance), and 7–10 (high importance). About 48% of the respondents indicated that GMOs were of high importance, while 29% reported that they were of moderate importance, and 23% reported that they were of no importance in increasing agricultural productivity.

On a scale of 1–10, with 1–3 representing (no focus), 4–6 (moderate), and 7–10 (high) organization/institute/workplace focus in the field of GMOs/GM technology were ranked. About 35% had no focus, 49% had moderate focus, while 16% had high focus (Figure 3).

3.3. Benefits of GMOs. Fifty-seven percent of the respondents indicated GMOs and GM foods are a solution to food security in Kenya and Africa. The respondents believe that the

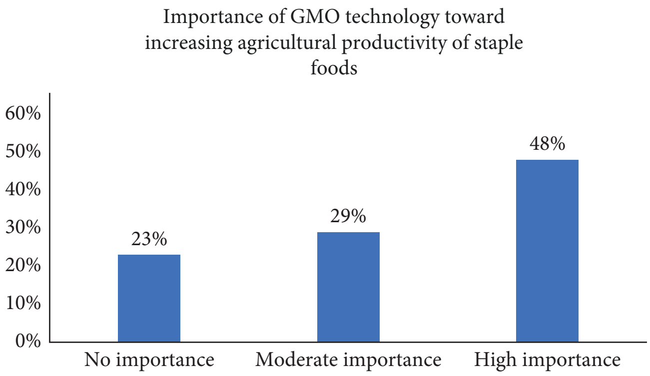

FIGURE 2: GMOs importance in increasing agricultural productivity of staple foods.

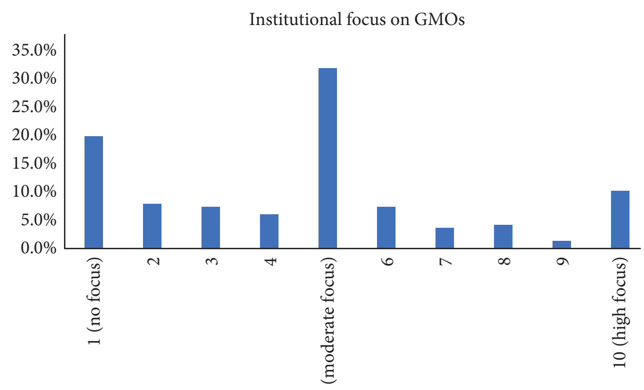

FIGURE 3: Organizational and institutional workplace focus in the field of GMOs.

introduction of GMO technology and use of GM food is beneficial (52.3%), while 25.0% indicated that it was harmful among others who reported that it did not make a difference (9.7%), and others chose not to respond (13%). In regards to the benefits of GMOs, most of the respondents indicated that GMOs can result in increased crop resistance to drought (77.8%); increased food supply (71.3%); reduction in use of pesticides and plant protection products (68.5%); increased food security (68.1%); higher yields of crops (64.8%); reduction of hunger in Kenya (59.3%); reduction in food loss (56.5%); better shelf life of foods (56%); increased resistance to pathogens (56%); improve shelf life (56%); and enhanced taste, flavor, and appearance of food (50%). Further, it was noted that GMO technology reduces water use (49.1%); increases the nutritional quality of foods (47.7%); and makes GM foods more affordable (43.1%). Figure 4 shows the benefits of GMOs/GM food identified by respondents on a scale (1 = strongly agree; 2 = agree; 3 = neither agree nor disagree; 4 = disagree; 5 = strongly disagree).

The respondents also ranked the benefits of GMOs in terms of importance in the country on a scale ranging from high importance to no importance (Figure 5). It was shown that increased crop resistance to drought (77.8%), higher yields of crops (64.8%), reduction of hunger in Kenya (59.3%), and increased resistance to pathogens (52.5%) were of high importance, while production of cheaper feed for livestock (49.4%), uses in medicines vaccines production (43.2%), production of affordable food (42.6%), low use of chemicals pesticide in crops (42.6%), and better food quality (39.5%) were identified to be of moderate importance. The key informants also identified some positive effects, including increased shelf life of food with reports that GMOs have been engineered to have a longer shelf life; reduction of food loss; increased yields, and productivity, indicating that GMOs have the potential to increase crop yields and improve agricultural productivity. Some respondents also noted that with good controls, environmental degradation from GMOs can be mitigated positively. Some believe that with proper regulation and oversight, the negative environmental impacts of GMOs can be minimized. Some respondents were of the opinion that GMOs do not have any harmful effects. Some respondents reported that the criticism of GMOs is based on misinformation or unfounded beliefs. They indicated that GMOs are tested adequately before release. Some respondents have faith in the regulatory system and believe that GMOs undergo sufficient testing before they are approved for release.

3.4. Impact of GMO Technology. Fifty-five percent of the respondents indicated that GM foods are safe. The majority of the respondents (91%) indicated that GM foods are perceived differently from traditional or conventional foods. Fifty-seven percent indicated that there are known main issues of concern for human health caused by the consumption of GM foods. The majority of the respondents (85.6%) reported that the country does not have adequate data and information on the GMO technology, as opposed to 14.4% who say there is enough data. The respondents rated the impact of GMOs and GM foods on key issues on a scale of one (1) = no threat to five (5) = high threat. About 24% indicated that there is a low threat of GMO technology on the environment compared with 17% who reported that there is a high threat. In regards to health, 18% indicated a low threat, while 20% reported a high threat. On human life, 22% indicated a low threat compared to 20% who reported a high threat. On animal health, 23% indicated a low threat, while 16% reported a high threat. Regarding other key aspects, about 27% of the respondents indicated a low threat, while 17% reported a high threat. Figure 6 shows the rating of perceived threats, focusing on key issues of concern with regard to GMOs.

