Article

Responsible Governance of Technological Risks of Food Innovations towards Food Security.

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Abstract: Recently, the world has experienced severe food insecurity problems with most countries having inadequate access to affordable, nutritious and safe foods. Consequently, many food innovations and technologies have been approved to secure sustainable access to food for millions of people. This study investigated the implementation of two technologies to address food insecurity, namely genetically modified foods (GMOs) and the use of antibiotics in crops and animal 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 antibiotic resistance risks and GMO foods were assessed. In-depth key interviews were conducted for the qualitative survey with triangulation with quantitative data sources. The findings showed that 46% of the population have little knowledge about GMOs with about 79% indicating that food with GM ingredients were being consumed in the country. The main concerns reported on GM foods by most respondents were impact on environment, human health and adverse effects on traditional farming practices with 36% indicating that it intensifies contamination and 32% indicating that it contributes to loss of biodiversity. Notably, 64%) reported that GMOs are a solution to food security and that they are safe. On the use of antimicrobials mainly meant to prevent diseases and access better markets, respondents perceived their use to be associated with antimicrobial resistance a "large level of risk" (score 2 in a scale of 1-3) (M = 1.85, SD = 1.06). Overall, the study found that efforts towards promoting awareness on antibiotic resistance risks and response in human health is relatively limited as reported by 56% of the respondents. Findings show that most of the respondents have only seen minimal or small-scale awareness campaigns. On governance of the two technologies, 71% and 50% of the respondents reported that scientists and elected officials respectively have the greatest role in governance of GMOs with small scale farmers playing a negligible role. Further, it was noted that all the respondents were knowledgeable in AMR and GMO technologies and these findings are crucial to the advancement of food innovations that are geared towards achieving food security in Kenya. This study highlights 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 that will benefit the achievement.

Keywords: Technological risks; Governance; Food Security; Food Innovations; Technologies; Ethics

1. Introduction

Food and nutrition insecurity as an outcome of existing food systems has 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 which 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 in the population that was evaluated between the year 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, growth of food production is slow compared to the increasing population. For instance, in Sub-Saharan Africa, the rate of population growth rate per year is at 3 percent which means that it could lead to doubling of the current generation. In Kenya, food security has been a challenge since 2008 and between 2014-2019 severe droughts were experienced resulting in more than double the number of food insecure people from 1.3 million to 2.7 million [5].

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 [6]. It is thus essential to ensure that agricultural production is effective, efficient, and sustainable [7]. Potential solutions to some of these risks are offered by emerging technologies and innovations [8,9]. A number of measures have been put forward to combat the problem of food security globally. Biotechnological innovations such as genetic engineering have been shown to be successful in addressing food production challenges [10]. However, the poor implementation of innovations and technologies to achieve food to 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 [10].

1.1 Genetically modified crops

In regards to this, many crops have been genetically modified to increase resistance to diseases, herbicides and insect pests among other beneficial characteristics [8]. Some of the crops that have been genetically engineered include maize, cotton, soya bean and canola. For instance, the GM insect resistant maize have been shown to be resistant to infestation by mycotoxins and also contains great health benefits [11]. 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 [12]. Moreover, other benefits include a reduction in the use of pesticides. In 2003, studies conducted in USA showed a reduction of pesticide use due to cultivation of GM crops. In 2001, China also recorded a reduction in the number of formulated pesticides that were being used by 78000 tonnes [13]. Therefore, a reduction in pesticide use reduces the risk of exposure and poisoning to farmers and the environment as well [14].

Despite the prospects and benefits of GM crops, most of the African countries have been reluctant to adopt GM crops due to a number of factors including limited knowledge and awareness on the application of the technologies, lack of regulatory policies and lack of assured safety and long-term effect [15]. Only 12 countries out of the 54 have national biosafety frameworks that are operational. Further to this, only five of the countries plant GM crops [16]. 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 the GM technology. However, the Ministry of Health placed a ban in 2012 on the development and cultivation of GM crops [17]. The ban lasted for seven years and with the government direction, the cultivation of GM crops in particular the Bt cotton started in 2020 [18]. However, in 2022 the Government has lifted the ban on GMOs allowing for cultivation of GM crops. Despite evidence on many projects from different research institutions geared to improve the indigenous crops, lack of required expertise and funds limit their implementation [19]. Currently, at least six GMO projects have been approved for research by National Council of Science and Technology, National Biosafety Authority, Kenya Plant Health

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Inspectorate and National Environmental Management. They are under confined field trials while others are in various stages of application. The main stages under biotechnology include; research and development, contained research, confined field testing and commercial production. Some of the GMOs 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 rinder pest vaccine, while GM crops can be more resilient to climate change and/or provide greater output, anecdotal evidence point some negative socioeconomic consequences, such as high cost of seeds especially for small holder farmers and undermining biodiversity. The effects of GM crops in Kenya are yet to be seen.

