

The legal aspect of the current use of genetically modified organisms in Kenya, Tanzania, and Uganda

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ABSTRACT

Many African nations place a high priority on enhancing food security and nutrition. However, unfavorable environmental conditions interfere with the achievement of food security in Africa. The production of genetically modified organisms (GMOs) presents intriguing possibilities for improving food security on the continent. In Africa, countries in the same regions have different GMO usage policies and laws. While some nations are updating their laws and policies to allow GMOs, others are still debating whether they are worth the risk. However, there is still little information available regarding the most recent status of GMO applications in Kenya, Tanzania, and Uganda. The current review summarizes the state of GMO applications for enhancing food security in Kenya, Tanzania, and Uganda. Currently, Tanzania and Uganda do not accept GMOs, but Kenya does. This study can assist governments, academics, and policymakers in enhancing GMO acceptance for boosting nutrition and food security in their nations.

ARTICLE HISTORY

Received 4 December 2022
Revised 20 April 2023
Accepted 26 April 2023

KEYWORDS

Africa; genetically modified;
GM crops; GMOs; Kenya;
Tanzania; Uganda

1. Introduction

One of the biggest problems facing humanity in the twenty-first century is food insecurity. Globally, over 800 million people are chronically malnourished, with Africa accounting for one-third of this population in 2017.¹ Despite having 25% of the world's arable land, the Sub-Saharan Africa (SSA) region produces only 10% of the world's agricultural output.² This may be a result of the problem of food loss and spoilage brought on by pathogenic microorganisms and pests.¹ Through agricultural biotechnology, genetically modified organisms (GMOs) offer ways to improve nutrition and food security.¹ Through breeding, agricultural biotechnology can raise the quality and yield of crops. The use of DNA markers to ensure accurate and speedy traditional breeding of animals and seeds has recently piqued the interest of many researchers.² Genetic engineering (GE) has been used to create genetically modified (GM) crops, opening the door to the potential transfer of advantageous genes to crops across species boundaries. Additionally, GE helps create crops with better quality or storage

capabilities, like higher vitamin A content³ and increased resistance to abiotic stress such as ultra-violet-B radiation.⁴ Reduced pesticide and insecticide use, the development of pathogen-resistant GM crops, the development of climate and drought-resistant crops, the development of crops with shorter harvesting times and higher yields, improved nutrition composition, decreased toxicology, and increased food security are just a few of the reasons why GM crops should be adopted in Africa.^{1,5} However, in recent years, East African countries like Kenya, Tanzania, and Uganda have largely been devoid of information about the use of these GMOs.

GMOs are defined as organisms (microorganisms, plants, or animals) whose DNA has been altered in a manner distinct from natural recombination or natural mating.⁶ DNA recombinant technology allows the transfer of genes from one organism to another unrelated organism.⁶ Farmers may benefit economically from the development of GM crops that are herbicide-tolerant, pest- and disease-resistant, and have

