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Gene Modification Technology and Food Security in East Africa

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Abstract

Food insecurity remains a critical global issue, with about 30 percent of the world's population (2.4 billion) considered food insecure (moderate and severe). Food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". The four pillars of food security are availability, access, utilization, and stability, with nutrition considered an integral part of the food security concept. An estimated 600 million people will be food insecure in 2030. Food insecurity prevalence in East Africa remains high, despite the improved economic growth rates in Africa. Nearly half of the people facing hunger in Africa are in East Africa. Gene Modification Technology adoption has increased globally over the last 30 years and provided agriculture and food security solutions. However, in East Africa, their acceptance and adoption have been significantly low. Some concerns persist in terms of safety, ethics, and environment, among others, particularly the long-term effects. This paper examines the extent to which Gene Modification Technology has contributed to improving food security in East Africa. The exploratory research methodology and content analysis were used for this paper.

Keywords: gene modification technology, food insecurity, sustainability, innovation, sovereignty

INTRODUCTION

Food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006). The four pillars of food security are availability, access, utilization, and stability with nutrition considered an integral part of the food security concept (FAO, 2006). Food insecurity remains a critical global issue, with about 30 percent of the world's population (2.4 billion) considered food insecure (moderate and severe). About 600 million will be food insecure in 2030, indicating an immense challenge towards the Sustainable Development Goal (SDG) target of eradicating hunger by 2030 (FAO et al., 2023). Food insecurity prevalence in East Africa remains relatively high, despite the significant economic growth as compared to other regions of Africa (Africa Development

Bank, 2024; Ntiamoah et al., 2023). The major drivers of food insecurity include poverty, infrastructure gaps, climate change, conflict, and challenging economic situations (Abdullahi et al., 2024). Other major challenges to food security in the East African region include pests and diseases, which continue to affect livestock and crops, with traditional farming methods and technologies struggling to cope with some of the pests and diseases (Lokuruka, 2021). Despite hunger slightly reducing in East Africa between 2022 and 2023, nearly half of the people facing hunger in Africa are in East Africa (FAO et al., 2024).

Gene Modification Technology has provided solutions across various sectors, including the environment, industry, and agriculture, in solving some of the global challenges (Otim et al., 2023). Gene Modification Technology refers to laboratory-based techniques used to alter the Deoxyribonucleic Acid (DNA) of organisms (Otim et al., 2023). This DNA may either be synthetic (artificial) or collected from other organisms (Massel, 2023). In this paper, we will consider both Genetically Modified Organisms (GMOs) and those made through gene editing. GMOs are organisms (both plant and livestock) whose genetic material has been artificially altered by inserting a piece of foreign DNA while on the other hand, gene editing involves making precise changes to an organism's genome without the integration of foreign DNA elements (Massel, 2023). Unlike with GMOs, gene- editing introduces only minor modifications, which are indistinguishable from natural mutations (Massel, 2023). Some progress on Gene Modification Technology for food security has been recorded in East African countries (ISAAA, 2021). However, some concerns persist in terms of safety, ethics, and the environment, among others, particularly the long-term effects (Otim et al., 2023; Massel, 2023).

This paper examines the extent of contribution and adoption of Gene Modification Technology as a solution to address food insecurity among East African countries.

METHODOLOGY

This research used an exploratory research methodology, which often contributes to understanding topics that are under-investigated or not clearly understood, including new technologies. A secondary review was conducted on various literature by different authors on Gene Modification Technology and food security. The researcher assessed studies to cover the period 2015 to 2025 in scholarly websites, especially ProQuest, SpringerLink, and EBSCOhost. Additionally, the researcher also reviewed media articles, given the civil society and public interest in this topic (Anami, 2024). The analysis method of content analysis was used (Columbia University, 2024).

LITERATURE REVIEW

Gene Modification Technology and Food Security in East Africa – What is the progress?

Globally, the use of Gene Modification Technology has increased in the past three decades in response to food insecurity and malnutrition (ISAAA, 2021; Mathur et al., 2017). Gene Modification Technology has contributed to improving biological and genetic tolerance of the various food sources in response to various challenges, including climate change, pests, and disease, among others (Tripathi et al., 2017). In Australia, about 70% of cattle are genetically polled (hornless) (Massel, 2023). Polling cows, a practice recommended for improving animal welfare, upgrades the quality of meat since there is less injury to the meat (Massel, 2023). Genome editing has played a big role in agriculture and in the treatment of diseases with no apparent cures (Otim et al., 2023). In the US, fast-growing genetically modified salmon

has been approved for consumption (Massel, 2023). The genetically modified rainbow papaya was developed in the late 1990s, in response to a ringspot virus outbreak that nearly wiped out the global papaya industry (Massel, 2023). The papaya, which is virus-resistant and has foreign DNA, is among the highest consumed papayas today (Massel, 2023). The agriculture sector was the first to initiate the significant investment in genetic technology, and this has led to a significant proliferation of Genetically Modified (GM) crops (Raman, 2017; Kumar et al., 2020).