1.2. Antibiotics in livestock production

Sustainable food production is becoming critical to ensure food and nutrition security for all. Some of the solutions that can afford to boost sustainable production particularly in agriculture and livestock include use of antimicrobials [20]. Globally, antimicrobial resistance has been recognized as one of the emerging threats to public health [21]. 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, decline in livestock production, poverty, hunger and malnutrition [22,23,24]. 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 [25]. 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 [26]. In addition, in response to the AMR threat, investments such as the UK Fleming Fund have been established to improve the AMR surveillance through the One Health approach and provide evidence for development of appropriate policies and interventions. Kenya is one of the countries that agreed to initiate a national action plan on 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 90percent of these deaths being reported in Africa, Asia and South America. Around 75percent of all antimicrobials are used in animal agriculture. In developing countries, the use of antimicrobials is often unregulated [27]. 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 are projected to increase than in developed countries. Prominent and direct effects of antimicrobials include increased mortality, high morbidity and economic losses [28]. 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 a post COVID scenario [29]. Therefore, it is crucial to address antimicrobial resistance to achieve sustainable development goals associated with poverty and hunger alleviation and improvement of health and economic growth [30]. 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 regards 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 are 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 effort is to minimize 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 [20,31]. These needs strengthening of surveillance or AMR hotspots, training of stakeholders, support of research and innovations, and incentivizing stakeholders to transform 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 antibiotic resistance in livestock and is therefore facing a number of factors that impact the food security of its population. Two new national initiatives on technologies to address food insecurity have been observed including the lifting of a ban on using

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GM crops and a One Health policy plan to regulate the use of antibiotics. This makes this study and its foci are extremely timely and the findings can facilitate policy impact. Nevertheless, research on technological risk governance in most African countries remains nascent with no 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 GM crops and use of antibiotics in livestock pro-duction, the main objectives of this study were twofold; to establish the current status of food innovations for foods security particularly on GMOs and antimicrobial resistance; and determine the knowledge, attitudes and practices on food innovations particularly GMOs and antimicrobial resistance and influence by governance on innovations.

2. Materials and Methods

The study focused on two technological risks in the context of food security in Kenya, specifically the loss of biodiversity and social economic consequences of the introduction of GMO crops and the rise of antimicrobial resistance as a result of the over- and misuse of antibiotics to combat communicable diseases in crops and livestock.

The main research question was: How can and should innovations and technologies for food security be responsibly governed? By addressing this question, this study aimed to influence 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 were interviewed who are knowledgeable in GM technology and Antimicrobial Resistance using a structured questionnaire. In addition, comprehensive literature review was conducted.

2.1. Methodology for quantitative data collection

The primary sources for this review were the electronic databases such as Elsevier, PUBMED, EMBASE and Web of Science. In addition, government reports for 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, term truncation and limiting to specific fields. The results were compared and checked against articles known to be relevant for the review. Publications were searched with the search terms "genetically modified foods/GMO" or "antimicrobial resistance/AMR" or its synonyms or subgroups (e.g., governance, technology, innovations, resistance, risks, policy). Related reference to food safety, toxicities, or plant and human health effects by surveys were also considered in the review. All publication results particularly abstracts were stored using the literature data management software Zotero that is effective in managing references, abstracts, and full-texts including checking for duplicates. The bibliographic reference lists of included journal articles and reports as well as citation tracking were verified in the selection and extraction procedure of the review. A MS-Excel sheet was created for the data extracted and reviewed independently by three scientists. In addition, secondary data was used.

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2.2. Methodology for qualitative data collection

2.2.1. In-depth Interviews

A total of 55 in-depth key interviews were conducted using respondents who were selected to participate in the survey. The respondents were technical specialists drawn from public institutions, private companies and research organizations. All the respondents were knowledgeable in GMO and AMR technologies and their inputs have assisted in the advancement of food innovations that are geared towards achieving food security in the country. The interviews determined the knowledge, attitudes and practices on food innovations particularly GMOs and antimicrobial resistance and influence by governance on innovations. The study also elucidated the perceptions of participants on the safety and ethics of GMOs compared with foods with no GMOs. 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, a score of 1 to all correct answers and 0 to all wrong answers was assigned, and an aggregate score was calculated (range 0 - 14). Higher scores indicated more knowledge about AMR. To measure attitudes, the key informants rated the perceived risks of AMR to farmers and perceived tendency of 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 perceived tendency of its misuse was measured on a scale 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 government and non-governmental). Practices were measured on a 1-3 scale (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 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/AMR theme and was cross-checked with all members of the research team to gain consensus, consistency, and result validity. Once the themes and associate sub-themes were determined, a perspective theme mapping was created to illustrate the inter-relationships between themes and subthemes. Data was then analysed 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 analyzed thematically using NVivo 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 on GM foods

The respondents were asked the definition of GMO foods and whether they agreed/disagreed with the following definition of GMOs. Results indicate that 50% strongly agreed with the GMO 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 (WHO). 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 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). Generally, half of the respondents agreed to the definition, 46% did not know exactly what GMOs were and about 4% of the respondents disagreed to the definition. The right answer was given a score of 1 whiles the incorrect answer and those who answered "Don't know" attracted a score of zero. The knowledge score then ranges between 0 and 1. The results show an average knowledge score of 0.5. This implies that only half of the respondents had accurate knowledge of GMOs. About 79% of the respondents indicated that food with GM ingredients were being consumed in the country. The main foods with GM ingredients include maize, rice, beef, cassava, soya bean products and corn products (corn flakes, biscuits). In addition, there are animal products such as milk, beef from animals fed with animal feeds containing GM ingredients such as soya beans.

Further, the study examined the sources from which the respondents heard about GMOs. The results revealed that schools and colleges were the major sources of information about GMOs since majority (71%) respondents heard about GMOs from these sources. The media was the next most important source of information about GMOs given that about 64% of the respondents got information about GMOs from this source. Campaigns about GMOs are proving to be effective since about 36% of the respondents heard about GMOs through this source. The results are presented in Table 1.

Table 1. Major sources of GMO and AMR information and sectors represented.

