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Perceptions of the Governance of the Technological Risks of Food Innovations for Addressing Food Security

Catherine Nkirote Kunyanga [1,*], Morten Fibieger Byskov [2], Keith Hyams [2], Samuel Mburu [3], Grace Werikhe [1] and Cecilia Moraa Onyango [4]

[1] Department of Food Science, Nutrition and Technology, University of Nairobi, Nairobi P.O. Box 29053-00625, Kenya; gwerikhe@students.uonbi.ac.ke

[2] Department of Politics and International Studies, University of Warwick, Coventry CV4 7AL, UK; mortenfb@hotmail.com (M.F.B.); k.d.hyams@warwick.ac.uk (K.H.)

[3] Save the Children International, Kenya Programme, Nairobi P.O. Box 27679-00506, Kenya; mburusam2@gmail.com

[4] Department of Plant Science and Crop Protection, University of Nairobi, Nairobi P.O. Box 29053-00625, Kenya; cecilia.onyango@uonbi.ac.ke

* Correspondence: ckunyanga@uonbi.ac.ke; Tel.: +254-7228-73357

Abstract: Food and nutrition insecurity continue to risk the lives and wellbeing of millions of people throughout the world today. Further, food and nutrition insecurity are still major challenges in Kenya and have triggered the adoption of a number of modern biotechnologies for agricultural transformation. Consequently, many food technologies have been approved to secure sustainable access to food for millions of people. This study investigated the perceptions and implementation of two technologies for addressing food insecurity in Kenya, namely, genetically modified organisms (GMOs) and the use of antibiotics in livestock production. In particular, the study explored how their implementation can be governed responsibly through approved legislation. Therefore, the knowledge, attitudes and practices, as well as the governance, of GMO technology and antibiotic resistance risks were assessed. In-depth key interviews were conducted for a qualitative survey with triangulation using quantitative data sources. The findings showed that 46% of the population have limited knowledge about GMO technology, with about 79% indicating that foods with GM ingredients were already being consumed in the country despite the government ban. The majority of respondents agree that GMOs can contribute to an increase in the global food supply (65%), make food affordable (57%) and produce more nutritious foods (50%). Further, most agree that GMOs can produce crops more resistant to pests and reduce pesticide use on food crop plants (89). The main concerns reported regarding GMO technology by most respondents included the impact on the environment and human health and the adverse effects on traditional farming practices. About 36% of these respondents indicated that the technology diminishes traditional farming technologies, and 32% reported that it contributes to loss of biodiversity. Notably, 64% reported that GMO technology is a solution to food security and that GM foods are safe. Regarding the use of antimicrobials mainly meant to prevent diseases and access better markets, respondents perceived their use to be associated with a "large level of risk" of antimicrobial resistance (score of 2 on a scale of 1–3) (M = 1.85, SD = 1.06). A total of 56% of the respondents reported that the efforts towards promoting awareness of antibiotic resistance risks and their associated effects on human health are relatively limited. Our findings show that most of the respondents have only observed minimal awareness campaigns. Regarding the governance of the two technologies, 71% and 50% of the respondents reported that scientists and elected officials, respectively, have the greatest roles in the governance of GMOs, with small-scale farmers playing a negligible role. These findings are crucial to the advancement of food innovations that are geared towards achieving food security in Kenya as they highlight the risks associated with the poor governance and implementation of technologies. Therefore, there is a need for a framework for technological risk governance that is sensitive to local values and socio-economic circumstances and that will facilitate the achievement of food security goals.

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1. Introduction

Food and nutrition insecurity as outcomes of existing food systems have often been described as a 'wicked problem' due to the complex nature of the food security phenomenon. Food insecurity has been attributed to the steadily rising global population, conflict and climate, among other factors, and poses a major risk to human lives and well-being, especially in the Global South [1,2]. Further, the Global Report on Food Crises [3] has reported a worsening acute food insecurity situation and a substantial (22 percent) expansion of the global population between the years 2020 and 2021. In Africa, about 250 million people are undernourished, with reports indicating that Sub-Saharan Africa will continue to face severe hunger challenges [4]. Notably, the growth of food production is slow compared to the increasing population. For instance, in Sub-Saharan Africa, the population growth rate per year is at 3 percent, which means that it could lead to doubling of the current generation. Therefore, the promotion and implementation of agricultural and food technologies is recognized as integral to achieving the SDGs (SDG 9), including the urgent need for "increased investment in infrastructure and technology for sustainable agriculture" in order to meet SDG 2, which aims to end hunger and achieve food security through sustainable agriculture [5]. It is thus essential to ensure that agricultural production is effective, efficient and sustainable [6]. Potential solutions to some of these risks are offered by emerging technologies and innovations [7,8]. A number of measures have been put forward to combat the problem of food security globally. Biotechnological innovations such as genetically modified organisms (GMOs) and the use of antibiotics have been shown to be successful in addressing food production challenges [9].

In Kenya, Food and nutrition insecurity is still a major challenge, and since 2008 and between 2014 and 2019, severe droughts were experienced, resulting in more than double the number of food-insecure people from 1.3 million to 2.7 million [10]. 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 increased from 3.1 million in February 2022 to over 4.1 million in May 2022 according to the recent Kenya Food Security Outlook, 2022 [11]. Climate variability and extremes, among other factors like the recent COVID-19 pandemic, continue to harm agricultural productivity across the country, creating vulnerability concerns for many people, the majority of whom are women who rely on agriculture for a living [12]. Therefore, to move Kenya closer to sustainable food security, deliberate initiatives based on solid research and anchored in the uniqueness of the agricultural systems and culture must be addressed. Globally, scientists have been searching for novel ways to boost agricultural productivity and ensure sustainable food security [13]. Subsequently, farmers have adopted different strategies, including improved seed varieties, mechanization, the use of fertilizers and pesticides, information technology as well as modern biotechnology, to mention but a few. Similarly, genetically modified (GM) crops have been proposed as a potential strategy to promote sustainable food production [14]. Since the mid-1990s, genetically modified organisms (GMOs) and genetic engineering (GE) technology have been available. However, their adoption has been fraught with controversy, with anti-GMO activists raising concerns about the health and environmental risks. On the other hand, the proponents of GMOs argue that they reduce the use of pesticides and increase crop yields. The technique has been slowly embraced in various regions of the world, with acreage under GM crops rising. In 2019, GM crops were grown in economically significant amounts in United States over 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) [15]. In addition, soybean was the most adopted crop (50%), followed by maize (30%), cotton (13%) and canola (5%) [15]. In South Africa, the commercialization of GM maize began in 1998, with the release of Bt maize (Monsanto 810) and pest-resistant Bt11 in 2003 [16]. In 2019, it was among the top 10 countries that planted GM crops, with an area of 2.68 million hectares. It has been 22 years since the commercialization of genetically modified crops [17]. The adoption of GM maize cultivars was more significant among commercial farmers than small-scale farmers. In 2009, the adoption rate among commercial farmers was 26% Bt, 15% Ht and 20% Stacked Bt/Ht yellow types, while for white varieties, the adoption rate was 60% Bt, 5% Ht and 8% stacked Bt/Ht [16,18]. Despite these global trends, the adoption of genetically modified (GM) crops in Africa, including Kenya, has been slow due to the EU's contradictory messages on the health and safety of genetically modified foods, negative views, a lack of information and hostility towards biotechnology, among others [16].

However, the poor implementation of innovations and technologies to achieve food security, including the use of GM crops and antibiotics in livestock farming, are likely to foster unsustainable agricultural practices that increase the risks of biodiversity loss and antibiotic resistance [9].

1.1. Genetically Modified Organism (GMO) Technology

In regard to this biotechnology, many crops have been genetically modified to increase resistance to diseases, herbicides and insect pests, among other beneficial characteristics [18]. Genetic modification is a special set of gene technology that alters the genetic machinery of such living organisms as animals, plants or microorganisms. GMOs are organisms (including plants, animals or microorganisms) in which the genetic material (DNA) has been altered in a way that does not occur naturally through mating and/or natural recombination. The technology is often called "modern biotechnology" or "gene technology", or sometimes "recombinant DNA technology" or "genetic engineering", and allows selected individual genes to be transferred from one organism into another, and also between non-related species [17]. These modern biotechnologies have contributed to more sustainable agriculture, higher yields, a reduction in pesticide use and the provision of more nutritious food [16]. Some of the crops that have been genetically engineered include maize, cotton, soya bean and canola. For instance, GM insect-resistant maize has been shown to be resistant to infestation by molds and also contains great health benefits [19]. Widespread experiments conducted in about 21 different fields in a homogenous environment showed lower levels of mycotoxin in Bt maize as compared with the non-Bt isoline [20]. Moreover, other benefits include a reduction in the use of pesticides. In 2003, studies conducted in the USA showed a reduction in pesticide use due to the cultivation of GM crops. In 2001, China also recorded a reduction in the number of formulated pesticides that were being used by 78,000 tonnes [21]. Therefore, a reduction in pesticide use reduces the risk of exposure and poisoning to farmers and the environment, as well [22].