3.4.1. Perceptions on Negative Effects of GMOs. The negative effects of GMOs/GM food identified included transfer of toxicity and toxic potential of the modifications (−56.9%); transfer of allergenicity (−56%); transfer of antibiotic resistance (−51.9%); GM food consumption leads to immune-suppression (−46.8%); causes allergenic reactions (−45.5%); causes cancer (−40.7%); cause teratogenic effects (−37.5%); and loss of nutrition in foods (−31.9%). There are different perceptions of GMO foods noted as compared to traditional foods. Overall, 91.2% perceived that GMOs are different from traditional foods, as opposed to 8.8% who did not agree with this observation. These included the perception that

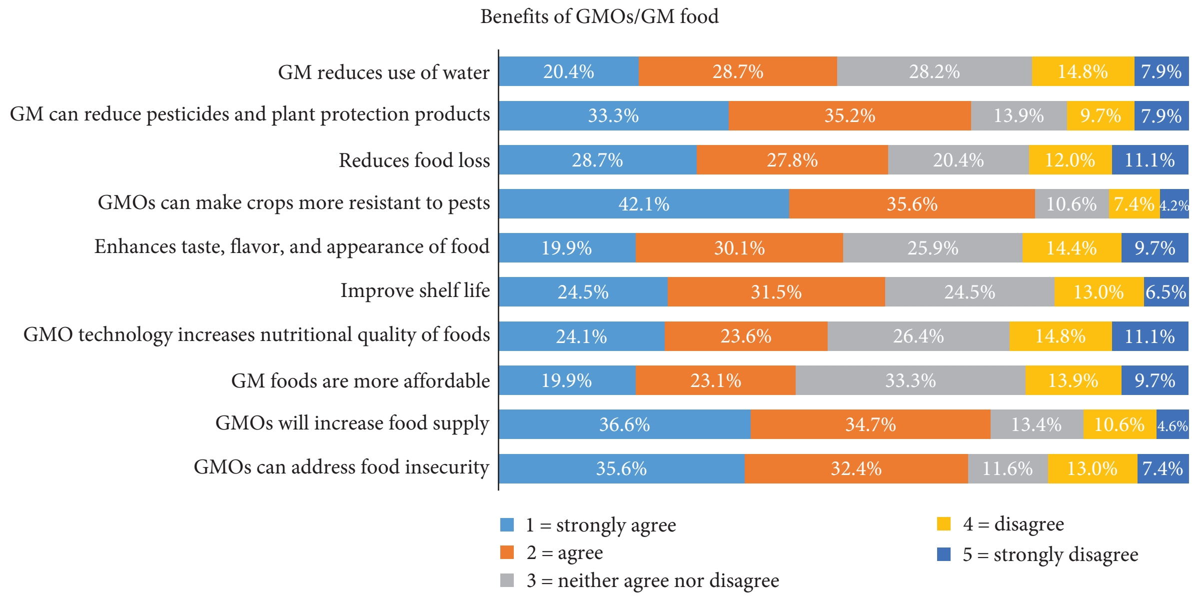

Figure 4: Benefits of GMOs and GM foods as classified by respondents.

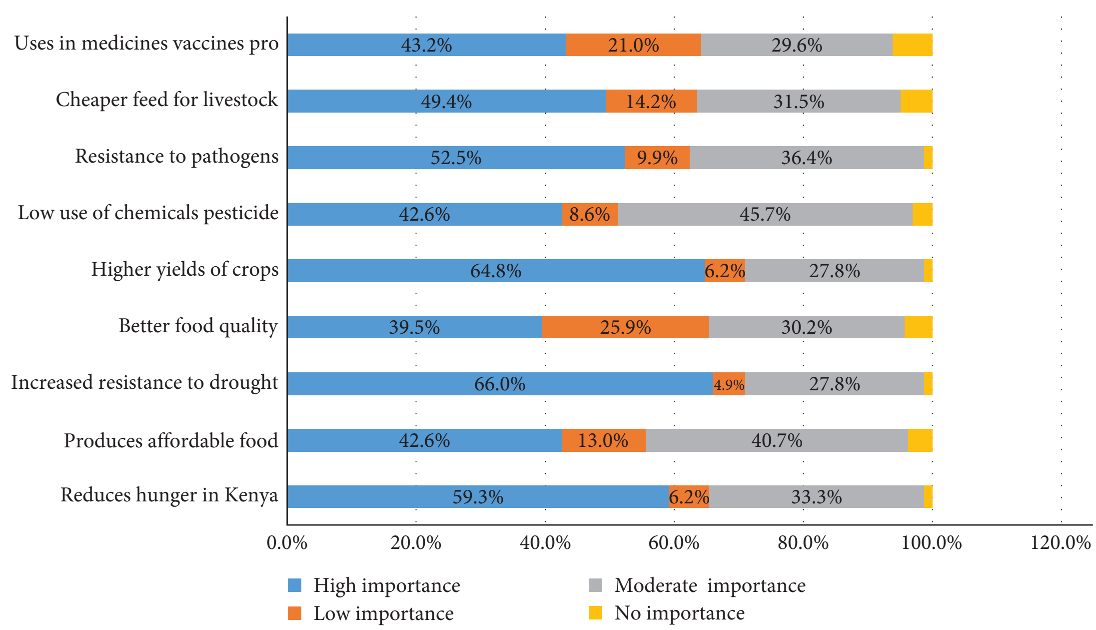

Figure 5: Importance of GMO technology in Kenya as ranked by respondents.