Source of information	Percent cases GMO (%)	Sectors for AMR (%)	Percent (%)
School/college	71.4	Human Health	11.1
Media (newspaper, TV, radio)	64.3	Animal Health	48.2
Specific campaign	35.7	Plant Health	14.8
Family member or friend	17.9	Food Production	22.2
Extension worker	17.9	Food Safety	29.6
Others (workshops, projects)	17.9		
Agrovet shop	10.7		
Can't remember	3.6		

3.2. Main uses of GM foods

The respondents strongly agreed that GMO 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. They however strongly disagreed that GMOs can support in the production of cheaper foods.

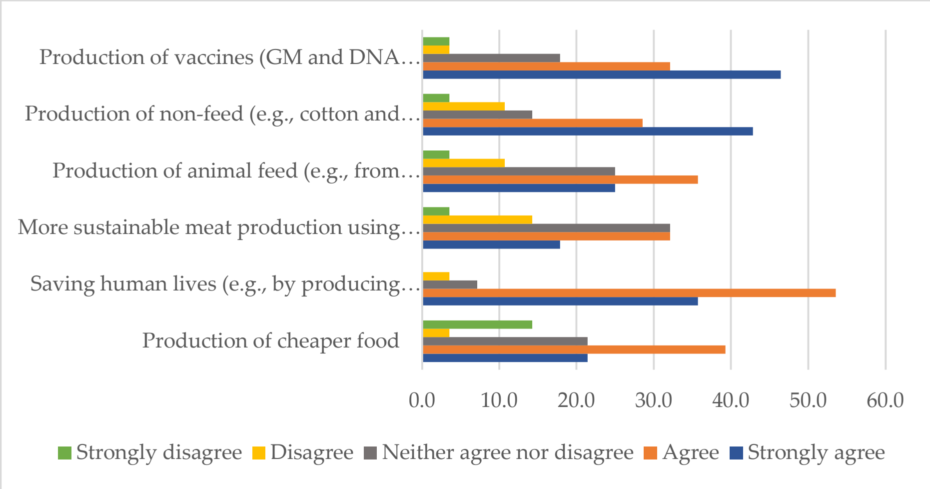

Figure 1. Major uses of GM foods in Kenya.

3.3. GMO Innovations and Food Safety

The findings showed that approximately, 79% of the Kenyan population reported that GMO foods are already being consumed in the country. The main food safety issues with GMOs included immune suppression, transfer of toxicity, antibiotic resistance and transfer of allergenicity. The perceptions of safety of GM foods show that compared with foods without GMOs, foods with GMOs are generally neither better nor worse (Table 2). This is reflected in the belief of majority of the respondents that compared with foods without GMOs, GMOs are neither better nor worse in terms of transfer of antibiotic resistance (39%), transfer of toxicity (43%), transfer of allergenicity (36%), cancerous (36%), immune suppression (43%) and loss of nutrition (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 on how GMO can potentially increase one's chances of getting other non-communicable disease besides cancer. According to one respondent "*GMOs foods are not safe as they can make one get non-communicable diseases like diabetes, hypertension, blood pressure*". The significant neutrality of respondents shows their level of indifference and that their only main concern is the possibility of getting some chronic diseases when GMOs are consumed by humans. Some of the fears that GMOs can be cancerous were backed by some scientific research which respondents were exposed to.

Table 2. Perceptions on safety of GMOs.

Safety of GMO	**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%)
Transfer of 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	4 (14%)	9 (32%)	5 (19%)	6 (21%)	4 (14%)

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3.4. GMOs and Environmental Safety

The environmental issues reported included loss of diversity, contamination due to gene flow from GM crops to wild and weedy crop relatives, non-GM crops and foods and the development of Herbicide-Resistant Weeds "super weeds". On whether GMOs are environmentally safe compared with foods without GMOs, the 29% of the respondents reported that GMOs are much better in terms of herbicide use while 35% reported that GMOs intensifies contamination while 32% reported that it con-tributes to loss of biodiversity. About 25% of the respondents reported that GMOs could be worse, better or neither better nor worse in terms of the development of insect-resistant crops "super bugs". 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, long term effects not yet conclusive as we stand exposed to unknown future compromising in health. Loss of biodiversity is a sure practice which will set in the agricultural production. Most GMOs crops have stopper genes incorporated which will automatically lead to reliance of corporate for planting materials. Might lead to invasive species which might dominate the indigenous species"*

The uncertainty of the respondents seems to be based on speculations and fears of the damages that GMOs could cause to the environment.

Table 3. GMOs and Environmental Safety

GMO and environmental safety	**Frequency and percent (%)**				
Classification statements	**Worse**	**Neither better nor worse**	**Better**	**Not sure**	**No Answer**
Increased herbicide uses	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%)

3.5. Ethics and GMO innovations

The results revealed that GMOs are generally not perceived as ethical as majority of respondents reported that it can harm the environment, human health, have adverse effects on traditional farming practices, lead to excessive corporate dominance and is generally unnatural. Categorically, on 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 while 39% indicated that they 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". The main ethical issues with GM foods that were reported included corporate dominance; negative impacts on traditional farming practices; and potential harm to the environment.

Table 4. Ethics on GMOs as compared to other non-GM foods.

Ethics and GMO	**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%)
"Unnaturalness" of technology	7 (25%)	9 (32%)	2 (7%)	5 (18%)	5 (18%)

The study analyzed how GMOs relates to people's beliefs. The results show that GMOs are not against the religion of majority of the respondents (Table 5). The respondents further disagree that GMO has anything to do with God (50%). Also, a majority of the respondents were either neutral or disagreed 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 agree that GMOs are tampering with nature, they do not believe that makes it unacceptable. One respondent in the qualitative responses believed that: *"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, unnaturalness of technology"*. The ethical arguments on GMO foods show some strong ethical arguments expressed in the study. About 25% of the respondents strongly agreed that GM produces food products that are being forced on developing countries by developed nations while over 40% of the respondents strongly disagreed that GM technology is not an ethically acceptable method for medicine production.