Despite the prospects and benefits of GMO technology, most of the African countries have been reluctant to adopt genetically modified (GM) crops due to a number of factors, including limited knowledge and awareness on the application of the technologies; a lack of regulatory policies; a lack of assured safety; and long-term effects [23]. Only 12 countries out of the 54 have national biosafety frameworks that are operational. Further to this, only five of the countries allow the planting of GM crops [24]. Policies are important in protecting the environment, human health as well as research and development. The national biosafety authority in Kenya was developed to enhance the uptake of GMO technology. A number of controversies over the benefits and harms GMO technology, widely propelled by many challenges, such as a lack of sufficient information and data, misconceptions, regulations, ignorance and philosophical concerns, rather than ethics, among others, led the Ministry of Health to place a ban in 2012 on the development and cultivation of GM crops [25]. The ban lasted for seven years and with government direction, the cultivation of GM crops, in particular, Bt cotton, started in 2020 [26]. In this context, foods produced from or using GMO technology of genetically modified organisms are often referred to as GM foods. However, in 2022 the Government lifted the ban on GMOs, allowing for the cultivation of GM crops to address food insecurity. Despite evidence in many projects from different research institutions geared towards improving indigenous crops, the lack of required expertise and funds limit their implementation by farmers [27]. Currently, at least six GMO projects have been approved for research by the National Council of Science and Technology, the National Biosafety Authority, the Kenya Plant Health Inspectorate and National Environmental Management. They are under confined field trials for early testing in confined greenhouses and field trials with controlled access, while others are in various stages of application. The main stages of biotechnology include: research and development, contained research, confined field testing and commercial production. Some of the GM crops that have been approved for contained experiments and confined field trials include insect-resistant maize and cotton, virus-resistant cassava, virus-resistant sweet potato and rinderpest vaccine. While GM crops can be more resilient to climate change and/or provide greater output, anecdotal evidence points to some negative socioeconomic consequences, such as the high cost of seeds, especially for smallholder farmers, and undermining biodiversity. The effects of GMO technology and GM crops in Kenya are yet to be seen.

1.2. Antibiotics in Livestock Production

Sustainable food production is becoming critical to ensuring food and nutrition security for all. Some of the solutions that can boost sustainable production, particularly in agriculture and livestock, include the use of antimicrobials [28]. Globally, antimicrobial resistance (AMR) has been recognized as one of the emerging threats to public health [29]. AMR poses huge risks for agriculture, with the livestock sector as the primary user of antimicrobials. The impact of AMR can lead to economic losses, a decline in livestock production, poverty, hunger and malnutrition [30–32]. Given this reality, the world health organization has urged its member countries to develop national action plans to tackle the problem of AMR, as endorsed by the World Health Assembly in resolution WHA 67.25 [33]. Following the WHO recommendations, the UN FAO action plan also focuses on monitoring and promoting best practices to optimize antimicrobial use along the food chain [34]. In addition, in response to the AMR threat, investments such as the UK Fleming Fund have been established to improve AMR surveillance through the One Health approach and provide evidence for the development of appropriate policies and interventions. Kenya is one of the countries that agreed to initiate a national action plan for AMR that is consistent with the Global Action Plan, and to implement relevant policies and plans to prevent, control and monitor AMR. AMR is recognized as a silent pandemic that threatens to kill up to 10 million people by 2050.

Currently, up to 700,000 people die annually due to AMR, with 90 percent of these deaths being reported in Africa, Asia and South America. Around 75 percent of all antimicrobials are used in animal agriculture. In developing countries, the use of antimicrobials is often unregulated [35]. While there have been demonstrated links between AMR in animals and humans, little is known about the role of the environment. Further, the rate of antimicrobial resistance-related infections is high and is projected to increase in developed countries. The prominent and direct effects of antimicrobials include increased mortality, high morbidity and economic losses [36]. A loss in GDP is also projected in developing countries due to antimicrobial resistance by the year 2050, which will further decline as a result of economic slowdown in the post-COVID scenario [37]. Therefore, it is crucial to address antimicrobial resistance to achieve sustainable development goals associated with poverty and hunger alleviation and the improvement of health and economic growth [38]. In Africa, a large proportion (50%) of antibiotics is used in animal farming to treat diseases or promote animal health. However, in many African countries, there are no clear guidelines controlling the contamination of feedstuffs. Additionally, available information in regard to antibiotic residues in animal-derived foods is still lacking. The greatest significant sources of AMR have been reported to be fertilizers of fecal origin, irrigation and water in plant-based food and/or aquaculture, while feeds, humans, water, air or dust, soil, wildlife, rodents, arthropods and equipment are the major potential sources in animal production. Concerted global efforts to minimize the risks of AMR and scientific knowledge and/or science-based evidence are required to detect and manage AMR risks before they become large-scale emergencies [28,39]. These require the strengthening of surveillance of AMR hotspots, the training of stakeholders, the support of research and innovation, and incentivizing stakeholders to transform the awareness of AMR risks into action according to the FAO Action Plan on AMR 2021–2025.

Currently, Kenya is one of the global hotspots of two main food innovations, including GMO technology and antibiotic resistance in livestock, and is therefore facing a number of factors that impact the food security of its population. These two new national initiatives geared towards addressing food insecurity have been observed to be undergoing an increasing trend, as evidenced by the lifting of the ban on using GM crops and the One Health policy plan to regulate the use of antibiotics. This makes this study and its foci extremely timely, and the findings could facilitate policy impact. Nevertheless, research on technological risk governance in most African countries remains nascent, with limited information on (i) how to conceptualize such double-edged development technologies and (ii) how technological risk governance can be sensitive to and inclusive of African values and knowledge. Subsequently, interventions are frequently dependent on technocratic knowledge, with little clarity on how to incorporate cultural and value-based concerns into the development and implementation of technologies for development.

Given the potential benefits and risks of GMO technology and the use of antibiotics in livestock production, the main objectives of this study were twofold, i.e., to establish the current status of food innovations for food security, with a particular focus on GMOs and antimicrobial resistance, through a comprehensive desk review from secondary information, and to determine the knowledge, attitudes and practices regarding food innovations, particularly GMO technology and antimicrobial resistance, and the influence of the governance of the technological risks of these innovations.

2. Materials and Methods

This study focused on two technological risks in the context of food security in Kenya, specifically, the perceptions, knowledge, loss of biodiversity and social economic consequences of the introduction of GMO technology and the rise of antimicrobial resistance resulting from the over- and misuse of antibiotics to combat communicable diseases in livestock.

The main research question was: How can and should innovations or technologies for food security be responsibly governed? By addressing this question, this study aimed to inform Kenyan food security policies through the discussion of the following issues.

i. How can innovative technologies help secure ample food supply?
ii. How can the interests of producers, including smallholder farmers and consumers, be adequately represented within food security policy and planning?
iii. What role can and should non-governmental actors play in setting out food policies?
iv. What factors affect food (in)security and how do they relate to each other?
v. Who should be responsible for ensuring food innovations and technologies are safely and responsibly implemented?
vi. What platforms for collaboration can help ensure the safe and responsible implementation of food innovations?

The study was largely quantitative, and key informants who are knowledgeable about GMO technology and antimicrobial resistance were interviewed using a structured questionnaire. In addition, a comprehensive literature review was conducted as detailed below.

2.1. Methodology for Quantitative Data Collection

Desktop Review

The primary sources for the review were electronic databases such as Elsevier, PUBMED, EMBASE and Web of Science. In addition, government reports on various ministries and organization involved in issues of GMO and AMR were reviewed. A number of broad search categories were targeted with relevant hits for this study. The searches were focused by changing the search terms and term truncation and limiting the search to specific fields. The results were compared and checked against articles known to be relevant to the review. Publications were searched with the search terms "genetically modified foods/GMOs" or "antimicrobial resistance/AMR" or its synonyms or subgroups (e.g., governance, technology, innovations, resistance, risks and policy). Related reference to food safety, toxicities or plant and human health effects through surveys were also considered in the review. All publication results, particularly abstracts, were stored using the literature data management software Zotero 6.0.26 version, which is effective in managing references, abstracts and full texts, including checking for duplicates.

2.2. Methodology for Qualitative Data Collection

In-Depth Interviews

A total of 55 respondents representing 28 experts in GMOs and 27 in AMR were selected to participate in the survey, conducted using in-depth key interviews. The respondents were technical specialists drawn from research and academia (66%), training (57%), policy/advocacy (38%), institutions with GMO innovations (29%) and regulation (12%), among others, like public institutions, private companies and civil societies (31%). All the respondents were knowledgeable in GMO and AMR technologies and were chosen based on the fact that their expertise has contributed to the advancement of food innovations that are geared towards achieving food security in the country.