GMO foods are unnatural and man-made, the perception that GMO foods are unsafe, negative press reports on GMO products, the association of high quality with non-GMO foods, concerns about potential unknown negative effects on human health, and concerns about potential harm to the ecosystem and biodiversity loss. Figure 7 shows a summary of the negative effects of GMOs/GM foods.

3.4.2. GMOs as a Solution to Food Insecurity. The opinions of the respondents on whether GMOs are a solution to food security in Kenya showed that the majority supported the use of GMOs in the production of cheaper food (70.8%); production of medicines and vaccines to save human lives (69%); production of more sustainable meat using farmed animals (60.6%); production of animal feed from plants, algae, and microorganisms (68.1%); production of nonfeed, e.g., cotton and fabrics, cosmetics (76.4%); and production of vaccines to prevent diseases (65.3%). Some respondents argue that GMOs can increase crop production, nutritional value, and pest control, which can contribute to food availability and farmer income. Others are indifferent to the GMO debate or believe that other production technologies, such as agroecological approaches, should also be applied. Concerns on GMOs as a solution to food security include the potential loss of biodiversity and domination of the seed industry by a few companies. Some argue that GMOs may

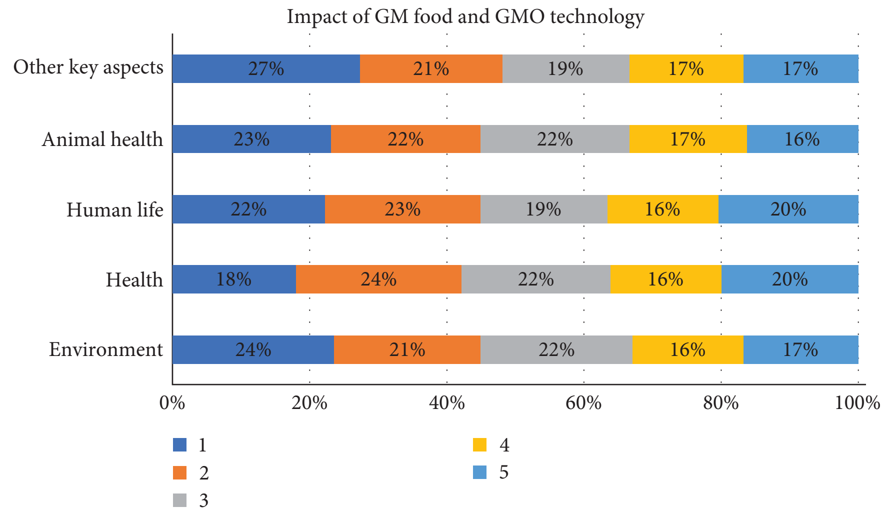

Figure 6: Impact of GMO technology based on perceived threats.

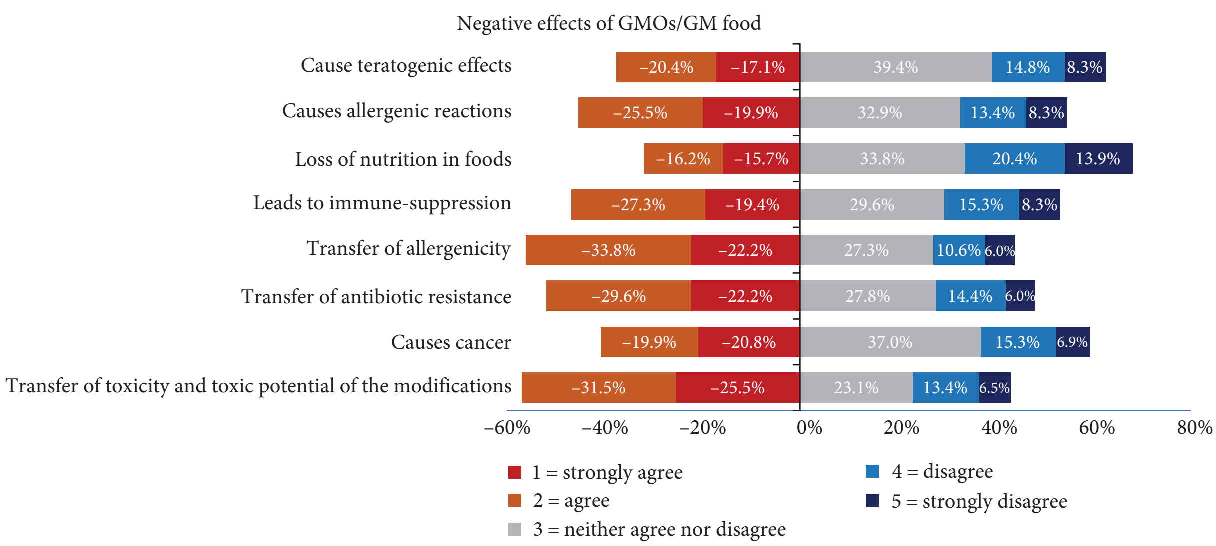

Figure 7: Negative effects of GMOs and GM foods as rated by respondents.

not be the answer to food security in Kenya and Africa due to food safety concerns, the need for huge investments in agriculture, training of farmers, and market access of GMO seeds. Others suggest that if well-structured, GMOs could promote food security by allowing diversity of food products and preserving endangered species. Figure 8 shows a summary of the supported GMO uses toward food security.