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Table 5. Ethical Arguments and Ethical Considerations on GMOs.

Ethical arguments on GMO	**Frequency and percent (%)**				
Classification statements	**Strongly Agree**	**Agree**	**Neither agree Nor disagree**	**Disagree**	**Strongly disagree**
GM technology is against my belief/religion.	2 (7%)	2 (7%)	10 (36%)	7 (25%)	7 (25%)
By using GM technology, we are "playing God".	4 (14%)	2 (7%)	8 (29%)	6 (21%)	8 (29%)
GM technology is not acceptable in animal production due to animal welfare concerns.	2 (7%)	5 (18%)	9 (32%)	4 (14%)	8 (29%)
GM technology is not ethically acceptable in food production.	1 (4%)	6 (21%)	6 (21%)	8 (29%)	7 (25%)
GM technology is not an ethically acceptable method for producing animal feed.	1 (3%)	7 (25%)	7 (25%)	5 (18%)	8 (29%)
GM technology is not an ethically acceptable method for medicine production.	0 (0%)	3 (11%)	6 (21%)	7 (25%)	12 (43%)
Using GM technology is "tampering" with nature i.e., "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. Ethical issues that limit adoption and use of GMO technologies

The ethical arguments on GMO foods showed some strong ethical arguments expressed in the study (Figure 3). About 25% of the respondents strongly agreed that GM technology produces food products that are being forced on developing countries by developed nations while over 40% of the respondents strongly disagreed that GM technology is not an ethically acceptable method for medicine production.

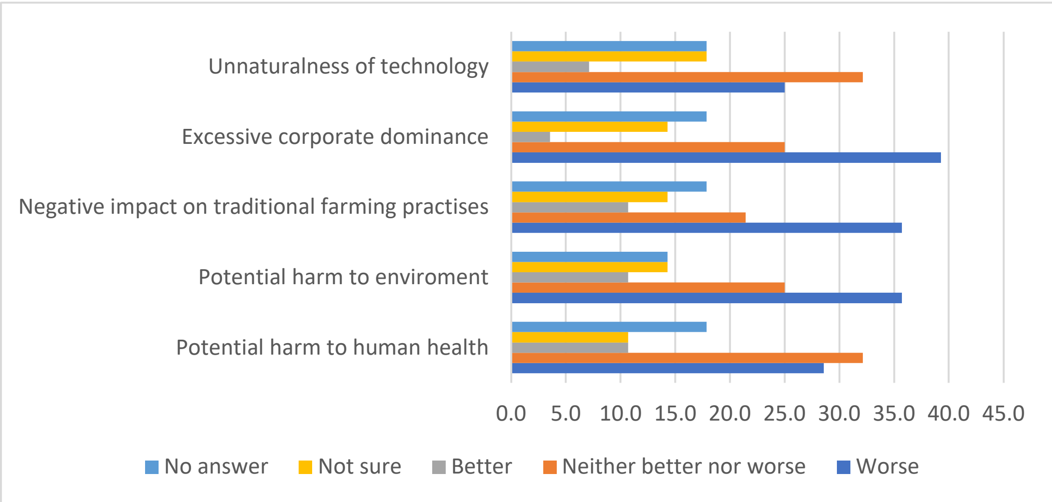

Figure 2: Ethics on GM foods

The main ethical issues with GM foods include corporate dominance, negative impacts on traditional farming practices and potential harm to the environment (Figure 2). The perceived threats ranged from the integrity and intrinsic value of the organisms involved; concept of natural order; and integrity of species used in GMO technology. Perception that people reported included that use of hormones in development of GMOs crops can impact the health of individuals; the permanent risks of destroying the original and uniqueness of various animal products and food products which may in return cause harmful environmental and human problems; lack of clear information; perceived secrecy in the GMOs issue by scientists thus lack of openness; lack of honesty in the part of the scientists to the citizenry; and inequality of information sharing which showed that they do not value the final consumer or clients who eventually consume the GM foods.

3.7. Food security and GMOs innovations.

The results show that majority (64%) of the respondents agree that GMOs are a solution to food security in Kenya. Most respondents perceived that GMOs will increase food production by providing more food reserves; reducing post-harvest wastage and losses; and reduce the cost of production as Gm crops are more resistant to diseases and pest infections. The few respondents who were opposed to GMO technology cited examples of negative impact on the 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 GMO food production and marketing to ensure that 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. Majority of the respondents (54%) reported that farmers and consumers do not have a voice when it comes to 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 on 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 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 potatoes. These crops are prone to pests and viral diseases thereby exposed to heavy use of chemicals which results in high chemicals residues in human food posing a bigger threat to food safety. The results also show that 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 the GMO crop production. One of the major finding was the fear by farmers with regard to potential elevated costs of production of GMOs and scarcity of the seeds in future as the GMO technologies are patented and therefore cannot be reproduced. Most of the respondents expressed concern about the ease of access of the 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 GMOs foods.

Table 6. Frequency on Perception (percent) on GMOs.