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higher nutritional value and yields.⁷ Despite the advantages, the adoption of GM crops in Africa has been slow and contentious.⁸ Although nine African nations among fifty four, including Ghana, Malawi, Sudan, Burkina Faso, Nigeria, Uganda, Egypt, South Africa, and Kenya, have recently conducted GMO field trials, only four African nations – Egypt, Burkina Faso, Sudan, and South Africa – had fully commercialized genetically modified crops before.⁷ Farmers in Sudan are growing GM cotton, and in Nigeria, GM cowpea (pod-borer resistant cowpea) known as SAMPEA 20-T was approved in 2019.⁹ Globally, there is a wide range in the attitudes of both the public and the government toward the acceptance of GMOs. For instance, GM technology is discouraged in Europe but promoted in the United States (US).⁷ Kenya, Tanzania, and Uganda are close neighbors and East African nations that have different views on the GMO issue. Tanzania, Kenya, and Uganda have been chosen for this study as representative East African countries due to their long history of sharing a variety of cultures, languages, and lakes.¹⁰ For instance, there is ongoing debate regarding Tanzania's compliance with GMO regulations, biosafety guidelines, and the existence of the regulatory system.¹¹ GM technology, product inspections, and laws have all received less stern enforcement in Tanzania.¹¹ The acceptance of GM products, however, appears to be handled differently in Kenya and Uganda. Since 2012,¹² the Ugandan government has failed to reach a consensus on a law allowing the use of GMOs. Nevertheless, GM bananas in Uganda showed in 2011 that they could reduce poverty, despite opposition from affluent urban consumers.^{13,14} Similar, Kenya is currently importing GM maize as a result of the severe drought that has affected East Africa.⁵ Kenya announced at the end of 2019 that Bt cotton is now being commercialized and that plantings would start in 2020.¹⁵ This occurred following Kenya's seven-year ban on GE crops.¹ Even though, farmers in Kenya have since revised their optimism and anticipate a successful transition to Bt cotton in 2020,¹⁵ there are numerous persistent rumors on the internet regarding the shifting circumstances surrounding the use of

GMOs in Kenya,^{16,17} Tanzania,^{18,19} and Uganda.^{20,21}

The disparities in how these nations view GM crops may be the result of expert ignorance, media hype, and exaggerated health risks, all of which raise the possibility of confusion and misinformation similar to that which has already been reported in other nations.^{22–24} As a result, there is a critical need to disseminate accurate information about the use of GM crops in these nations at the moment. Moreover, the destruction caused by locusts in 2020 in Eastern Africa, which consumes enough food to feed 35,000 people for a day, calls for the adoption of new technology, such as GE's development of GM crops that reduce crop loss due to disease and pests and improve nutritional quality, which is required to address food insecurity.^{25,26} Additionally, the population of SSA increased exponentially, necessitating a rise in the availability of cheap and healthy foods. Because of this, methods like GE "Gene Revolution" present exciting possibilities for ensuring food security in Africa.²⁷ Thus, for governments, stakeholder groups, farmers, researchers, and policy makers to fully realize the potential of agriculture biotechnology in enhancing the yield and quality of many economically significant crops in Kenya, Tanzania, and Uganda, it is essential that they are aware of the most recent developments regarding GMO applications in those nations. However, information on the use of GMOs in Kenya, Tanzania, and Uganda at the moment is scarce.

This review discusses the use of GMOs as it stands right now with a focus on Kenya, Tanzania, and Uganda in East Africa. In this study, the disparities between the three countries' current GMO regulation policies and laws were compared (Fig. 1). According to the study, Tanzania and Uganda should think about adopting GM crops and legislation to improve food security, as recently demonstrated by Kenya. In addition, this study suggested gene editing methods like clustered regularly interspaced short palindromic repeats (CRISPR)-associated endonuclease Cas9 (CRISPR/Cas9) as potential approaches to change and eradicate a crop's undesirable traits with the least amount of public opposition and biosafety concern. Such information is essential for promoting biotechnological development and GMO