3.5. GMOs and Human Health/Safety. The negative effects of GMOs/GM food on human health and safety were identified as loss of biodiversity (−63.9%); contamination due to gene flow and escape to wild species and non-GM crops (−56.9%); development of superweeds and superbugs (−43.5%); increased herbicide use (−32.9%); and among other negative concerns on human health and safety (−36.6%). Figure 9 shows a summary of the negative effects on human health and safety.

Fifty-six percent of the respondents reported that there are known main issues of concern for human health with regard to GM food consumption, including causing an increase in diseases, cancer, AMR, and allergic reactions, among other health concerns. The KII respondents indicated that there are known main issues of concern for human health related to GMOs. These include allergenicity, gene transfer, and outcrossing. Allergenicity refers to the potential for GM foods to provoke allergic reactions, but currently, no allergic effects have been found in GM foods on the market. Gene transfer refers to the transfer of genetic material from GM foods to cells of the body or bacteria in the gastrointestinal tract. While the probability of transfer is low, it would be a concern if the transferred genetic material adversely affects human health, especially if antibiotic resistance genes are transferred. Outcrossing refers to the movement of genes from GM plants into conventional crops or related species in the wild, which may have indirect effects

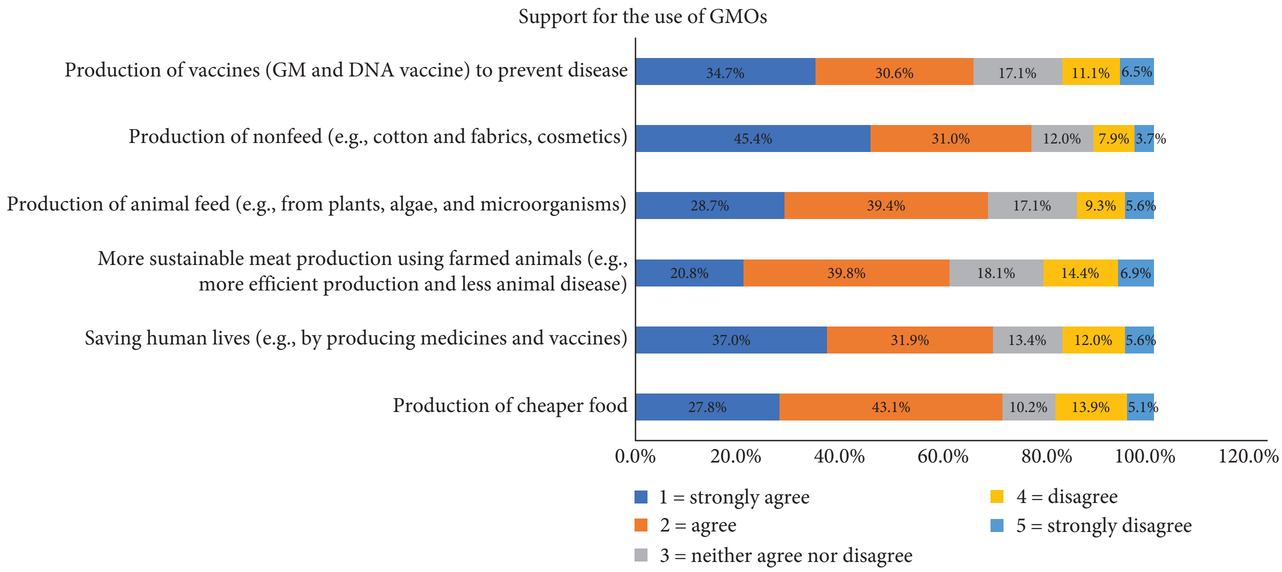

Figure 8: Supported GMO uses toward food security.

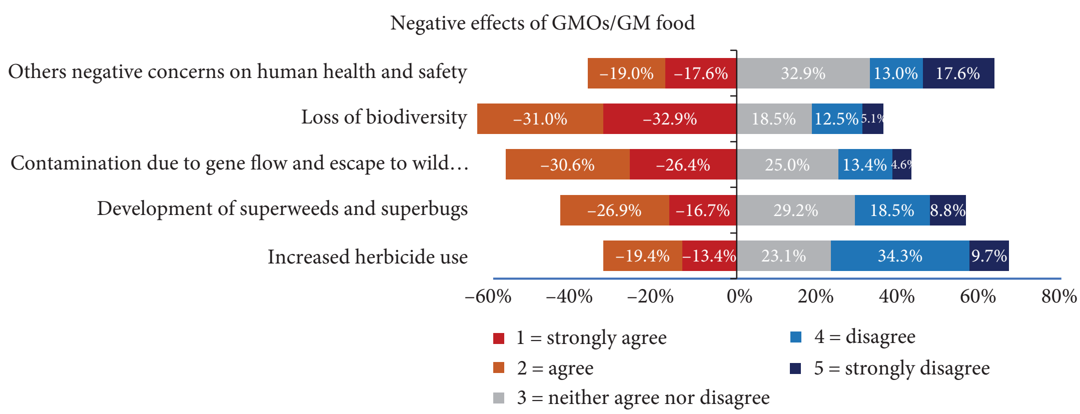

Figure 9: Negative effects of GMO technology on human health and safety.

on food safety and security. There have been beliefs and perceptions that the consumption of GMO foods could trigger allergies and have potential carcinogenic effects associated with the consumption of GMO products. However, concrete evidence linking GMOs to cancer is currently lacking.

3.6. Ethical Issues of GMOs. Some of the ethical arguments reported by the respondents included the fact that adoption of GMO technology is perceived like "Playing God" (57.9%); GMO technology is against people's beliefs (53.2%); GMO technology is unconventional/"unnatural" and hence not acceptable (52.3%); GM technology is not ethically acceptable in food production (51.4%); GM technology is not ethically acceptable for producing animal feed (48.6%); GM technology is not ethically acceptable in animal production (42.1%); and that using GMO technology is seen as tampering with nature (42.1%).