Perceptions on 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

3.7.1. 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. The results show that majority of respondents agree that GMOs will contribute to an increase in the global food supply. Similarly, majority of respondents agreed that GMOs will make food affordable. About half of the respondents agree that GMOs will lead to the production of more nutritious foods. However, the farmers will have to regularly rely on seeds from biotechnology companies. This could lead to reduced use of traditional seeds especially for food and cash crops. Whereas most of the respondents agree that GMOs can produce crops more resistant to pests and reduce pesticides use on food crop plants, majority of them do not agree that GMOs improves shelf life or enhances taste in food. Some respondents noted that GMOs crops will make the health of farmers and public worse because of food safety issues while at the same time making them poorer. The perception was that the cost of GMOs seeds will keep increasing as the farmers would have to purchase seeds every planting season as GMOs seeds cannot be re-planted from the previous season unlike traditional seeds. GMOs also require purchase of expensive synthetic fertilizers as farm inputs to grow, further increasing famers input costs. Since the seeds are patented and can only be used per season, farmers have to buy seeds each season making it difficult to adopt because they have always saved and banked best seeds for each planting season. Intellectual property rights are likely to be an element in the debate in GM foods with an impact on the right of farmers. Majority of the respondents agreed that GM foods can reduce the use of pesticides on foods crops and make crops more resistant to pests and ultimately increase the global food supply.

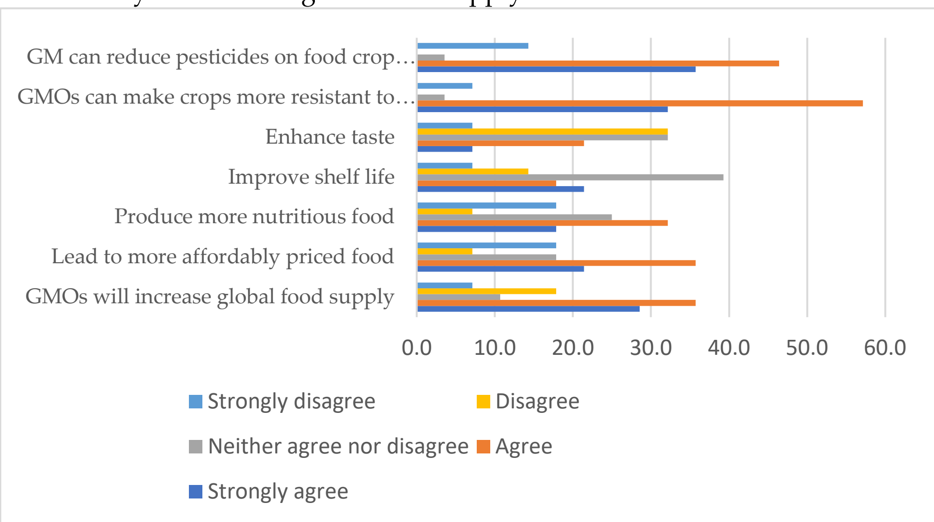

Figure 3. Positive effects of GM foods as perceived by respondents towards food security.

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

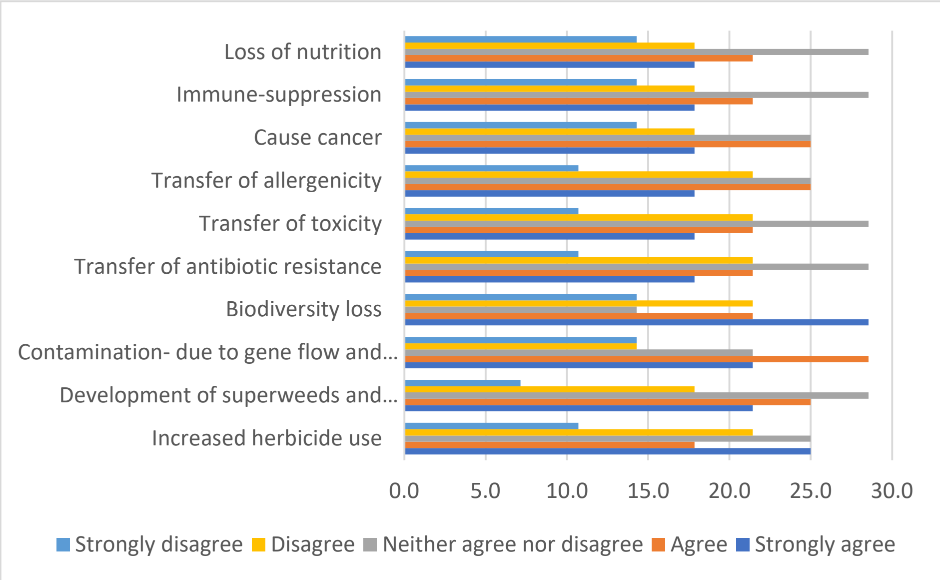

Figure 4. Negative effects of GMOs towards food security.

3.8. Policy, legal and regulatory framework on GMOs

About 60% of the respondents indicated that Kenya has adequate legal and regulatory framework to ensure research on and commercialization of GM foods is conducted in a safe and responsible manner. Further Kenya is a signatory to the biodiversity convention and Cartagena protocol that govern global adoption of GMOs. GMOs are regulated by the National Biosafety Authority nationally. Scientists and elected leaders have a major role on policy issues related to GMOs. The science 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 majority of the respondents reported that scientists (71%) and elected officials (50%) have greatest role in 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 have not too much role to play in the governance of GMOs.