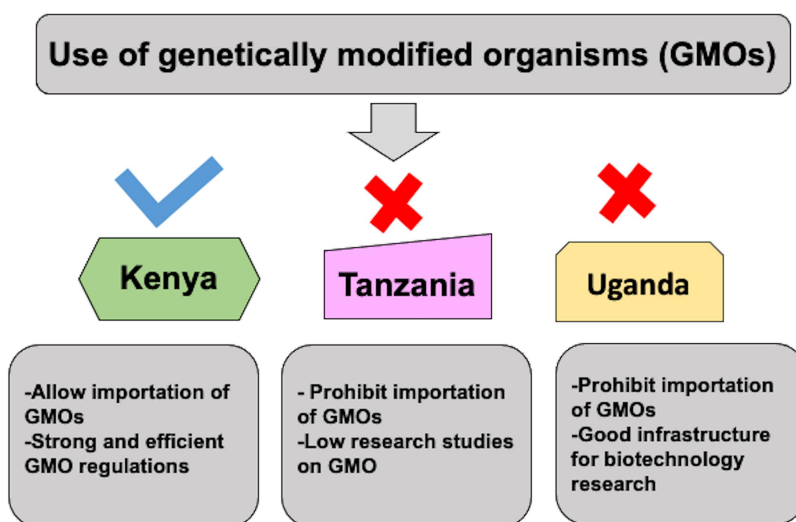


Figure 1. The current state of using of genetically modified crops in Kenya, Tanzania and Uganda.

acceptance in Africa. This study's findings will clear up misconceptions and promote acceptance of GM technologies, which have the potential to boost crop yields in East Africa.

2. The Current State of GMO Use in Kenya

A consistent increase in the number of hectares of biotech crops being grown in developing nations was shown by James et al. four-year's analysis (2012–2016); this increase exceeded the 14.1 million hectare difference between industrialized and developing nations.²⁸ Future trends may even surpass this difference. Why should we remain silent in the face of widespread malnutrition and hunger in Africa and instead of using the cutting-edge technologies like GMOs to partially address the issue? Global Hunger Index (GHI) data from 2000 to 2022 show that many African countries that were slow to adopt GM technology, such as Tanzania and Kenya, had higher GHI than those that were quick adopters, such as Egypt and South Africa. The GHI was even higher in the resister nations, such as Zambia (Fig. 2). New methods or approaches are therefore urgently required to address Africa's malnutrition and hunger issues. Kenya has imported GM maize to make up for the

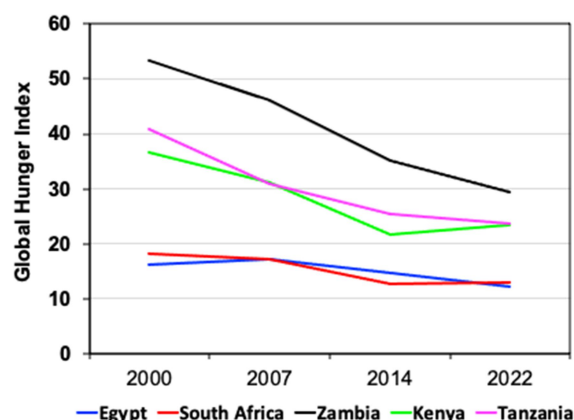


Figure 2. The global hunger index of selected African countries from 2000–2022. Egypt and South Africa serve as examples of early adopters of genetically modified crops in Africa, while Zambia serves as an example of a resistance group and Kenya and Tanzania serve as examples of East African nations⁶². Source: <https://www.globalhungerindex.org/ranking.html>

shortage of maize as a result of the severe drought in East Africa.⁵ Only Kenya has commercialized GM crops to address the issue and increase food security,^{16,17,20} even though other East African nations like Tanzania²⁹ and Uganda³⁰ are also affected by drought stress. The current use of GMOs in Kenya, Tanzania, and Uganda, however, is largely unknown. Understanding the current situation concerning the use of GMOs in these nations is crucial. With the help of this study, you will have access to the most recent

information on the use of GM foods and products in Kenya, Tanzania, and Uganda and potential ideas for boosting the acceptance of these GM techniques in Africa.