The interviews determined the knowledge, attitudes and practices in food innovations, particularly GMOs and antimicrobial resistance and the influence of governance on innovations. The study also elucidated the perceptions and knowledge of participants on the safety and ethics of GM foods compared with non-GM foods. The definition of GMOs was presented to respondents to assess their level of knowledge of GMOs on a scale of 1–3 (1 = agree, 2 = don't know, 3 = disagree) among other knowledge questions to identify the extent of agreement with the definition of GMO by the respondents. The responses and questions on GMO knowledge were assessed using a 5-point Likert Scale instead of the 3-point Likert Scale used in the scoping survey. A total of 15 items were used to assess the respondents' knowledge on AMR. Respondents were required to answer True or False to the questions. Following a rubric, scores of 1 to all correct answers and 0 to all wrong answers were assigned, and an aggregate score was calculated (range: 0–14). Higher scores indicated more knowledge about AMR. To measure attitudes, the key informants rated their perceived risks of AMR to farmers and the perceived tendency towards antibiotic misuse. Perceived risk to farmers was measured on a scale of 1–4 (1 = extremely high risk, 2 = large level of risk, 3 = medium level of risk, 4 = no risk at all), and the perceived tendency of antibiotic misuse was measured on a scale of 1–5 (1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high). These measures signify individuals' beliefs about the possible harm and the severity of the harm that can be caused by AMR. To measure practices, the key informants' perceptions were examined on how antibiotics should be handled or used by individuals and organizations (both governmental and non-governmental). Practices were measured on a scale of 1–3 (1 = agree, 2 = don't know, 3 = disagree), where lower scores represent agreement.

2.3. Data Analysis

The interview transcripts were transcribed verbatim, after de-identification, through Microsoft Word processing, and cross-checked for accuracy and reliability against recordings. Transcripts were thematically organized at least twice using the data management qualitative analysis software tool NVivo version 12.0 (QSR International Version 12.0). The qualitative data were coded inductively using coding principles for each GMO/AMR theme and were cross-checked by all members of the research team to gain consensus, consistency and result validity. Once the themes and associated sub-themes were determined, perspective theme mapping was conducted to illustrate the inter-relationships between themes and subthemes. Data were then analyzed using ATLAS.ti version 23.1.2 and NVivo 11 software. Secondary data analysis after mining was performed using STATA (version 14.0). Data analysis included descriptive, bivariate and multivariate analyses. The qualitative data from key informants were translated and the transcripts analyzed thematically using NVivo 11 software. Other relevant statistical software was used depending on the data parameters.

2.4. Ethical Consideration

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Nairobi, Kenya (KNH-UON ERC application reference P447/06/2021) and Warwick University in the UK (application reference HSSREC 154/20-21).

3. Results

3.1. Knowledge, Attitudes and Practices Regarding GMOs

The respondents were asked to give the definition of GMOs and whether they agreed/disagreed with the actual definition of GMOs. The results indicate that majority of the respondents agreed with the GMO definition (93%) with 67% strongly agreeing and 26% agreeing with the definition that "GMOs are organisms (i.e., 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. The technology is often called "modern biotechnology" or "gene technology", sometimes also "recombinant DNA technology" or "genetic engineering". It allows selected individual genes to be transferred from one organism into another, also between nonrelated species. Foods produced from or using GM organisms are often referred to as GM foods. One of the objectives for developing plants based on GM organisms is to improve crop protection. The GM crops currently on the market are mainly aimed at an increased level of crop protection through the introduction of resistance against plant diseases caused by insects or viruses or through increased tolerance towards herbicides". The respondents were 97% male and 44% female, with the majority aged 41–50 years (41%), 31–40 years (40%) and 18–30 years (33%). In terms of expertise and level of education, the respondents for the individual survey were highly educated. The majority of respondents (56.74%) had undertaken postgraduate level studies, with only 4.26% having secondary education as their highest level of education. The types of organizations represented indicate that most of the respondents were in academia (38%), private industry (34%) and NGOs (13%). The main fields of expertise represented in the study were Agriculture and Food Sciences (88%) and Plant Sciences/Plant Health (18%), among others like biological sciences (13%), social sciences (12%), economics (12%), environmental sciences (11%), policy (11%), data analysis (10%), veterinary medicine (9%), public health/epidemiology (7%), ecology (5%) and human health (4%). About 79% of the respondents indicated that foods with GM ingredients were already being consumed in the country. The main foods reported to contain GM ingredients included maize, rice, beef, cassava, soya bean products and corn products (corn flakes, biscuits). In addition, it was noted that some animal products, such as milk and beef, from animals fed with animal feeds containing GM ingredients such as soya beans are also being consumed in the country.

Further, the study examined the sources of information on GMOs. The major source of information was colleges and schools (71%), while the media was second (64%) as historically, the tendency of most media sources is to report negativity around sensitive subjects such as GMOs. Campaigns about GMOs proved to be effective since about 36% of the respondents had heard about GMOs through this source. The results are presented in Table 1.

Table 1. Major sources of information on GMOs.

Source of Information on GMOs	Percent (%)
School/college	71.4
Media (newspaper, TV, radio)	64.3
Specific campaign	35.7
Family member or friend	17.9
Extension worker	17.9
Others (workshops, projects)	17.9
Agrovet shop	10.7
Can't remember	3.6

3.2. Main Uses of GMO Technology

The respondents strongly agreed that GMO technology can be used in the production of vaccines, cotton fabrics and cosmetics (Figure 1). They also agreed that GMOs can be used in the production of animal feeds and enhance sustainable meat production. However, they strongly disagreed that GMOs can support the production of cheaper foods.

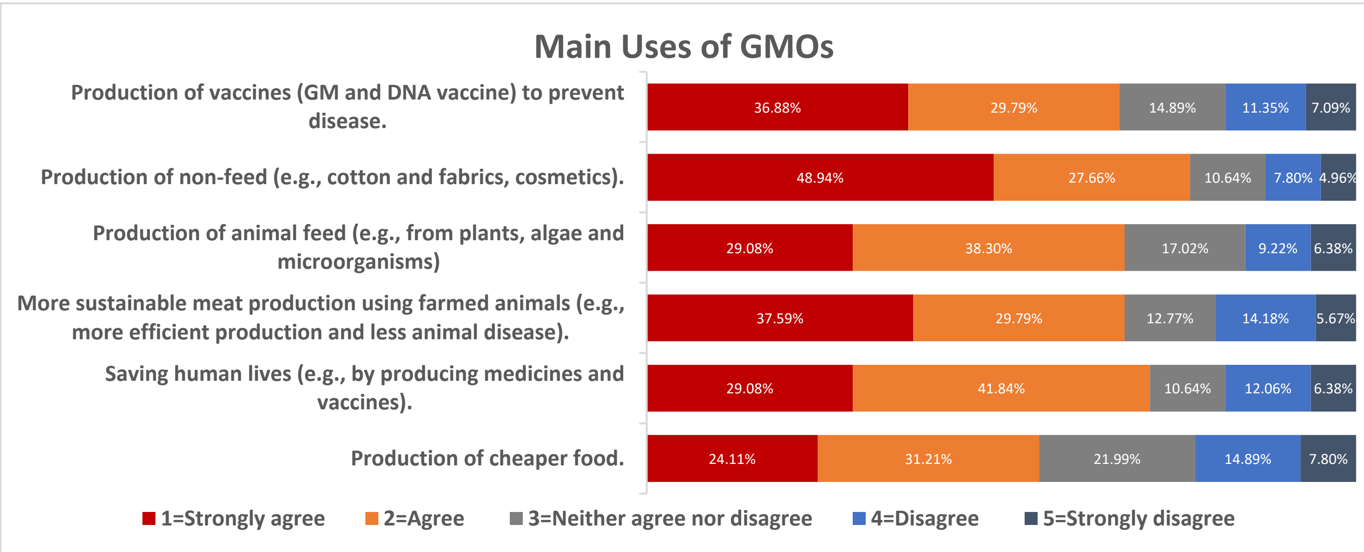

Figure 1. Major uses of GMOs in Kenya.