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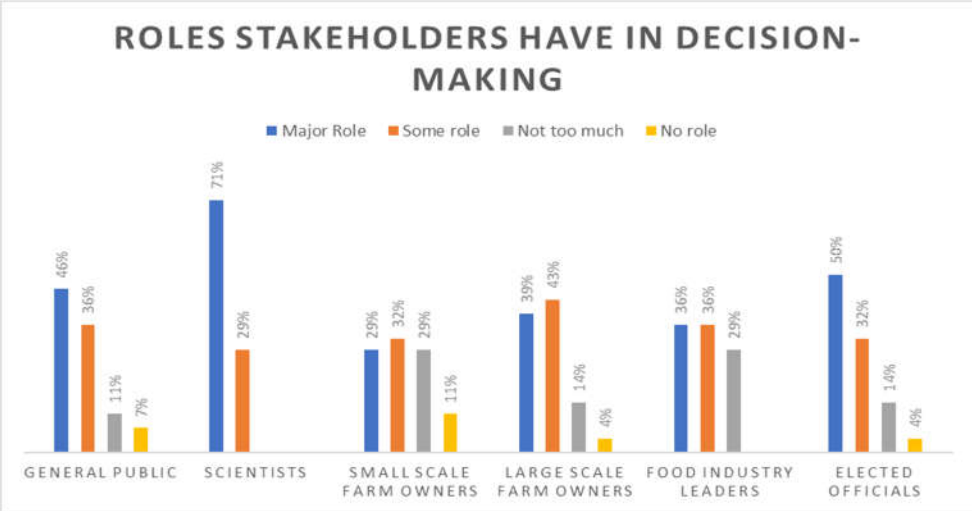

Figure 5. Stakeholders roles in policy issues related to GMOs.

The results show considerable support 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 on its nutritional and ability to solve national food security issues.

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

Statement 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 Food Innovation.

4.1. Awareness of AMR and sources of information about AMR food information.

The respondents noted that the media was the predominant source of information about AMR. The results also revealed that campaigns about AMR and the veterinary doctors played significant roles in creating awareness of AMR. With regards to awareness of AMR risks and human health, the findings show that some of the participants were aware of AMRs (27%). This could be attributed to the level of campaigns and publicity about the existence of AMRs in Kenya. On farmers' awareness of AMRs, the study revealed that farmers barely knew about AMRs (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 AMRs.

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 no longer work as well. All of the respondents correctly answered that it can affect their family, make medical procedures dangerous and can be difficult or impossible to treat infections caused by antibiotic resistance. A notable number of the 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 touch or use unclean surfaces and don't wash your hands or clean surfaces.

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

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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 faeces.	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 don't wash your hands.	93	7
You can become sick with bacterial infections that are resistant to antibiotics if touch or use unclean surfaces and don't wash your hands or clean surfaces.	85	15
Antibiotics widely used in the country for food production.	96	4

The respondents perceived the use of AMRs to be associated with a "large level of risk" (score 2) (*M* = *1.85, SD* = *1.06).* All perceptions about tendency of AMRs misuse were either high or moderate (score 3). Categorically, the propensities of AMRs being misused in an attempt to prevent disease is high (*M*= *3.89, SD* = *1.84*), and to enhance growth (*M* = *3.37, SD* = *1.47*), treat clinical disease (*M* = *3.15, SD* = *1.20*) and to use it as therapy (*M* = *3.33, SD* = *1.41*) are moderate. The reasons for the possible risk associated with the use of AMRs above are strongly reflected in the qualitative responses. For the reason that it is mostly misused in an attempt to prevent diseases, most respondents reported that farmers tend to abuse antibiotics because of its ability to treat a broad spectrum of bacteria and other infectious diseases as well as its ease of access in the market (Figure 6).

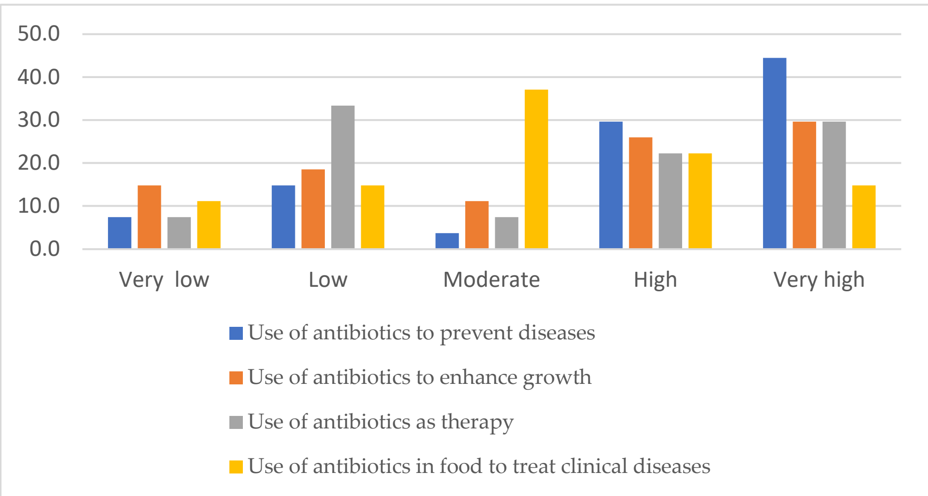

Figure 6. Misuse of antibiotics in use of AMR as a food innovation.