Figure 10 shows a summary of the ethical concerns as perceived by the respondents. The KII indicated that the ethical issues that limit the adoption and use of GMO technologies include the potential risks to human health, concerns about interference with traditional farming practices, potential harm to the environment, the perception that GMO products are not natural, patent rights leading to monopolization of certain foods, cultural beliefs and religious perceptions, lack of sufficient data on safety, lack of awareness among consumers, and concerns about the control and regulation of GMOs. Other concerns include potential long-term health effects, loss of biodiversity, the perception that GMOs are unnatural or against nature, and the fear of unknown or unexpected consequences. Additionally, corruption, misinformation, inadequate policies, and lack of transparency in GMO technology also contribute to the ethical concerns.

3.7. GMO Ban and Opportunities Gained or Lost Due to the Ban in Kenya. Overall, 48.6% of respondents agreed that GMO foods are regulated nationally as opposed to the rest (51.4%) who did not believe that GMOs were regulated at the national level. About 22.7% agreed that there are adequate legal and regulatory frameworks to ensure research on and commercialization of GM foods is conducted in a safe and responsible manner as opposed to 77.3% who did not agree

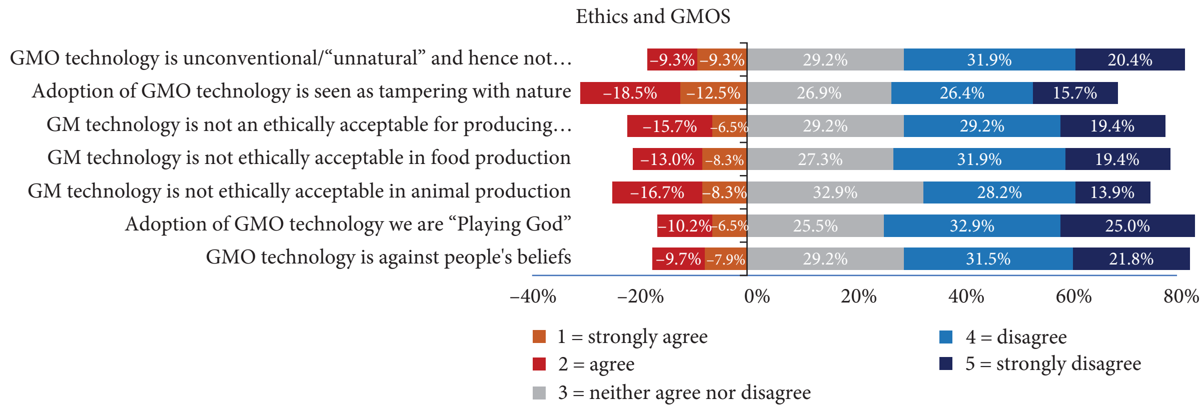

Figure 10: Ethical arguments on GMOs and GM foods as perceived by respondents.

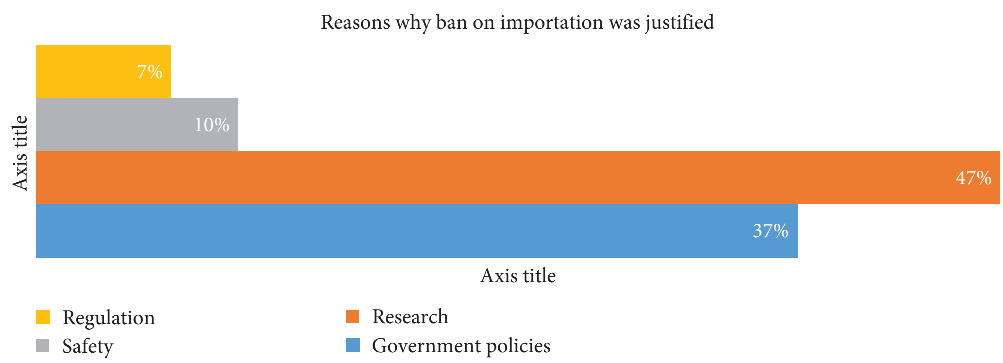

Figure 11: Reasons for GMO ban justification in Kenya.

on this statement. Some of the other gains mentioned are increased awareness and curiosity about GMOs among the public; more time to consider alternative ways of increasing food production; potential for research opportunities; potential for increased yields and crop varieties for farmers; potential improvement in medical and health outcomes; potential for technological advancements; potential for business opportunities; regional recognition of Kenya's sovereignty and expertise in relation to GMO acceptance, exploration; cheap products; public safety and health; confusion caused by mixed signals from the government; preservation of biodiversity and protection of natural biodiversity; international political affiliations with other countries; cultural gains; and potential for lower food prices.

Overall, 52.3% of the respondents reported that the ban on GMOs in Kenya was justified. This was attributed to a lack of adequate GMO research, limited regulations, lack of data and information, questionable safety of GMOs, and an adverse effect of GMOs, among other factors. The respondents indicated that the decision to ban GMOs was made because there was not enough reliable information and research on their safety.

Figure 11 shows why the ban on importation was justified, according to the respondents. The government wanted to protect the public and ensure food security. There were concerns about unknown side effects and potential risks to human health, and the country lacked the regulatory mechanisms and expertise to guarantee the safety of GM foods. More research and education on GMOs were needed before allowing their consumption. The ban followed the precautionary principle and aimed to protect the uninformed public. There were also concerns about the negative attributes and potential harm associated with GMOs. Overall, the ban was seen as necessary until more research, regulations, and public awareness could be established. Figure 11 shows the main reasons why the GMO ban in Kenya was justified, according to the respondents.