3.3. GMO Innovations and Food Safety

The findings show that approximately 79% of the Kenyan population reported that GM foods are already being consumed in the country. The main food safety issues identified include the potential to cause immune suppression, the transfer of toxicity, antibiotic resistance and the transfer of allergenicity. The perceptions of the safety of GM foods show that compared with non-GM foods, foods with GMOs are generally neither better nor worse (Table 2). This is reflected in the belief by majority of the respondents that GM foods are neither better nor worse in terms of the transfer of antibiotic resistance (39%), causing toxicity (43%), the transfer of allergenicity (36%), causing cancer (36%), immune suppression (43%) and the loss of nutrition in foods (4%). Notably, a significant proportion of the respondents reported that GMOs can transfer allergens (25%) and can cause cancer (21%). Based on the qualitative data, some respondents further emphasized how GMOs can potentially increase one's chances of contracting other non-communicable disease besides cancer. The neutrality in the responses reported indicates a significant level of indifference with regard to GMOs and safety concerns. These findings emphasize the importance of the key concern by the majority of the respondents of the potential for GMOs to cause chronic diseases when consumed by humans.

Table 2. Perceptions of safety of GMOs.

Safety of GMOs	**Frequency (Percent %)**				
Classification Statements	**Worse**	**Neither Better nor Worse**	**Better**	**Not Sure**	**No Answer**
Transfer of antibiotic resistance	4 (14%)	11 (39%)	4 (14%)	6 (22%)	3 (11%)
Causes toxicity	4 (14%)	12 (43%)	2 (7%)	2 (25%)	3 (11%)
Transfer of allergenicity	7 (25%)	10 (36%)	2 (7%)	6 (21%)	3 (11%)
Can cause cancer	6 (21%)	10 (36%)	2 (7%)	6 (21%)	4 (15%)
Immune suppression	4 (14%)	1 (43%)	3 (7%)	6 (21%)	4 (14%)
Loss of nutrition in foods	4 (14%)	9 (32%)	5 (19%)	6 (21%)	4 (14%)

3.4. GMOs and Environmental Safety

The environmental issues reported included loss of diversity; contamination due to gene flow from GM crops to the wild and weedy crop relatives, non-GM crops and foods; and the development of herbicide-resistant weeds ("super weeds"). A total of 29% of the respondents reported that GMOs are much better in terms of herbicide use, while 35% reported that GMOs intensify contamination, with 32% reporting that it contributes to loss of biodiversity. With regard to environmental safety, about 25% of the respondents reported that GMOs could be 'neither better or worse' in terms of increased herbicide use. A total of 25% indicated that GMOs were 'worse', while 25% reported that they were 'neither better nor worse' in terms of the development of herbicide-resistant weeds. A total of 21% mentioned that GMOs were 'worse' and 21% said they were 'neither better or worse' in terms of the development of insect-resistant crops. A total of 36% reported that GMOs can cause contamination due to gene flow from GM crops to wild and weedy crop relatives, non-GM crops and foods, while 32% indicated that they contribute towards biodiversity loss (Table 3).

Table 3. GMOs and environmental safety.

GMOs and Environmental Safety	**Frequency and Percent (%)**				
Classification Statements	**Worse**	**Neither Better nor Worse**	**Better**	**Not Sure**	**No Answer**
Increased herbicide use	4 (14%)	7 (25%)	8 (29%)	6 (21%)	3 (11%)
Development of herbicide-resistant weeds ("super weeds")	7 (25%)	7 (25%)	4 (14%)	7 (25%)	3 (11%)
Development of insect-resistant crops ("super bugs")	6 (21%)	6 (21%)	6 (21%)	7 (25%)	3 (11%)
Contamination due to gene flow from GM crops to wild and weedy crop relatives, non-GM crops and foods	10 (36%)	6 (21%)	2 (7%)	7 (25%)	3 (11%)
Biodiversity loss	9 (32%)	7 (25%)	3 (11%)	6 (21%)	3 (11%)

About a quarter of the respondents were not sure if GMOs were environmentally safe. One of the unsure respondents relayed that "...Main concern is safety, studies on the long-term effects are not yet conclusive as we stand exposed to unknown future which compromises health. Loss of biodiversity is a sure practice which is already evidenced in the current agricultural production. Most GMOs crops have stopper genes incorporated which will automatically lead to reliance of corporate private multinationals for GMO planting materials. Might lead to invasive species which might dominate the indigenous species".

The uncertainty of the respondents seemed to be based on speculations and fears of the damage that GMOs could cause to the environment, rather than on scientific evidence.

3.5. Ethics and GMO Innovations

The results revealed that GMOs are generally not perceived as ethical, as the majority of respondents reported that they can cause harm to the environment and human health; have adverse effects on traditional farming practices; lead to excessive corporate dominance; and are generally a non-conventional method of production. Categorically, regarding human health, 32% of the respondents reported that GMOs are 'neither better nor worse', while 36% of the respondent indicated that GMOs can harm human health and the environment. Further, 39% of the respondents indicated that GMOs can disrupt traditional farming practices. These figures are supported by the qualitative data as a respondent succinctly states, in his opinion, that GMOs can lead to "Massive loss of indigenous varieties from our seed bank—basically loss of our biodiversity, completely unknown impact on consumer health as well as environmental changes". Of the respondents, 11–18% were not sure of their responses on ethics and GMO technology, and at least five respondents in each category did not answer, which probably indicates limited knowledge on GMOs in the country (Table 4).

Table 4. Ethics and GMO technology.

Ethics and GMOs	**Frequency and Percent (%)**				
Classification Statements	**Worse**	**Neither Better nor Worse**	**Better**	**Not Sure**	**No Answer**
Potential harm to human health	8 (29%)	9 (32%)	3 (11%)	3 (11%)	5 (18%)
Potential harm to environment	10 (36%)	7 (25%)	3 (11%)	4 (14%)	4 (14%)
Negative impact on traditional farming practices	10 (36%)	6 (21%)	3 (11%)	4 (14%)	5 (18%)
Excessive corporate dominance	11 (39%)	7 (25%)	1 (4%)	4 (14%)	5 (18%)
Non-conventional method of production	7 (25%)	9 (32%)	2 (7%)	5 (18%)	5 (18%)

The study analyzed how GMOs relate to people's beliefs and presents some of the ethical arguments and considerations (Table 5). The results show that GMOs are not against the religion of the majority of the respondents (50%). The respondents further disagreed that GMOs have anything to do with 'Playing God' (50%) as indicated in most myths. Additionally, the majority of the respondents were either neutral (32%), disagreed (14%) or strongly disagreed (29%) that GMOs are not acceptable in animal production due to animal welfare concerns. Further, the respondents disagreed that the technology is not ethically acceptable in food, feed and medicine production. Although a significant proportion of the respondents agreed that GMOs are tampering with nature, they did not believe that this makes them unacceptable. One respondent in the qualitative responses believed that: "There is misinformation concerning alteration of DNA of consumers and potential harm to human health, harm to environment, negative impact on tradition farming practices, excessive corporate dominance, and unnaturalness of technology". Strong ethical arguments regarding GMOs were expressed in the study. About 25% of the respondents strongly agreed that GMO technology produces food products that are being forced on developing countries by developed nations, while over 40% of the respondents strongly disagreed that GMO technology is not an ethically acceptable method for medicine production.

Generally, the perceptions that were reported on GMO technology included that use of foreign and DNA material in the development of GMO crops can impact the health of individuals; the permanent risks of destroying the originality and uniqueness of various animal products and food products, which may in return cause harmful environmental and human problems; a lack of clear information; perceived secrecy of GMO issues by scientists, and thus, a lack of openness; a lack of honesty on the part of scientists to the citizenry; and inequality of information sharing, which suggests that they do not value the final consumer or clients who eventually consume the GM foods.

Table 5. Ethical arguments and ethical considerations regarding GMOs.

Ethical Arguments regarding GMOs	**Frequency and Percent (%)**				
Classification Statements	**Strongly Agree**	**Agree**	**Neither Agree nor Disagree**	**Disagree**	**Strongly Disagree**
GMO technology is against my belief/religion.	2 (7%)	2 (7%)	10 (36%)	7 (25%)	7 (25%)
By using GMO technology, we are "playing God".	4 (14%)	2 (7%)	8 (29%)	6 (21%)	8 (29%)
GMO technology is not acceptable in animal production due to animal welfare concerns.	2 (7%)	5 (18%)	9 (32%)	4 (14%)	8 (29%)
GMO technology is not ethically acceptable in food production.	1 (4%)	6 (21%)	6 (21%)	8 (29%)	7 (25%)
GMO technology is not an ethically acceptable method for producing animal feed.	1 (3%)	7 (25%)	7 (25%)	5 (18%)	8 (29%)
GMO technology is not an ethically acceptable method for medicine production.	0 (0%)	3 (11%)	6 (21%)	7 (25%)	12 (43%)
Using GMO technology is "tampering" with nature ("unnaturalness").	5 (18%)	6 (21%)	6 (21%)	5 (19%)	6 (21%)
GM technology is unnatural and hence not acceptable.	4 (14%)	2 (7%)	8 (29%)	7 (25%)	7 (25%)

3.6. Food Security and GMO Innovations

The results show that the majority (64%) of the respondents agreed that GMOs are a solution to food security in Kenya (Table 6). Most respondents perceived that GMOs can increase food production by providing more food reserves; reducing postharvest losses; and reducing the cost of production, as GM crops are more resistant to pests and diseases. The few respondents who were opposed to GMO technology cited examples of its negative impact on environmental and human safety, and the lack of smallholder farmers' capacity to manage GMO production. Further, most of the respondents (61%) reported that there is an adequate legal and regulatory framework to monitor GM food production and marketing to ensure that the commercialization of GM foods is conducted in a safe and responsible manner. All respondents agreed that there was a regulatory agency in place in Kenya and a regulatory framework stated in the National Biosafety Act. The majority of the respondents (54%) reported that farmers and consumers do not have a voice when it comes to the development, production and sale of GM foods. Most respondents reported that even though there are policies that promote farmer and consumer engagement before accepting GMOs into the country, usually, there is no public participation in such a key matter in practice. A few respondents, however, thought otherwise and were convinced that farmers and consumers are involved in the approval process from the beginning to the end.