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Other reported risks of high resistance of antibiotics were how respondents mentioned that a few farmers use it 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 AMRs for disease prevention thereby posing a large level of risk for 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 should not keep antibiotics and use them later for 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 do not know if government and companies should produce more antibiotics. The respondents did not report that medical experts will solve the problem of antibiotic resistance before it becomes too serious (*M = 2.33, SD = 0.68*), that there are not more people like me who can stop antibiotic resistance (*M = 2.96, SD = 0.19*) and that they are not at risk of getting an antibiotic resistant infection, as long as I take my antibiotics correctly. The respondents agree that antibiotic resistance is one of the world's biggest problems (*M = 1.07, SD = 0.27*) and that they are worried about the impact that antibiotic resistance will have on their health, and that of their family (*M = 1.0, SD = 0*). Given the 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 also to prudently use antibiotics. The above results indicate the level of knowledge of respondents on the abuse of AMRs by farmers and the best practices that could be put in place to control the potential effects of AMRs on food production in the country.

Table 10. Knowledge, attitudes and practices on AMRs.

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

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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 response in human health is relatively limited as majority (55.6%) of the respondents have only seen little or small-scale awareness campaigns. This case was similar in the Veterinary sector as majority (40.74%) of the respondents claim that antimicrobial resistance awareness campaign targeting some but not all relevant stakeholders within sector is limited or on a small-scale.

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

Statement raising awareness on AMR risks	**Frequency**	**Percent (%)**
1. Statement 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 campaign targeting some, but not all, relevant stakeholders (e.g., general public, pharmacists, nurses, medicine sellers)	15	55.56
Nationwide, government-supported antibiotic awareness campaign targeting all or the majority of stakeholders.	2	7.41
2. Statement raising AMR risks in other sectors like Veterinary		
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 campaign targeting some but not all relevant stakeholders within sector.	11	40.74
Nationwide, government-supported antimicrobial resistance awareness campaign targeting all or the majority of relevant stakeholders within sector.	2	7.41
Focused, national scale government supported activities implemented to change behavior of relevant stakeholders within sector, with	1	3.7

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monitoring undertaken of their awareness and behavior change over last 2-5 years

On 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. Reduction of AMR through Sanitation.

Reduction of AMR by Sanitation	Frequency	Percent (%)
No responses	2	7.41
A national Infection prevention and control (IPC) programme 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 programme 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 programme 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

On good health management systems, about 41% of the respondents believe 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.

4.3.1. Optimizing antimicrobial use in human health, animal and plant health sector.

On 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 its appropriate us. 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 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. Optimizing antimicrobial use in human health, animal and plant health sector.

Optimizing antimicrobial use	Frequency	Percent (%)
1. Statement on optimizing AMR use in human health sector		
No response	3	11.11
No/weak national policy & 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. Statement on optimizing AMR 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

On the country use of policy, most of the respondents reported that the country has regulations on 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 prescription and sale of antimicrobials, including requirements for prescriptions for human use. Further, 15% reported that country does not authorize use of human and animal critically Important antimicrobials for growth promotion.

5. Discussion

This study highlights 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 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). GMOs food may offer solutions to the many problems that farmers experience thus increasing food availability and quality of the food. GMOs technology offers opportunities for breeding for plant diseases which in normal cases will have taken years. The rapid growing population needs food and the current food production methods might not be able to meet the needs of the country. Use of GMOs foods provide the possibility to overcome losses as a result of insects and pests. The cost of labour for weed control has continued to increase as the labor movement is global and urbanized. The use of herbicide tolerant crops is important for Kenya today and especially for field crops. However, some respondents reported that GMO foods are not the ultimate solution but supplement the pressure on food security in Kenya and Africa against the increasing population. GMOs deprives seed sovereignty, seeds sharing, seed saving which many rural farmers practice. Kenya and Africa require investments in Agriculture to support irrigation, training of farmers on GAP and market access for their produce. In most developing countries, the demand for food surpasses the agricultural production due to poor and unsustainable agricultural practices and environmental degradation [32]. GM foods can contribute to increased food production and quality as well as increased incomes to farmers affording them the resources to buy more quality food [33]. In Africa, GM foods are increasingly being used to boost food supply. As of 2018, the GM market value was estimated to be USD 615.4 million and projected to increase to USD 871 million by 2025 [34]. 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. Recently, Nigeria, has adopted two GM crops including cowpea and pest resistant bt cotton [35]. In Kenya, applications for commercialization of GM crops including Bt maize and water efficient maize for Africa are still in field trials except for the Bt cotton which was commercially released in 2020 for adoption by farmers [16].

GMO food innovation and governance

About 46% of the respondents indicated that farmers have a voice in the production and sale of GMOs in the country through National Parliament and Farmer advocacy groups like Cereal Growers Association of Kenya all recognized by law. This is also through representation in the Board of the National Biosafety Authority (NBA) and also through public participation as contemplated in the Act. Before GMOs are released for planting or selling to public, forums are held for the public to give input. However, there is a feeling that farmers voices on traditional farming practices are quite weak. Half of the respondents (50%) indicated that consumers have a voice in the production and sale of GMO foods. Consumers play a vital role in food supply chain, if not involved they will not accept products that are not produced ethically. Public awareness is important to loop in the consumers. Consumers are concerned if the GMOs are significantly cheaper, have increased shelf life and better taste. Therefore, they have a voice. Consumers should made aware that products contain GM by ensuring they are properly labelled. The safety concerns and risks of the GMOs foods are the major reasons why GMOs foods are not well adopted by both the farmers and consumers**.** GMOs are assumed to be unnatural with unverified concerns that GMOs causes cancer and other diseases**.** Long term safety effects of consumption of GMOs foods is not clear yet. There is also inadequate public exposure to the benefits of GMOs foods as well as lack of adequate scientific research to support uptake of GMOs foods.