3.8. Legal Framework and Regulation of GMOs and GM Foods. In general, the majority of the respondents (77%) indicated that the country does not have an adequate legal and regulatory framework that can ensure research on and commercialization of GM food is conducted in a safe and responsible manner. Overall, 71.8% were not aware of the Cartagena Protocol on biosafety and GMOs except for 28.2% of the respondents. Only 21.3% of the respondents agree that they are aware of current GMO policies and laws strong enough to protect human and animal health and the environment, as opposed to 78.7% of the study population.

Respondent's agreement on whether the current GMO regulations are strong enough to protect health and the environment was sought by getting their responses (if they agree, disagree, or do not know/not sure). The respondents agreed that the status on current regulations show that Kenya has

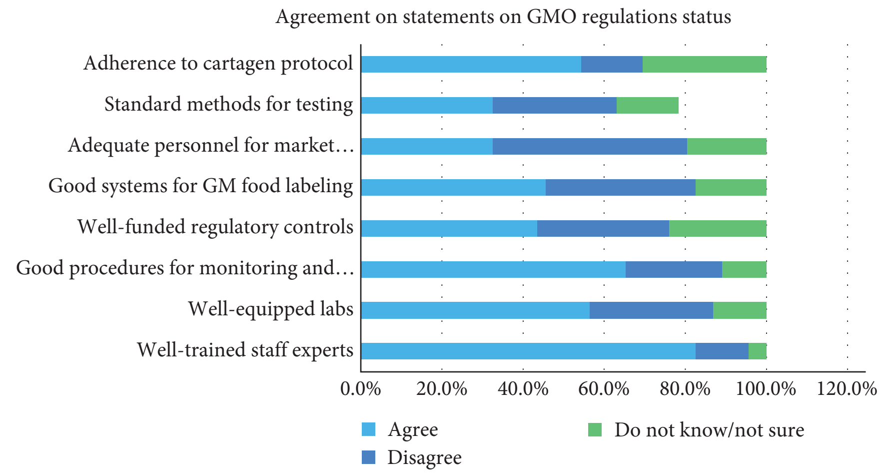

Figure 12: Agreement on the status of GMO regulations in Kenya.

well-trained staff experts (82.6%), good procedures for monitoring and surveillance (65.2%), well-equipped labs (56.5%), and good adherence to Cartagena Protocol (54.3%). The respondents also rated good systems for GM food labeling (45.7%), well-funded regulatory controls (43.5%), adequate personnel for market monitoring of GM foods (32.6%), and standard methods for testing (32.6%) fairly (Figure 12).

Correlation is a measure of the strength of relationship between two variables on how a change in one variable influences the other variable. The correlation coefficient can range from −1 to +1, with −1 indicating a perfect negative correlation, +1 indicating a perfect positive correlation, and 0 indicating no correlation at all. The correlation between awareness of the Cartagena Protocol on biosafety and views on whether there are adequate legal and regulatory frameworks in the country was $r = 0.4$, indicating a weak but positive relationship between the two. Those who responded that the legal and regulatory frameworks were adequate were, therefore, likely ($r = 0.4$) to be aware of the Cartagena Protocol. There was a moderate positive correlation ($r = 0.67$) on views that GM food is a solution to food insecurity in Kenya and its safety. There was a moderate negative relationship ($r = -0.57$) between regarding GM food as a solution and its profitability, indicating that though respondents perceived GM food as a solution to food insecurity in Kenya, they did not perceive it as profitable. Understandably, the relationship between GM food health concerns and GM food as safe was moderately negative ($r = -0.4591$). The correlation coefficients are summarized in Table 2, with those that are highly significant ($p = 0.001$) highlighted in bold. Table 2 shows the correlation between awareness of the Cartagena Protocol on biosafety and views on the adequacy of legal and regulatory frameworks in Kenya.

3.9. Public Participation in GMO Technology. Overall, 30.1% agreed that the members of the public, farmers, and consumers have a voice when it comes to the development, production, and sale of GMOs and GM foods in Kenya, as opposed to 69.9% who did not share the same views. This indicated limited public participation in GMO technology adoption in the country. About 57.4% of the respondents agree that adopting GMOs in crop production is profitable for individual farmers and beneficial for the whole agricultural sector, while 22.7% disagreed, and 19.9% were not sure about GMO profitability. Overall, 63.9% of the respondents indicated that there are certain crops for which they would advocate the use of GMO technology. The crops, including maize, rice, beans, wheat, and cotton, will be drought and disease-resistant. Further, 74.1% of the respondents indicated that there were implications for farmers if they turned to GM crops, compared to 25.9% who showed no concerns. The implications on farmers included the high cost of seeds, loss of traditional/indigenous seeds, effects on seed sovereignty, monopoly of GMO seed companies, and high costs of production for GMO crops, among other factors. Most respondent support the use of GMOs for a number of purposes, as shown in Figure 9.

The findings on stakeholders with major roles in making decisions about policy issues related to GM foods were scientists (73.1%), elected officials (59.7%), consumers (58.8%), and large-scale farm owners (58.3%). The general public (42.6%), small-scale farm owners (43.1%), civil societies (42.1%), media (42.1%), food industry leaders (38.4%), and NGOs (38.0%) have some limited roles in policy decisions on GMOs. Figure 13 shows the roles played by different stakeholders in policy decisions on GMOs.