According to Kenya's "Vision 2030," the goal is to achieve middle-income status by using the agricultural sector as a key engine for economic growth with an annual growth rate of about 10%.³¹ According to recent reports, Kenya has been added to the list of nations that accept GMOs.¹⁷ The national biosafety regulatory authority was established in Kenya after a biosafety policy was passed in 2010.² Kenya was one of the first African nations to sign the Cartagena Protocol on Biosafety in 2002. Additionally, it is the first nation in the world to consider requiring GM cassava crops for environmental release, and many other crops are undergoing various stages of regulatory approval.² Two crops, the Bt cotton and the enhanced cassava variety for CBSD tolerance have been approved for commercial use in Kenya as of 2020. A total of 36 applications for various crops have been made for the year 2021, and they are still being examined.³² Additionally in 2021, the National Biosafety Agency (NBA) authorized the release of GM cassava containing Event 4046.³² Strong and efficient GMO regulations are in place in Kenya to control the labeling, environmental release, export, import, and contained use.³³ This may be attributed to the Kenya NBA board's appropriate training, which gave them sufficient knowledge of the regulatory process for genome-edited organisms and its results,³³ and recent research on the use of gene editing techniques in food and agriculture provides an advanced area for registration and regulation in Kenya.² Even though Kenya has made progress with GMOs, the rigid and time-consuming acceptance framework remains one of the biggest obstacles to GMO adoption.³⁴ Although Bt cotton has been commercialized and Bt maize is currently being tested at the National Performance Trials (NPT), there are still drawbacks to the commercialization process, including a lack of sufficient monitoring data for Bt cotton and difficulty obtaining credit to buy Bt cotton seeds.² Kenyans have a negative perception of GMOs as a result of the negative press and publicity surrounding GM products.³⁴

Though slowly, attitudes and perceptions toward GMO crops and products have changed on the continent, particularly in Kenya, as more people are becoming aware of the benefits of GMO technology.³⁴ This is in line with recent reports that Kenyan authorities approve the cultivation of GM crops to boost crop yields.^{2,16,17,20,35} Kenya is currently the only nation in East Africa that permits the cultivation and importation of GM maize for human consumption.³⁶ This comes after nearly 20 years of attempts to adopt high-yielding varieties. This has caused some confusion among the East African region's citizens. Tanzania and Uganda, for instance, have banned the official use and importation of GMOs, even though GM crops have already been tested in those nations.³⁶ Additionally, the biotechnological research conducted in nations like Burundi and Rwanda primarily relies on conventional methods and traditional biotech approaches rather than GE.³⁶ Given that only a short time has passed since Kenya formally approved GMOs, this study suggests additional research be done to keep evaluating the safety of the release of GM crops. Since Kenya, Tanzania, and Uganda share many commonalities, it will be crucial to establish harmonization soon about the use of GMOs in these nations.

3. The Present State of GMO Use in Tanzania

GM crops have been a contentious topic in Tanzania for more than three decades, even though this technology has been shown to have advantages elsewhere.^{28,37} Tanzanian scientists have suggested that CBSD, banana bacterial wilt, cassava mosaic virus disease (CMD), coconut lethal disease (LD), tomato leaf miner, and maize stalk borer are the issues that require the use of biotechnology.³⁷ But Tanzania lags behind Kenya and Uganda in terms of the number of studies that have been done on the perception, public understanding, and attitude toward agricultural biotechnology.^{38,39} This may be because individual perceptions in Tanzania are influenced by a variety of factors, including educational attainment, religion, age, occupation, rudimentary familiarity with science and technology, and marital status.³⁷ Lewis et al. investigated Tanzanians' attitudes toward GM food and crops and found that farmers were intrigued by the

prospect of utilizing GM technology to increase crop productivity for household income and food security.³⁹ The GM crops grown in Tanzania by February 2017 were cassava for the development of CMD and CBSD-resistant varieties, and maize for drought tolerance and insect resistance.³⁷ However, the newly appointed Tanzanian agriculture minister by that time Hon. Dr. Adolf Mkenda announced the end of research trials requiring GMOs in mid-January 2021.¹⁸ According to reports, the choice was made to protect Tanzania's genetic resources and native seeds.¹⁸ The current Tanzanian agriculture minister Hon. Hussein Bashe also recently expressed strong opposition to the use of biotechnology in food production in 2022.^{19,36} The minister even suggested strict measures to prevent the importation of GM foods or cash crops produced in nearby nations.³⁶ The fact that Kenya's government supports GMOs while the other nations oppose them and fight to secure their porous borders appears to be dividing all of East Africa. Nevertheless, the situation surrounding the use of GMOs in Tanzania is not constant and, like that of Kenya, may change in the future, depending on the extent to which the community has received the necessary education from molecular biologists, experts, and researchers. Tanzania currently permits biotechnological research trials, but only for academic ones. This allows Tanzania and its citizens to better understand the benefits of biotechnology and how it affects the environment.¹⁹ Tanzanian experts and biotechnology researchers have recently been tasked with providing the government with useful scientific advice to help improve the quality of people's lives using new technology.⁴⁰ Tanzania should adopt a proactive attitude by embracing cutting-edge technologies like GMOs for boosting food production, taking a cue from its neighbors Kenya and Uganda.