AMR innovations, risks and governance

Antimicrobials are active substances that can be used to prevent or kill microorganisms. They can also be used to increase the proficiency of the feed or as growth promoters [22, 23]. They include antibiotics, antivirals, antifungals and antiparasitics used as medicines used to prevent and treat infections in humans, animals and plants [36]. Currently, antimicrobial use in food producing animals is growing at an alarming rate. Global average annual consumption of antimicrobials in swine, poultry and cattle has been estimated to be at 172mg/kg, 148mg/kg and 45mg/kg respectively, and it is projected to increase by 67percent by 2030 to keep up with the growing demands of the increasing population. In the past, developed countries such as USA, China and Brazil were among the largest consumers [24]. However, the usage in developing countries has rapidly increased, where greater commercialization and intensification has necessitated the increase in antimicrobial use [37]. Notably, usage of antimicrobials in plants and aquaculture is predicted to increase as well. Increased usage has resulted in an increased risk of contamination food products with antibiotic residues posing a risk to consumers including the development of antimicrobial resistance [38]. It is increasingly making some infections in humans difficult to treat. Moreover, it has compromised animal production and destabilized food security. In most of the developing countries, levels of antibiotic residues above the recommended limits have been reported [2]. The developing countries are more susceptible due to lack of adequate monitoring programs to track antimicrobial use as well as poor detection facilities [10]. New antibacterials are immediately required for instance to treat carbapenem-resistant gram-negative bacterial infections as identified in the WHO priority pathogen list [36]. But these new antibiotics will befall the same fate as the existing ones and end up ineffective if there is irresponsible use and poor governance. In Kenya, AMR is rapidly becoming a threat to public health. Widespread presence of antimicrobial resistant microorganisms in poultry influenced by lack of responsible and prudent antimicrobial use has been reported [8]. Increasing trends in AMR in *Vibrio cholerae, Salmonella typhimurium* and *Staphylococcus aureus* have also been reported [39,40]. Despite knowledge and awareness of AMR among farmers along the food value chain and health care workers, utilization is lacking. Moreover, the existing framework on regulation of antimicrobial use is poor and weak [27]. In Kenya, a lot of effort has been directed towards prevention of antimicrobial resistance. For instance, various policies targeting antimicrobial resistance have been implemented. Also, media campaigns to create awareness on AMR have been done. 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.

Globally, antimicrobial resistance (AMR) is a serious public health problem that threatens the sustainability of an effective, global public health response to the enduring threat from infectious diseases. The systematic misuse and overuse of these drugs in human medicine and food production have put every nation at risk. Antimicrobial resistance is the capacity of a microorganism to resist inhibitory activity of an antimicrobial beyond the normal susceptibility of the specific bacterial species [41]. The authors also note that limited studies have verified the favourable niche for resistance development. Antimicrobial comprises any substance that has a killing effect on microorganisms. In the agrifood chain, antimicrobials are used for various purposes such as treatment of diseased animals, treating a group of animals to prevent infections (metaphylaxis) and also used during high susceptibility periods of infections (prophylaxis). Currently about 80percent of food producing animals get medication for most of their lives. Most commonly used antimicrobials in food producing animals are the β-lactams, tetracyclines, aminoglycosides, lincosamides, macrolides, pleuromutilins, and sulfonamides [42]. Antibiotic residue in foods may be harmful to the human health [43]. The use of antimicrobials in food producing animals may leave residues in foodstuff of animal origin such as milk, meat and eggs due to use of unlicensed antibiotics, contamination of feed with excreta of treated animal, extra dosage level for drugs and failure to observe the withdrawal periods. Antibiotics have also been used to promote growth especially in broilers and fatteners. In 2006, the use of growth promoters was banned in the EU. The benefits and risks of the use of growth promoters is still debated and prudent use of antibiotics and the establishment of scientific monitoring systems have been reported to be the best way to limit the adverse effects of the abuse of antibiotics, and ensure the safety of animal-derived food and environment [44]. Research indicates that provision of antimicrobials to livestock can result in the occurrence of antimicrobial resistance bacteria [42]. Current reports indicate high levels of antibiotic resistance in *Escherichia coli* and *Salmonella* among other bacteria [32,37]. Antimicrobial resistance may also lead to the selection of resistant veterinary pathogens like *Mannheimia haemolytica* which causes bovine respiratory disease [45]. Evidence shows that there is a correlation between antibiotic use in animals and the emergence of antimicrobial resistance in humans [46]. In farming environments antimicrobials can be detected as large proportion of those administered maybe excreted unmetabolised [47]. Antimicrobial use is not only confined in the terrestrial agrifood chain but also used in aquaculture [48]. The aquaculture industry has been associated with overuse of antimicrobials [49]. Fruits and vegetables can also potentially result in antimicrobial resistance. Since 1950s, antibiotics have been used to control bacterial diseases in vegetables, high value fruit and ornamental plants. However, their use is relatively small compared to animals [50]. Kenya has reported high levels of antimicrobial resistance. In the livestock sector, studies indicate that *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 two or three antimicrobials [51]. The mechanisms of resistance identified in bacterial agents *Staphylococcus aureus* and the *Enterococci* towards two priority classes of antibiotics, the fluoroquinolones and the glycopeptides is notable as well as 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 [52]. These infections are considered as public health problems of global significance.

6. Conclusion

From our findings, it's 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 as 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 for political action that involve comprehensive policy assessments that are cost-effectiveness 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 concerns of specific counties should be implemented. Recommendations on priority areas for research in AMR further are vital in addressing data gaps that can assist risk managers to implement the One Health Action plan against AMR.

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

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