About 75% of the respondents agreed that there are certain food crops that should be genetically modified. The main food crops reported included maize, sorghum, millet, cassava and sweet potato. These crops are prone to pests and viral diseases and are thereby exposed to heavy use of chemicals, which results in high chemical residues in human food, posing a bigger threat to food safety. The results also show that the majority of the respondents (64%) reported that GM foods are safe, although 57% of these respondents also acknowledged that there are several key issues of concern with regard to risks to human health. Of the total number of respondents, 93% reported that GMOs are perceived differently from traditional foods. The findings showed that most of the respondents (86%) were aware of a number of hinderances for farmers if they were to adopt GMO crop production. One of the major findings was the fear felt by farmers with regard to the potential elevated costs of the production of GMOs and the scarcity of seeds in future, as GMO technologies are patented, and therefore, cannot be reproduced. Most of the respondents expressed concern about the ease of access to seeds in the future. It was also noted that different GM organisms include different genes inserted in different ways. This means that individual GM foods and their safety should be assessed on a case-by-case basis to avoid making general statements on the safety of all GM foods.

Table 6. Frequency of perceptions (percent) of GMOs.

Perceptions of GMOs	**Respondents Feedback (YES vs. No)**	**Frequency (N)**	**Percent (%)**
Are GMOs safe?	Yes	18	64
	No	10	36
Are GMOs perceived differently from traditional foods?	Yes	26	93
	No	2	7
Are there known main issues of concern for human health?	Yes	16	57
	No	12	43
Are there implications for farmers if they turn to GMOs crop production?	Yes	24	86
	No	4	14

Perceptions and Positive Effects of GM Foods in Crop Production

About 85% of the respondents indicated that there would be implications to farmers if they turn to GMO crops. Figure 2 presents the perceptions of GMOs for addressing food security. Over 65% of the respondents strongly agreed (29%) and agreed (36%) that GMOs will contribute to an increase in the global food supply. Similarly, the majority of respondents agreed that GMOs will make food affordable (57%). About half of the respondents agreed that GMOs will lead to the production of more nutritious foods (50%). However, the farmers will have to regularly rely on seeds from biotechnology companies. This could lead to the reduced use of traditional seeds, especially for food and cash crops. Whereas most of the respondents agreed that GMOs can produce crops more resistant to pests and reduce pesticide use on food crop plants (89), the majority of them did not agree that GMOs improve the shelf life or enhance the taste of food (39%). Some respondents noted that GM crops will worsen the health of farmers and the public because of food safety issues, while at the same time, making them poorer. The perception was that the cost of GMO seeds will keep increasing; hence, the farmers would have to purchase these seeds every planting season. This is because they agreed that GMO seeds cannot be re-planted from the previous season, unlike traditional seeds. Further, they perceived that GMOs also require the purchase of expensive synthetic fertilizers as farm inputs to grow, further increasing famers' input costs. The adoption of GMO technology was perceived to be potentially difficulty since the seeds are patented and can only be used for one season. In conventional methods, farmers always save and bank the best seeds for each planting season. Intellectual property rights are also likely to be an element in the debate about GM foods with an impact on the rights of farmers.

The main negative effects of GMO technology that were reported include loss of biodiversity, contamination with non-GMO crops, the development of superweeds and the increased use of herbicides (Figure 3). Almost half of the respondents reported that GMOs will increase the use of herbicides. Similarly, more than half of the respondents did not report that GMOs will lead to the development of superweeds and superbugs. However, the majority of the respondents reported that GMOs can lead to contamination and reduced biodiversity. The respondents expressed a low level of disagreement with the fact that GMOs can have adverse effects on human health.

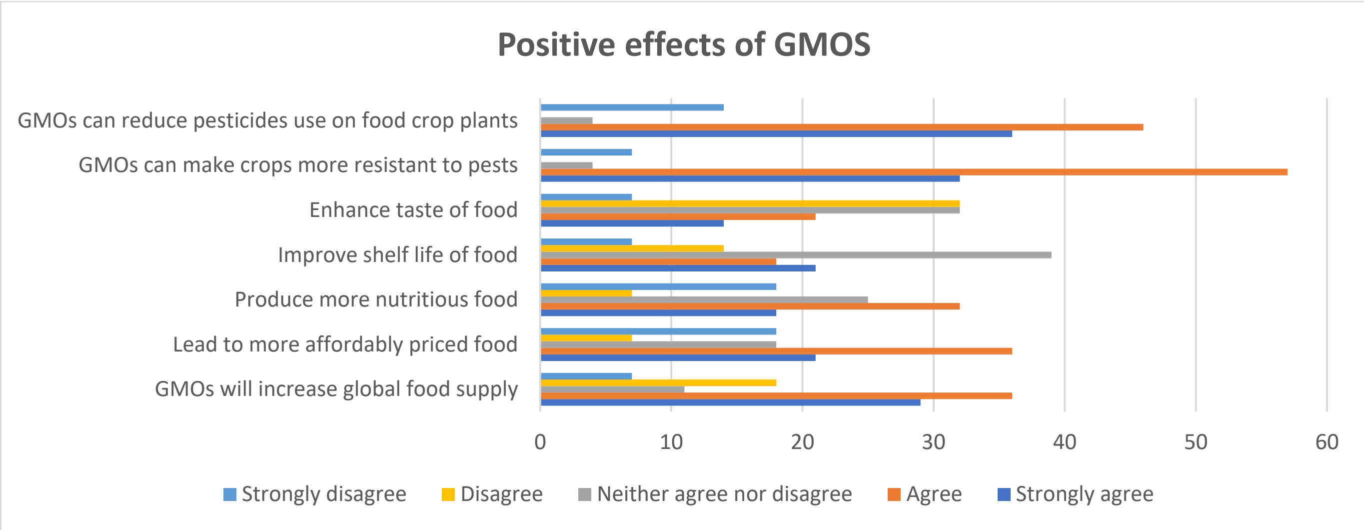

Figure 2. Positive effects of GM foods as perceived by respondents towards food security.

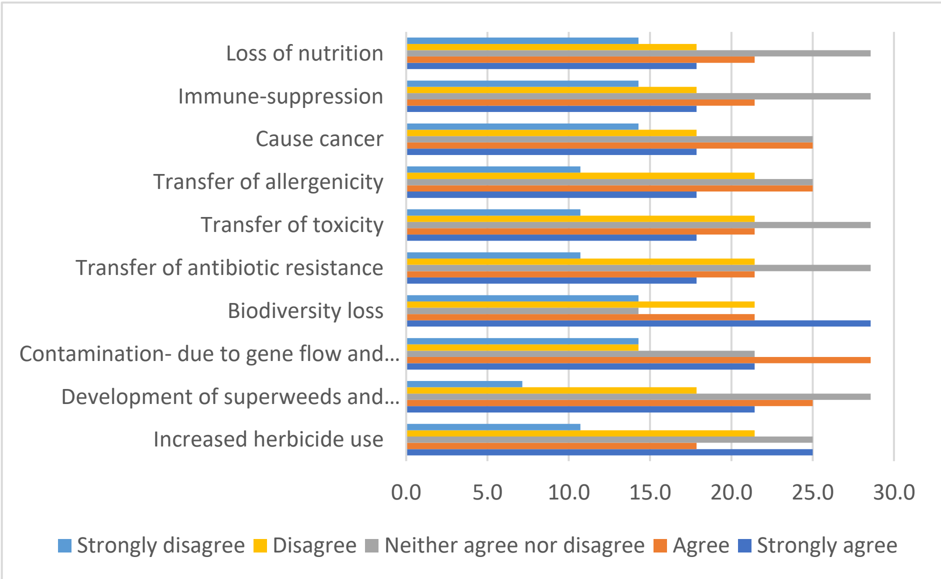

Figure 3. Negative effects of GMOs for improving food security.