4. The Most Recent Situation Regarding the Use of GMOs in Uganda

In Africa, GMO research and performance were expected to be led by Uganda.⁴¹ The government of Uganda is currently having difficulty passing a law that would prohibit the use of GMOs,^{21,42} even though GM crops have already been grown

there and produced encouraging results^{43–45}; biotechnology has been gradually incorporated into Uganda's national development processes, and local capacity has been increased.² The Uganda national biotechnology strategy has identified biotechnology as a tool to address issues in the agricultural sector.^{20,46} For instance, GM bananas were demonstrated in 2011 to have a high potential for eradicating poverty in Uganda.^{13,14} Unlike Tanzania, the government of Uganda has provided the research infrastructure for expanding biotechnology research innovation and support to strengthen human resources.² Other organizations like the National Agricultural Research Organization (NARO) and Makerere University have also backed this.² About ten research laboratories for biotechnology research and development have been started thanks to the support of development agencies and the government. The Ugandan scientific community has shown a strong level of acceptance for R&D that uses genetic engineering tools and contemporary biotechnology.² To provide a regulatory and institutional framework for the sustainable and safe employment of biotechnology for national advancement, Uganda's government amended the Cartagena Protocol on Biosafety in 2001⁴⁷ and adopted the National Biotechnology and Biosafety Policy in 2008.² The Ugandan parliament introduced the GE regulatory bill in November 2018 to be amended into an act to guarantee a comprehensive biosafety regulatory framework for trading GM crops.^{2,47,48} This was a celebration of the long wait for the bill that permits extensive field trials and the release of GM crops for commercial purposes.⁴⁸ Yoweri Museveni, the president of Uganda at the time, was expected to sign the bill into law within a month because he has previously expressed interest in and support for it.⁴⁸ The Ugandan parliament did, however, just pass a law outlawing GMOs.²¹ The majority of the parliamentarians think that GMOs are not beneficial to Africa, that those pushing for their acceptance are only doing so for their reasons, that they could be harmful to biodiversity and even contaminate our organic food, and that better regulation of GMOs should be implemented before accepting them.⁴⁷ The lack of knowledge regarding biotechnology and biosafety, conjecture, the alleged

influence of biosafety entrepreneurs, and caution have all been put forward as reasons for the objection.⁴⁹

The first field test of GM crops was carried out in Uganda in 2007,² and it involved genetically modified bananas resistant to the Black Sigatoka disease. Moreover, there are currently 17 approved field research trials using a variety of GM crops for various crops and traits.² However, scientists are unable to conduct product testing on farmer's fields to evaluate the performance of GM products in Uganda due to the absence of national biosafety legislation and regulation.² The experience Uganda has had with GM technologies seems to be more political than technical.⁴¹ This could serve as a potent lesson for Tanzania and Kenya, among other nations in Africa. African nations should learn to delegate authority over scientific matters to professionals in those fields, not to politicians. This will allow the government to make decisions that are appropriate for its citizens based on their thorough understanding of the subject. But what if we could replace GE, which combines genes from different organisms, with new gene editing methods like CRISPR- /Cas9, which allow us to alter genes within an organism's genome? Can this method support the use of biotechnology to increase food security and ease regulatory and biosafety concerns in Africa?