Public participation in GMO laws and regulations is limited in Kenya. There is a lack of public engagement and awareness on GMO issues, with most farmers and consumers not well informed. However, there have been calls for public views on GMO products before approval for release and commercialization. The public has the right to participate in the decision-making process, and there have been instances where public demand led to the banning of GMOs in 2012. Constitutional provisions also support public participation in policy development. However, there is a need for more awareness and education on GMOs to allow for informed decision-making. Stakeholder engagement, including farmers and consumer associations, is important in shaping GMO regulations. Overall, while there are mechanisms for public participation, they are currently limited and need improvement.

Table 2: Correlation between awareness of Cartagena Protocol on biosafety and views on the adequacy of legal and regulatory frameworks in Kenya.

	GM food is a solution	GM food is safe	GM health concerns	GM data is adequate	GM food is regulated	GM legal regulation adequate	Cartagena awareness	GM policies are strong	Public has a voice	GM is profitable	GM ban was justified
GM food is a solution	1	—	—	—	—	—	—	—	—	—	—
GM food is safe	**0.6675**	1	—	—	—	—	—	—	—	—	—
GM health concerns	−0.2567	**−0.4591**	1	—	—	—	—	—	—	—	—
GM data is adequate	0.1577	0.2702	−0.26	1	—	—	—	—	—	—	—
GM food is regulated	0.237	**0.3096**	−0.0882	0.2174	1	—	—	—	—	—	—
GM legal regulation adequate	0.2808	**0.3426**	−0.1875	**0.3293**	**0.3901**	1	—	—	—	—	—
Cartagena awareness	0.1709	0.2391	−0.0387	0.1602	**0.3225**	**0.4427**	1	—	—	—	—
GM policies are strong	0.258	0.3189	−0.1274	**0.3524**	**0.4105**	**0.5856**	**0.3434**	1	—	—	—
Public has a voice	0.232	**0.3019**	−0.0976	0.2814	**0.3901**	**0.4293**	0.2887	**0.4377**	1	—	—
GM is profitable	**−0.5748**	**−0.5332**	0.2932	−0.2204	−0.1819	−0.2352	−0.1947	−0.2889	**−0.3102**	1	—
GM ban was justified	**−0.4257**	**−0.4176**	**0.3308**	−0.1673	0.0353	−0.1628	−0.0487	−0.1772	−0.1023	0.2969	1

Parameters tested	Legal and regulatory framework is adequate	Awareness of Cartagena Protocol
Legal and regulatory framework is adequate	1.0000	—
Awareness of Cartagena Protocol	**0.4427**	1.0000

Interpretation: 0.1<|<.3 = minimal correlation, 0.3<|<.5 = moderate correlation, $|r|>.5$ = strong correlation (Cohen, 1988).

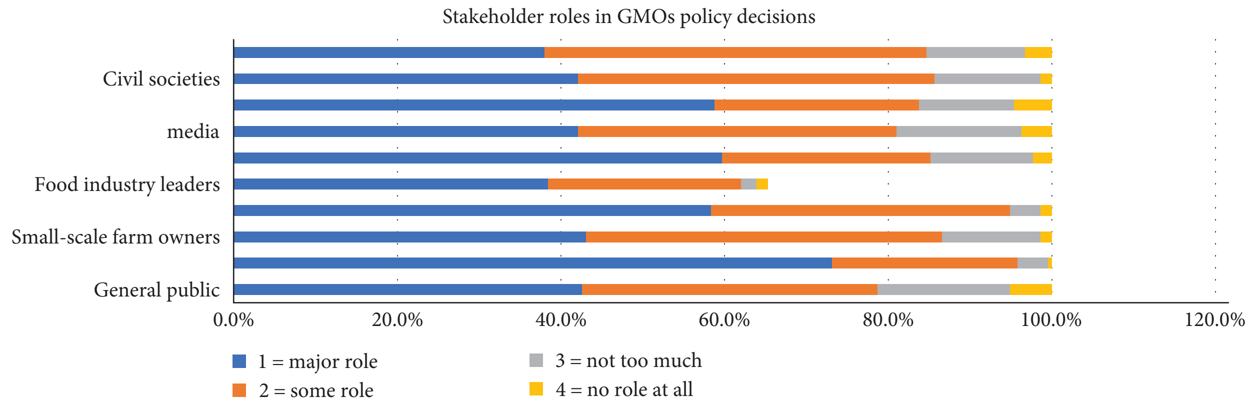

Figure 13: Roles of different stakeholders in decision-making on policy regarding GMOs in Kenya.

4. Discussion

Kenya's food nutrition and security agenda has been coupled up with challenges not only in production but also in frequent droughts; disease, and pests' outbreaks, which over the years have become a nightmare [4]. Kenya has a rapid annual human population growth rate [37]. Declining potential for agriculture is not immune to climate change effects that cause tremendous harm to food security [2]. Despite the need to increase food production to 70% by 2050 and meet the food-growing demand, there are limitations due to the scarcity of farmable land and climate change-related water shortages [24]. In addition, the amount used is increasing every year, thus becoming more and more scarce in the face of climate change. The effects of multiple crises on food systems, like climate-induced extremes, pandemics, and war conflicts, have attracted the interest of researchers, policymakers, and other actors to revise existing structures of the food sector toward other sustainable food alternatives [33, 38].