3.7. Policy and Legal and Regulatory Frameworks on GMOs

About 60% of the respondents indicated that Kenya has adequate legal and regulatory frameworks to ensure that research on and the commercialization of GM foods are conducted in a safe and responsible manner. Further, Kenya is a signatory to the biodiversity convention and Cartagena protocol that govern the global adoption of GMOs. GMOs are regulated by the National Biosafety Authority nationally. Figure 4 shows the roles of different stakeholders with regard to GMO technology. Scientists and elected leaders have a major role in policy issues related to GMOs. The scientific community have an obligation to provide clear evidence on the production and consumption of GMOs, while policy makers have to lobby and support policy and legislative framework on GMOs. Farmers also have to be involved in the policy debate on GMOs. The results show that the majority of the respondents reported that scientists (71%) and elected officials (50%) should have the greatest role in the governance of GMOs. A considerable proportion of the respondents reported that food industry leaders and the general public have major roles to play in GMO governance. A notable proportion of the respondents reported that small-scale farmers do not have much of a role to play in the governance of GMOs.

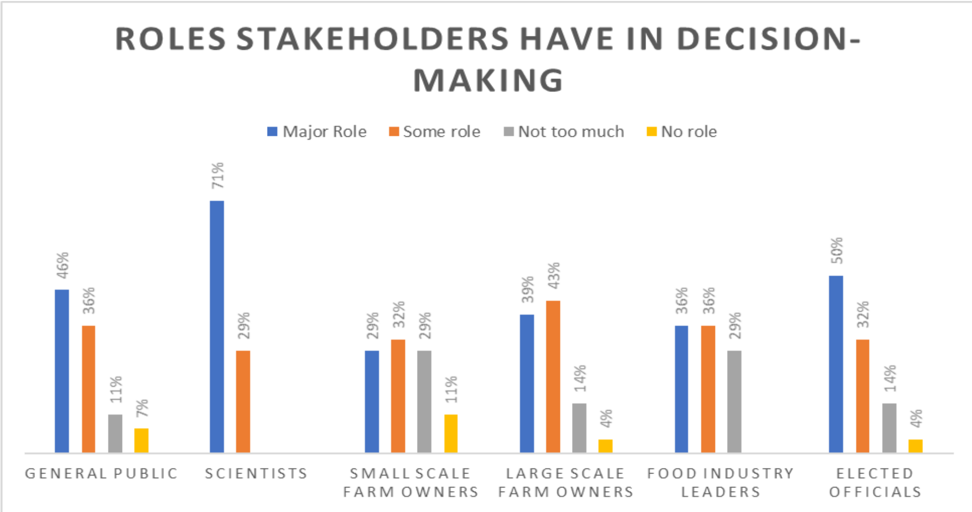

Figure 4. Stakeholders' roles in policy issues related to GMOs.

The results show considerable support for the use of GMOs for the sustainable production of cheaper food, meat, feed and non-feed products, such as cotton and fabrics. The majority of the respondents also supported the use of GMOs for medicinal purposes including the production of vaccines (Table 7). Most participants emphasized their nutritional effects and ability to solve national food security issues.

Table 7. Extent of support for GMOs for improving food security.

Statements on Support for GMOs	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
Production of cheaper food.	6 (21%)	11 (39%)	6 (21%)	1 (5%)	4 (14%)
Saving human lives (e.g., by producing medicines and vaccines).	10 (36%)	15 (53%)	2 (7%)	1 (4%)	0 (0%)
More sustainable meat production using farmed animals (e.g., more efficient production and less animal disease).	5 (18%)	9 (32%)	9 (32%)	4 (14%)	1 (4%)
Production of animal feed (e.g., from plants, algae and microorganisms)	7 (25%)	10 (36%)	7 (25%)	3 (10%)	1 (4%)
Production of non-feed (e.g., cotton and fabrics, cosmetics).	12 (43%)	8 (29%)	4 (14%)	3 (10%)	1 (4%)
Production of vaccines (GM and DNA vaccine) to prevent disease.	13 (46%)	9 (32%)	5 (18%)	0 (0%)	1 (4%)

4. Governance of Antimicrobial Resistance in Food Innovations

4.1. Awareness of AMR and Sources of Information about AMR in Food Innovation

The sectors represented by respondents in the AMR sector included human health (11.1%), animal health (48.2%), plant health (14.8%), food production (22.2%) and food safety (29.6%), indicating the importance of research in AMR for these disciplines. The respondents noted that the media was the predominant source of information about AMR. The results also revealed that campaigns about AMR and veterinary doctors played significant roles in creating awareness of AMR. With regard to the awareness of AMR risks and human health, the findings show that some of the participants were aware of AMR (27%). This could be attributed to the level of campaigns and publicity about the existence of AMR in Kenya. Regarding farmers' awareness of AMR, the study revealed that farmers barely knew about AMR (Table 8). This is because most (81%) of the key informants who directly interact with the farmers did not report that farmers have heard about AMR.

Table 8. Awareness and understanding of antibiotic resistance risks and human health.

Awareness and Understanding of Antibiotic Resistance Risks	Percent (%)
No significant awareness-raising activities on antibiotic resistance	11.1
Some activities in parts of the country to raise awareness about risks of antibiotic resistance and actions that can be taken to address it	25.9
Limited or small-scale antibiotic resistance awareness campaign targeting some, but not all, relevant stakeholders (e.g., general public, pharmacists, nurses, medicine sellers)	55.6
Nationwide, government-supported antibiotic awareness campaign targeting all or the majority of stakeholders	7.4

4.2. Knowledge, Attitudes and Practices Concerning AMR

Most respondents answered 13 out of 15 knowledge questions correctly (M = 13.74, SD = 1.35). Overall, the respondents appeared to be very knowledgeable about AMR. About 52% of the participants reported that antibiotic resistance occurs when your body becomes resistant to antibiotics and they are no longer effective. All of the respondents correctly agreed on the adverse effects of AMR on their families, medical procedures and the treatment of infections caused by antibiotic resistance. A notable number of respondents incorrectly reported that antibiotic-resistant bacteria can spread from animals to crop produce, such as fruits and vegetables, through unclean water or soil and that individuals can become sick with bacterial infections that are resistant to antibiotics if they touch or use unclean surfaces or do not wash their hands and clean surfaces (Table 9).

Table 9. Knowledge on AMR innovations.

Variables	Correct Percent (%)	Incorrect Percent (%)
Antibiotic resistance occurs when your body becomes resistant to antibiotics and they no longer work as well	52	48
Many infections are becoming increasingly resistant to treatment by antibiotics	93	7
If bacteria are resistant to antibiotics, it can be very difficult or impossible to treat the infections they cause	100	0
Antibiotic resistance is an issue that could affect me or my family	100	0
Antibiotic resistance is an issue in other countries but not here	96	4
Antibiotic resistance is only a problem for people who take antibiotics regularly	93	7
Bacteria which are resistant to antibiotics can be spread from person to person	96	4
Antibiotic-resistant infections could make medical procedures like surgery, organ transplants and cancer treatment much more dangerous	100	0
Antibiotic-resistant bacteria can spread from animals to animal products people eat, such as chicken and meat	93	7
Antibiotic-resistant bacteria can spread from animals to crop produce, such as fruits and vegetables, through unclean water or soil	89	11
Antibiotic-resistant bacteria can spread from animals to the environment, through animal feces.	96	4
You can become sick with bacterial infections that are resistant to antibiotics if eat food that's been infected with antibiotic-resistant bacteria and not properly prepared or cooked.	93	7
You can become sick with bacterial infections that are resistant to antibiotics if handle unclean animals and do not wash your hands.	93	7
You can become sick with bacterial infections that are resistant to antibiotics if touch or use unclean surfaces and do not wash your hands or clean surfaces.	85	15
Antibiotics widely used in the country for food production.	96	4

The respondents perceived AMR to be associated with a "large level of risk" (score 2) (M = 1.85, SD = 1.06). All perceptions about the tendency towards antibiotic misuse were either high or moderate (score 3). Categorically, the propensity for antibiotics being misused in an attempt to prevent disease was high (M = 3.89, SD = 1.84), and the propensities for their use to enhance growth (M = 3.37, SD = 1.47), treat clinical disease (M = 3.15, SD = 1.20) and as therapy (M = 3.33, SD = 1.41) were moderate. The reasons for the possible risk associated with the use of antibiotics above are strongly reflected in the qualitative responses. For the reason that antibiotics are mostly misused in an attempt to prevent diseases, most respondents reported that farmers tend to abuse antibiotics because of their ability to treat a broad spectrum of bacteria and other infectious diseases, as well as their ease of access on the market (Figure 5).