5. The Current Application of Gene Editing Technologies in Africa

African plant breeding can benefit from the use of new breeding techniques (NBTs), such as genome editing (GE).⁵⁰ The CRISPR/Cas9 protocol has shown improved accuracy, adaptability, simplicity, amicability, and efficiency in the process of creating GM crops with less complicated biosafety regulations, among other GE techniques.^{51,52} This method has made it simple to make precise and site-directed modifications to the genomes of various plant species.⁵³ CRISPR/Cas9-edited crops have additional advantages over transgenic plants because the gene to be modified is in the plant DNA, in contrast to the transgenic approach, which results in random insertions and phenotypes.⁵⁴ Most significantly it has straightforward steps that make it possible

to carry out GE projects in even a small laboratory with a basic plant transformation setup, which is typical for several underdeveloped nations in Africa like Kenya, Tanzania, and Uganda.⁵¹ Through GE, crop plants can now be more easily adapted to changing environmental conditions and contemporary challenges.⁵⁰ The executive council of South Africa has included "NBTs" in a similar risk assessment framework as applied to GMOs established from the definition of a GMO in the South African GMO Act; NBTs are regarded as GMOs⁵⁰ although NBTs are different techniques from GMOs. Kenyan guidelines, on the other hand, are similar to those in Nigeria and are based on a case-by-case assessment based on the presence of transgenes, such as in situations where foreign DNA is absent and cisgenesis deregulation ("all knockouts or deletions").⁵⁰ Three of the five GE events that Kenya has already accepted demonstrate resistance to plant pests.⁵⁰ Eswatini and Burkina Faso have created their modern drafts while other African nations are still debating GE.^{55,56} *Oryza sativa* rice, which was produced by GE technology and resistant to bacterial blight, is the subject of experiments currently being conducted in Burkina Faso. In the future, other African nations will open their regulations like that of South American nations.⁵⁰ To produce varieties of cassava that are resistant to CBSB, Ugandan scientists recently conducted research trials using the CRISPR-Cas9 gene editing tool by inserting gene extracts into cassava cells.²⁰ Another area of concern for Ugandan stakeholders and scientists is the risk governance of GE-created gene-drive mosquitos for malaria prevention.⁵⁷ There is a lack of information on recent GE applications and research in Tanzania, possibly as a result of political unpredictability surrounding decisions regarding the use of GE products and a lack of interest from the government in these novel methods. The risk governance frameworks for GE organisms aim to stop the spread of added genes in the environment.⁵⁷ Despite the above advantages, this technique occasionally has unintended off-target effects that put genetically modified food crops at risk.⁵⁸ However, this issue can be reduced by using a more precise gRNA design

approach⁵⁹ and lengthening the protospacer adjacent motif.⁵¹ Other African nations may relax their regulations and use these new gene modification techniques as more research on their application and advantages in enhancing food security is published.

6. Discussion

In Africa, the GMO market was estimated to be worth USD 615.4 million in 2018 and was projected to grow by 5% by 2025 to reach USD 871 million.³⁵ The adoption of GM crops in Africa, however, has been gradual.⁶⁰ This might be the result of contentious policies in different African nations,¹ influenced possibly by political, social and business conditions.^{31,61} Numerous African nations showed varying reactions to the acceptability of GM technology. Schnurr group the tradition GM crops and their regulation in Africa by categorizing the regulatory response into the resisters (Tanzania, Zambia, and Zimbabwe) and the renegades (Sudan and Kenya), the emerging adopters (Uganda, eSwatini, Ghana, Malawi, Mozambique, Nigeria, Cameroon, and Ethiopia), and the early adopters (Egypt, Burkina Faso, and South Africa).⁶² According to data from GHI for 22 years ago (2000–2022),⁶³ the early adopters of GM techniques seem to have a low GHI compared to the resisters and the slow adopters, possibly because of the advantages of quick adoption of GM technology for the production of foods (Fig. 2).