In February 2019, Nigeria became the first country in the world to approve the GMO cowpea seeds [12]. The seeds are blended to prevent attacks by winged pests that could deprive 80% of the West Africa stable every year. In addition, countries like South Africa were among the first in the continent to approve GM crops [11]. In 1997, Africa approved the commercial release of insect-resistant cotton, which was historically among other crops like maize and soybean [24]. This not only increases the yield to the farmers but also increases income earned as well as total production and food available for national consumption. However, in Kenya, the discussion around GMO's has for a very long time been surrounded by both myths, beliefs, misconceptions, and misinformation, with many arguing, "if other countries have banned GMOs, why bring it in Kenya?" [33]. However, with the recent lift of the ban by the president, what does it mean for Kenya and Food Nutrition and Security in Kenya?

Besides claims that GMOs would increase agricultural productivity and food production, a lot of controversies have emerged regarding the technology [39], with the primary points of contention being the socioeconomic effects, particularly those related to trade [40]. According to previous research, GE has been useful in developing fast-maturing, drought-tolerant, and pest-resistant crops, as well as contributing to a reduction in pesticide usage; however, their effects on the environment and consumers remain a subject of debate. Critics argue that GM crops jeopardize agricultural biodiversity by resulting to gene contamination [17]. From a trade standpoint, it is reported that GM technology use may result in diminished export capability, particularly in countries that prohibit GM foods [41]. On the contrary, proponents of biotechnology claim that GM crops have reduced the use of pesticides and increased crop yields [19, 42]. Further, some of the GM crops, such as transgenic golden rice, have been reported to deliver additional nutrients such as vitamin A, which is essential for healthy human existence [43].

Kenya has a fully functional national biosafety framework that supports the introduction of contemporary biotechnology and products [28, 29]. In 2003, the government ratified the Cartagena Protocol on biosafety to the convention on biological diversity, which provides guidelines for ensuring the safe handling, transportation, and use of live-modified organisms emerging from contemporary biotechnology that may have negative consequences on biological diversity, as well as threats to human health [29, 34, 35]. In 2006, the national biotechnology development policy was developed and resulted in the passage of the Biosafety Act No. 2 of 2009, which established a legal and institutional framework for capitalizing on the benefits of contemporary biotechnology. The NBA was founded by this act, which promotes ethical research in contemporary biotechnology while avoiding possible dangers to human and animal health and ensuring proper environmental protection. The authority has also developed four biosafety laws, namely, Contained Use (2011), Environmental Release/Marketing (2011), Import, Export, and Transit (2011), and Labeling (2012). By April 2020, the authority had handled about 80 GM applications. To further achieve its mandate of monitoring GM research and commercialization activities, NBA works closely with other regulatory entities, including the Department of Public Health, Veterinary Services, Kenya Bureau of Standards, Kenya Plant Health Inspectorate Services and National Environment Management Authority, Pest Control Products Board, Kenya Industrial Property Institute, and Kenya Wildlife Services.

Currently, Kenya's biosafety regulatory structure has remained legally faithful to the protocol, while also providing fairly feasible processes for applications in the various categories of activities regulated. However, there is very little coordination between the various regulatory agencies identified in the act when it comes to law enforcement. Other challenges include the overlap of GMO regulatory requirements of the Biosafety Act and the Environmental Management and Co-ordination Act, under the NBA and the National Environment Management Authority, respectively, Costly applications, lengthy decision-making process on applications, and heavy fines for breaking the law [32]. In Kenya, there has been a significant amount of research work involving the use of biotechnology [33]. This is notable in universities and at some research institutes such as Kenya Medical Research Institute and Kenya Agricultural Research Institute, where medical biotechnology, animal biotechnology, and agricultural biotechnology are undertaken. The major gaps identified in the baseline study included research gaps on GMOs in Kenya; limited funding for GMO research; limited public awareness and education on GMOs; safety of GMOs and GM foods and effects on human health; poorly equipped research institutions; and limited information on GMOs [33, 35, 36].

Some of the recommendations to improve biosafety regulation, including the areas that need to be enhanced or reviewed to improve biosafety systems in the country, according to the baseline survey, including labeling of GMO products to provide transparency to consumers; full implementation of biosafety policies; raising awareness among consumers about biosafety regulations; controlling misguided political reactions that may hinder the adoption of sound regulations; capacity building in emerging technologies like gene editing; improving GMO expertise through training and upgrading laboratory technology; enhancing funding for research and regulatory authorities and to increase awareness of biotechnology in the country; communication to the public about biosafety systems; infrastructure development with well-equipped laboratories and human and infrastructure capacity building through training of personnel; adequate legal policies and technologies to support biosafety regulations; increasing financial capacity and funding; surveillance capacity to monitor and enforce biosafety measures; monitoring and labeling of GMO food; GMO information dissemination and sensitization; creating robust policy and legal frameworks; market monitoring and standard testing methods for food labeling; providing resources for personnel, training, surveillance, and awareness campaigns. The same has been reported by previous studies [27, 34, 35].

5. Conclusions

For future developments, the GMO technology and GM foods have the potential to solve many of the hunger and malnutrition problems in Kenya and to help preserve the environment by increasing yield and reducing reliance upon synthetic pesticides and herbicides. Challenges ahead lie in many areas, viz., safety testing, regulation, policies, and food labeling. Public awareness is still very low; thus, the government should play an active role in advancing awareness on GMOs foods in the country. Further, it is clear that there are many opinions about scarce data on the potential health risks of GM food crops, even though these should have been tested for and eliminated before their introduction. It is definite that GMOs and GM crops have the potential to assist developing countries such as Kenya in leapfrogging biotechnology and ensuring improved food production, improved commercial crop production, increased food availability, and influencing farmers' income.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Mugiira, B. Roy and Muchiri, N. Josephat contributed equally to this work.

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