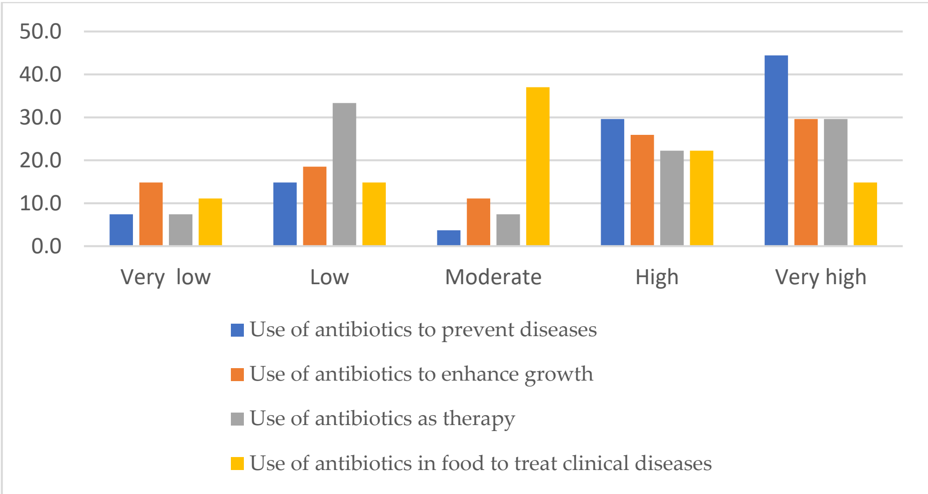

Figure 5. Misuse of antibiotics in food innovations.

The other reported risks of high resistance to antibiotics mentioned by respondents were that a few farmers use them as growth promoters, while some use them as therapy in a few instances. These statements make it clear that most farmers' fear of diseases among livestock increases their use of antibiotics for disease prevention, thereby posing a large level of risk to the animals. Regarding practices, the respondents reported that antibiotics should only be used when they have been prescribed by a veterinary doctor (M = 1.30, SD = 0.72) and that antibiotics should not be kept for later use in the treatment of other livestock diseases (M = 1.11, SD = 0.42). The respondents reported that fewer antibiotics should be given to food-producing livestock (M = 1.37, SD = 0.79). The respondents did not know if the government and companies should produce more antibiotics. The respondents did not report that medical experts can solve the problem of antibiotic resistance before it becomes too serious (M = 2.33, SD = 0.68), and that they are not at risk of contracting an antibiotic-resistant infection, as long as they take antibiotics correctly. The respondents agreed that antibiotic resistance is one of the world's biggest problems (M = 1.07, SD = 0.27) and that they were worried about the impact that antibiotic resistance will have on their health and that of their families (M = 1.0, SD = 0). Given their fears of antibiotic resistance, the respondents reported that everyone needs to take responsibility for using antibiotics responsibly (M = 1.0, SD = 0). This is corroborated by the qualitative data, where most respondents agreed that all hands must be on deck to fight AMR. Most of the respondents strongly entreated that governments must put in place measures to fully enforce policies backing antibiotic use, while farmers should also prudently use antibiotics. The above results indicate the level of knowledge of respondents on the abuse of antibiotics by farmers and the best practices that could be put in place to control the potential effects of AMR on food production in the country (Table 10).

Table 10. Knowledge, attitudes and practices regarding antibiotics.

Variables	Range	Mean	SD	Min	Max
Knowledge					
Knowledge scores	0–15	13.74	1.35	10	15
Attitudes					
Perceived risk to farmers	1–5	1.85	1.06	1	5
Perceived risk of misuse					
Use of antibiotics to prevent diseases	1–5	3.89	1.34	1	5
Use of antibiotics to enhance growth	1–5	3.37	1.47	1	5
Use of antibiotics as therapy	1–5	3.33	1.41	1	5
Use of antibiotics in food to treat clinical diseases	1–5	3.15	1.20	1	5
Practices					
People should use antibiotics only when they are prescribed by a vet doctor	1–3	1.30	0.72	1	3
Farmers should give fewer antibiotics to food-producing animals	1–3	1.37	0.79	1	3
People should not keep antibiotics and use them later for other livestock diseases	1–3	1.11	0.42	1	3
Governments should reward the development of new antibiotics	1–3	1.56	0.80	1	3
Pharmaceutical companies should develop new antibiotics	1–3	1.52	0.85	1	3
Antibiotic resistance is one of the biggest problems the world faces	1–3	1.07	0.27	1	2
Medical experts will solve the problem of antibiotic resistance before it becomes too serious	1–3	2.33	0.68	1	3
Everyone needs to take responsibility for using antibiotics responsibly	1–3	1.00	0.00	1	1
There is not much people like me can do to stop antibiotic resistance	1–3	2.96	0.19	2	3
I am worried about the impact that antibiotic resistance will have on my health, and that of my family	1–3	1.00	0.00	1	1
I am not at risk of getting an antibiotic resistant infection, as long as I take my antibiotics correctly.	1–3	2.74	0.66	1	3

4.3. Governance of Antibiotic Resistance Risks

The study assessed the governance of antibiotic resistance risks. Overall, the study found that efforts towards promoting awareness of antibiotic resistance risks and responses in human health are relatively limited, as the majority (55.6%) of the respondents had seen few or small-scale awareness campaigns. The case was similar in the veterinary sector, as the majority (40.74%) of the respondents claimed that antimicrobial resistance awareness campaigns targeting some, but not all, relevant stakeholders within the sector are limited or on a small scale (Table 11).

Table 11. Raising awareness and understanding of antibiotic resistance risks and responses in human health and veterinary medicine.

Statements on Raising Awareness of AMR Risks	Frequency	Percent (%)
1. Statements on raising AMR risks in human health		
No significant awareness-raising activities on antibiotic resistance	3	11.11
Some activities in parts of the country to raise awareness about risks of antibiotic resistance and actions that can be taken to address it	7	25.93
Limited or small-scale antibiotic resistance awareness campaigns targeting some, but not all, relevant stakeholders (e.g., general public, pharmacists, nurses, medicine sellers)	15	55.56
Nationwide, government-supported antibiotic awareness campaigns targeting all or the majority of stakeholders	2	7.41
2. Statements on raising AMR risks in other sectors like the veterinary sector		
No significant awareness-raising activities on relevant aspects of risks of antimicrobial resistance	6	22.22
Some activities in parts of the country to raise awareness about risks of antimicrobial resistance and actions that can be taken to address it	7	25.93
Limited or small-scale antimicrobial resistance awareness campaigns targeting some but not all relevant stakeholders within the sector	11	40.74
Nationwide, government-supported antimicrobial resistance awareness campaigns targeting all or the majority of relevant stakeholders within the sector	2	7.41
Focused, national-scale government-supported activities implemented to change behavior of relevant stakeholders within the sector, with monitoring undertaken of their awareness and behavioral changes over last 2–5 years	1	3.7

Regarding sanitation, the study revealed that most of the respondents reported that there were standards to improve water, sanitation and hygiene. However, these standards have not been fully implemented. A few of the respondents reported that the plans are available (11.11%) and have been implemented (11.11%) (Table 12).

Table 12. Reduction in AMR through sanitation.

Reduction in AMR through Sanitation	Frequency	Percent (%)
No responses	2	7.41
A national Infection prevention and control (IPC) program or operational plan is available. National IPC and water, sanitation and hygiene (WASH) and environmental health standards exist but are not fully implemented.	19	70.37
A national IPC program and operational plan are available and national guidelines for health care IPC are available and disseminated. Selected health facilities are implementing the guidelines, with monitoring and feedback in place	3	11.11
National IPC program available according to the WHO IPC core components guidelines and IPC plans and guidelines implemented nationwide. All health care facilities have a functional built environment (including water and sanitation), and necessary materials and equipment to perform IPC, per national standards.	3	11.11

Regarding good health management systems, about 41% of the respondents believed that some activities are in place to develop and promote good production practices. On the other hand, others (22%) indicated that there are no efforts to improve good production practices to reduce the need to use antimicrobials. About 30% of the respondents reported that there is a national plan to ensure good production practices which are in line with international standards.

Optimizing Antimicrobial Use in Human Health, Animal and Plant Health Sector

Regarding optimizing antimicrobial use in the human health sector, the results show that about 19% of the respondents reported that there are no or weak policies and regulations for their appropriate use. About 26% reported that such policies exist, whereas 37% reported that the policies have been implemented. In the plant and animal health sector, about 15% of the respondents reported that there is no national policy or legislation regarding the quality, safety and efficacy of antimicrobial products and their distribution, sale or use, 48% reported that the national legislation covers some aspects of the national manufacture, import, marketing authorization, control of safety, quality and efficacy and distribution of antimicrobial products, and 19% reported that it covers all aspects (Table 13).