Despite the absence of data from Uganda, Tanzania and Kenya's GHI data are still high when compared to Egypt and South Africa (Fig. 2). The slow adoption of GMOs in these nations, possibly as a result of political implications regarding biotechnology, may be the cause of the high GHI in those nations. For instance, Kenya approved the planting of Bt cotton in 2020¹⁵ following a seven-year GE crop ban.¹ Similar to Tanzania, the GM crops grown there were maize for drought tolerance and insect resistance and cassava for the development of CMD and CBSD-resistant varieties.¹⁸ However, the Tanzanian agriculture minister announced the end of research trials requiring GMOs in mid-January 2021. According to Schnurr & Gore,

Uganda's GM technology acceptance issues are more political than technical.⁴¹ The slow adoption of GM technologies in East African nations may make it more difficult for these nations, which are struggling with overpopulation, pest stress, insect infestations, and drought stress, to achieve food security.^{5,25,26} The highest GHI in Zambia, one of the African nations that opposes the adoption of GM crops, could also support the low food security brought on by resistance to accepting GMO foods (Fig. 2). Therefore, under the current climate change and global warming, nations that support GM crops have a better chance of producing more yield. Although there is currently no data available, the adoption of GM crops in Kenya could eventually lead to a decrease in the importation of maize,^{16,17,20} enhancing food security. This is because drought-resistant crops may grow to produce high yields even in the presence of drought stress.

Globally, Among the 26 nations that produced 190 million hectares of biotech crops over the past two years worldwide, 21 developing nations and five industrialized nations were included.⁶⁴ About ~54% grown by developing countries including India, Brazil, and Argentina, the top five countries with the extensive area of biotech crop cultivation; while industrial countries include countries such as Australia, Spain, Portugal United States, and Canada, growing ~46% of the of the total biotech crops.^{15,65} The first and largest producer of GM crops in Africa, South Africa, benefited from the development of GM crops earlier past decade,⁵ explaining the reason for low GHI from 2000–2022 (Fig. 2).⁶³ Farmers in developing countries benefited from the adoption of GM crops in 2010; this included three African countries (Burkina Faso, Egypt, and South Africa), where agricultural output increased by over 90% (14.4 million).⁶⁶ Although the limitation of adoption of GM crops in Africa could be due to different researchers arguments,^{67–69} environmental release approvals have current being allowed for GM cotton in Kenya, Malawi, Nigeria, and Ethiopia, and they have full commercialized in Egypt, Burkina Faso, Sudan, and South Africa.⁷ The rapid adoption of these methods and the elimination of disparities in Africa will be made possible by the coordination and harmonization of policy and biosafety

regulation for using GMO in all Africa nations. Therefore, it is crucial to coordinate the use of GM products across all East African nations because Kenya, Tanzania²⁹ and Uganda³⁰ share boundaries and local markets and are both affected by drought stress. The regulatory system and evaluation policy for GM crops in these nations may have low technical capacity in assessing the risk of GM products, which could be one explanation for the delay in the acceptance of GM crops in Africa. However, if confusion and false information are eliminated by proper education, as it has been shown in other nations, it might be possible for GM products to be accepted more readily in Tanzania, Uganda, and other African countries.^{22–24}

Future research in agricultural biotechnology in Africa ought to focus on enhancing the quality of indigenous crops that are crucial to their sizable domestic market and stay away from being impacted by the shock of the price of commodities globally. This is significant because domestic markets and agriculture are the mainstays of the economies of many African nations. Among the most significant agricultural products in Kenya, Tanzania, and Uganda are maize, coffee, and wheat.⁷⁰ Currently being tested as GM crops in these nations are maize, cassava, and cotton⁷¹ (Table 1). Adoption of GM crops resistant to drought in Tanzania and Uganda will increase yields and boost market trade between these countries because drought are affecting maize production in all of East Africa, forcing even Kenya to accept GM crops for improving food security in the country.^{16,17,20} For instance, using the maize variety known as Water Efficient Maize for Africa (WEMA), which was created in country partnerships with Kenya, Tanzania, Uganda, Mozambique, and South Africa to address insect resistance and drought tolerance,^{72,73} will increase maize yield production in these nations.