Table 13. Optimizing antimicrobial use in the human health and the animal and plant health sectors.

Optimizing Antimicrobial Use	Frequency	Percent (%)
1. Statements on optimizing antimicrobial use in human health sector		
No response	3	11.11
No/weak national policy and regulations for appropriate use.	5	18.52
National policy for antimicrobial governance and regulation developed for the community and health care settings	7	25.93
Practices to assure appropriate antimicrobial use being implemented in some healthcare facilities and guidelines for appropriate use of antimicrobials available	10	37.04
Guidelines and other practices to enable appropriate use are implemented in most health facilities nationwide. Monitoring and surveillance results are used to inform action and to update treatment guidelines and essential medicines lists.	2	7.41
2. Statements on optimizing antimicrobial use in animal and plant health sector		
No response	1	3.7
No national policy or legislation regarding the quality, safety and efficacy of antimicrobial products, and their distribution, sale or use.	4	14.81
National legislation covers some aspects of national manufacture, import, marketing authorization, control of safety, quality and efficacy and distribution of antimicrobial products.	13	48.15
National legislation covers all aspects of national manufacture, import, marketing authorization, control of safety, quality and efficacy and distribution of antimicrobial products	5	18.52
Guidelines for responsible and prudent use of antimicrobials based on international standards (e.g., OIE Terrestrial and Aquatic Codes, Codex Alimentarius) are available according to animal species and/or production sector and include restriction of specific antimicrobial classes listed as Critically Important for humans and animals.	4	14.81

Regarding the country's use of policy, most of the respondents reported that the country has regulations on the prescription and sale of antimicrobials, including requirements for prescriptions for human use. Of the total number of respondents, 85% indicated that the country has regulations on the prescription and sale of antimicrobials, including requirements for prescriptions for human use. Further, 15% reported that the country does not authorize the use of human and animal Critically Important antimicrobials for growth promotion.

5. Discussion

This study highlights experts' knowledge and perceptions of the risks and benefits, associated with GMOs and antibiotic use in Kenya, a country struggling to meet the needs of its rapidly growing population [10]. The study also presents the risks associated with the poor governance and implementation of technologies and the need for a framework for technological risk governance that is sensitive to local values and socio-economic circumstances and that will benefit the achievement of other SDGs, such as SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), and SDG 9 (industry, innovation and infrastructure). GMO technology and AMR are regarded controversial and have become hot issues of debate. However, despite these crucial issues, there is limited understanding about experts' knowledge and perspectives of GMOs and AMR in Kenya. The study findings revealed that the majority of the experts were knowledgeable about GMOs, which was similar to other studies [40]. The experts were mostly in agreement about the potential benefits of GM crops. GM foods may offer solutions to the many problems that farmers experience, thus increasing food availability and the quality of food. GMO technology offers opportunities for breeding for plant diseases, which, in normal cases, would have taken years. The use of GM foods provides the possibility to overcome losses as a result of insects and pests. The cost of labor for weed control has continued to increase as the labor movement has become global and urbanized. The use of herbicide-tolerant crops is important for Kenya today, and especially for field crops.

In most developing countries, the demand for food surpasses agricultural production due to poor and unsustainable agricultural practices and environmental degradation [41]. GM foods can contribute to increased food production and quality, as well as increased income for farmers, affording them the resources to buy more high-quality food [42]. In Africa, GM foods are increasingly being used to boost the food supply. As of 2018, the GM market value was estimated to be USD 615.4 million and is projected to increase to USD 871 million by 2025 [43]. Among the African countries, GM crops have been grown in South Africa, Burkina Faso, Malawi, Eswatini, Egypt and Sudan, while other African countries are still carrying out trials on various GM seeds strains [16]. Some of the GM crops that are being grown include Bt maize and Bt cotton. In Kenya, applications for the commercialization of GM crops, including Bt maize and water-efficient maize, in Africa are still in field trials, except for Bt cotton, which was commercially released in 2020 for adoption by farmers [16]. Given the history of GMOs, the majority of the respondents believed that public perceptions had a significant impact on governance and innovation. A study conducted in China found out that increased productivity and revenue, as well as crop management, have an impact on farmers' adoption of GMOs [44]. Meanwhile, another study conducted in Nigeria discovered that the nutritional advantages and reduced fertilizer consumption influenced farmers' views regarding the growing of GM crops [45]. The introduction and use of GMOs were deemed unethical due to the negative effects on health and the environment. It has been stated that the consumption of GMOs may lead to the development of allergenicity and the development of cancerous cells in human beings. Also, it may constitute a danger to agricultural biodiversity [46–48]. The safety concerns and risks of GM foods are the major reasons why GM foods are not well adopted by either farmers or consumers.

In regard to antimicrobial use, perceived misuse of antibiotics was reported. Currently, antimicrobial use in food-producing animals is growing at an alarming rate. The global average annual consumption of antimicrobials in swine, poultry and cattle has been estimated to be at 172 mg/kg, 148 mg/kg and 45 mg/kg, respectively, and it is projected to increase by 67 percent by 2030 to keep up with the growing demands of the increasing population. In the past, developed countries such as the USA, China and Brazil were among the largest consumers [32]. In many developing countries, antibiotic use without a prescription is common practice and is associated with the overuse and misuse of antibiotics, contributing to the development of antibiotic resistance [49]. Antibiotic overuse and inappropriate usage contaminate the environment, which can introduce ARGs and resistant bacteria into the human food supply and healthcare settings [50]. In most of the developing countries, levels of antibiotic residues above the recommended limits have been reported [2]. Developing countries are more susceptible due to a lack of adequate monitoring programs to track antimicrobial use, as well as poor detection facilities [9]. In Kenya, AMR is rapidly becoming a threat to public health. Kenya has reported high levels of antimicrobial resistance. In the livestock sector, studies indicate that *Escherichia coli (E. coli)* isolates from beef and poultry have been shown to be resistant to tetracycline, co-trimoxazole, streptomycin, ampicillin, quinolones and third-generation cephalosporins at varying frequencies. Some of the isolates were found to be resistant to two or three antimicrobials [44]. The mechanisms of resistance identified in the bacterial agents Staphylococcus aureus and Enterococci towards two priority classes of antibiotics, the fluoroquinolones and the glycopeptides, are notable, as are those of the other key antimicrobial-resistant food-borne pathogens (*E. coli*, *Salmonella enterica* and *Campylobacter* spp.), which have occurred with increasing frequency as causes of food-borne diseases ranging from mild gastroenteritis to life-threatening systemic infections [44]. The widespread presence of antimicrobial-resistant microorganisms in poultry influenced by a lack of responsible and prudent antimicrobial use has been reported [13]. This demands appropriate education on the causes of AMR, as well as improvements to the country's framework on the regulation of antimicrobial use and basic antibiotic sensitivity testing facilities, in order to avoid AMR. Our findings show that majority of the respondents were knowledgeable about AMR but they reported that most of the farmers they interacted with had a low level of knowledge on AMR. This could possibly be due to a low level of awareness. Similarly, a study conducted in Cameroon among poultry farmers reported a low mean knowledge score on AMR [51]. In addition, another study conducted in Zambia revealed a low level of awareness of AMR among poultry farmers [52]. There is an urgent need to increase awareness of antimicrobial usage, how it is connected to AMR and the consequences for human and animal health and ecosystems. In Kenya, a lot of effort has been directed towards the prevention of antimicrobial resistance. For instance, various policies targeting antimicrobial resistance have been implemented. Also, media campaigns to create awareness of AMR have been carried out. Further to this, a national action plan (2017–2022), with five strategic components aligned with the constitution of Kenya, 2010, was developed to reduce the burden of AMR in the country. Nonetheless, implementation of the policies and the action plan is still limited.

6. Conclusions

From our findings, it is clear that the effectiveness of existing policies to control antimicrobial resistance and GM foods is not yet fully understood. Therefore, a strengthened evidence base is needed to inform effective policy interventions across the human health and animal sectors in the country. The key policy action points include irresponsible use, surveillance, and infection prevention and control for their effective implementation at national and county levels. The implementation of such policies across sectors (animal, human, crop and environment) and in varying political and regulatory environments can be complex. Therefore, we recommend political action that involves comprehensive policy assessments that are cost-effective and apply standardized frameworks. A One Health approach that will enable the development of sensitive policies, accommodating the needs of each sector involved, and addressing the concerns of specific countries, should be implemented. Further, recommendations on priority areas for research on AMR are vital in addressing data gaps and can help risk managers to implement the One Health Action plan against AMR.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the University of Nairobi, Kenya (KNH-UON ERC application reference: P447/06/2021) and Warwick University in the UK (application reference: HSSREC 154/20-21).

Informed Consent Statement: All human subjects gave their informed consent for inclusion before they participated in the study.

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