Table 1. The genetically modified crops development status in Kenya, Tanzania, and Uganda as of 2019.

Countries	Genetically modified crops
Kenya	Maize, Sorghum, Sweet Potato, Cassava, and Cotton
Tanzania	Maize and Cassava
Uganda	Maize, Banana, Cassava, Cotton, Irish and Potato

Source : (Gbadegesin et al. 2022).

6.1. Conclusion

This analysis focuses on how GM products and crops are currently being used in Kenya, Tanzania, and Uganda. Despite coming from the same region of East Africa, the three nations have very different views on genetically modified organisms (Fig. 1). Tanzania currently opposes GMOs, Uganda has even failed to pass a GMO bill and currently opposes them as well.^{2,16–19,21,36,42} Kenya accepts and supports GMOs. One of the main arguments put forth by those opposed to GM crops is the adventitious unintended negative effects of GMOs on the environment.⁷⁴ This may be the result of ignorance regarding biotechnology and biosafety, conjecture, purported influence from biosafety entrepreneurs, caution, and lack of planning on the part of the relevant government for maintaining these high standards.⁴⁹ The decision-making process by government authorities to fully approve the commercial cultivation of a GM crop is hampered by unstable political decisions in many African nations as a result of influence from Europe or the USA. Consider the continued import ban on GMOs in Kenya,⁷⁵ which was later modified and formally accepted in 2022,¹⁷ or the president of Uganda's refusal to ratify a biosafety act that had been approved twice by the Ugandan parliament.⁷⁶ Similar to Tanzania, which outlawed GMO research in 2021,¹⁸ the government sought scientists to inform the public about this technology in 2022 and restricted the use of GMO research to academic settings only.¹⁹ Some of the information reviewed here needs more careful thought and research, which is outside the purview of this paper. Nevertheless, food insecurity and malnutrition are major issues in African nations, and increasing agricultural production is crucial. GE and GEd technologies fill the gaps left by conventional farming techniques. GM crops can boost agricultural productivity, end hunger, and poverty, improve health, and increase food security.⁵

In conclusion, it is critical for countries in the same regions, like Kenya, Tanzania, and Uganda, to harmonize biotechnology regulation roles and implement an appropriate government monitoring system to advance their trade. Along with ensuring strict biosafety regulatory standards,

governments and citizens should be adequately educated on the benefits and drawbacks of using GMOs and gene-edited crops. Food insecurity on the continent is caused by the slow and hesitant adoption of GM technology by African nations, possibly as a result of unfavorable policies shaped by low public education and opinion on GMOs. To prevent this, the government, non-governmental organizations, community education, and other stakeholder groups responsible for GM technology in African countries must take an active role in advancing GM awareness at the grass-roots level and educating journalists and agricultural extension officers on the best ways to discuss GMOs and present the science.⁷¹ Facilitating genetic literacy between the public and politicians is therefore essential for eradicating the negative perception of GMOs. The information presented here will be crucial for policymakers as they work to hasten the adoption of GM crops in Tanzania, Uganda, and other nations. Adoption policies in support of GM technology will increase native crops' resistance to a variety of environmental factors, including salinity, pests, diseases, and drought, and will enhance local farmers' incomes as agriculture provides both food and income.

Acknowledgments

The author will like to thank UDOM for providing office space for research write-ups.

Disclosure Statement

No potential conflict of interest was reported by the author.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Author Contribution Statement

G.S.M: Conceived, designed, interpreted the data, and wrote the paper.

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