Globally, since 1996 when commercialization of biotech crops started, their production increased substantially from 1.72 million hectares (Mha) to about 190.4 Mha in 2019; a more than 100-fold increment (ISAAA, 2021; Mathur et al., 2017). As of 2019, Soybean (48.2%), maize (32%), cotton (13.5%), and canola (5.3%), along with other crops (1%), constituted the four primary cultivated GM crops (Statista, 2025). The largest producers of GM crops are the USA, Brazil, Argentina, India, and Canada (Statista, 2025) As per the Food and Agriculture Organization (FAO), of the total GM Maize produced globally, 55% was used for animal feed, 20% for other non-food applications, and merely 12% for human consumption (FAO, 2025).

Enhanced access to knowledge and facilities about Gene Modification Technology has increased globally (Otim et al., 2023). With the rapid drop in the cost of DNA sequencing and synthesis, gene synthesis services are becoming more streamlined, and equipment is becoming more user-friendly; This has reduced barriers to entry (ISAAA, 2021; Otim et al., 2023) . Additionally, Gene Modification Technology laboratories are increasingly becoming accessed remotely as well, and the amount of tacit knowledge required to engineer pathogens is reducing , hence supporting more access (Otim et al., 2023).

Proponents of genetically modified crops and livestock point to their potential for enhancing yields, reducing food waste, and even combating climate change, given their improved environmental stress tolerance (Massel, 2023). GM crops exhibit disease and pest resistance, hence minimizing the dependence on chemical pesticides (Kumar et al., 2020; Massel, 2023). Additionally, the genetic modifications enhance nutritional quality by adding essential vitamins and minerals (Massel, 2023; Batista et al., 2017; Mathur et al., 2017). These are among the key challenges affecting agricultural production on the African continent, including East Africa. Food security in East Africa continues to face significant challenges, with agriculture increasingly becoming more vulnerable to biotic and abiotic stresses, including animal and crop pests and diseases, and climate-related challenges such as drought, hence affecting production and yields (Ntiamoah et al., 2023). Conventional breeding has become cumbersome, labour-intensive, and limited by linkage drag (ISAAA, 2021). Further, the several generations of conventional breeding and overall agricultural production in East Africa are rapidly falling out of touch with meeting the necessary safe and nutritious food needs of the rapidly growing population (ISAAA, 2021).

According to (ISAAA, 2021), some of the examples of projects in East Africa towards Gene Modification Technology for food security include the project against the Maize Lethal Necrosis (MLN) disease, which causes severe losses to maize in Kenya and neighbouring countries. Other prominent projects include a CGIAR project, the world's largest global agriculture innovation network, which aims to use genome editing to target disease susceptibility loci of popular roots, tubers, banana varieties, and promising breeding stocks including in the east African countries of Kenya, Uganda, Rwanda, Burundi and Tanzania and DR Congo (ISAAA, 2021). In East Africa, Kenya serves as an example of the progressive decision to adopt Bt cotton (Kavhiza et al., 2022).

Another project was on Animal African Trypanosomiasis, which is one of the diseases that cause huge losses to livestock-dependent communities in sub-Saharan Africa, including East African countries (ISAAA, 2021).

Despite some projects on Gene Modification Technology towards food security being initiated in East Africa, their adoption and acceptance in the region among farmers and consumers remain significantly low when compared to the global rates (Anami, 2024; Segawa, 2023). sEast African nations did not reach an agreement regarding the adoption of Gene Modification Technology as one of the solutions to food insecurity in the region (Anami, 2024). Uganda, Kenya, and Rwanda agreed to the idea, while the rest of the regional bloc, including Tanzania, South Sudan, Burundi, and the new entrants, the Democratic Republic of Congo and Somalia, tended towards the opposition (Anami, 2024).

Bananas, for instance, are a key staple food among a significant population in East Africa are an example that could significantly benefit from Gene Modification Technology (Uwamahoro et al., 2019). East African countries are globally the largest producers and consumers of bananas. About one- third of the global banana production comes from Africa, of which more than 50% is produced in East African countries including Burundi, Rwanda, the Democratic Republic of the Congo (DR Congo), Uganda, Kenya, and Tanzania (FAO, 2019). The Great Lakes Region (GLR) which includes East Africa countries, is the highest banana consuming region of the world with annual per capita consumption almost 15 times the world's average and triple that of Africa (FAO, 2019). Despite the great contribution of bananas to the region, average farm productivity has been declining since 2014, as opposed to African and global trends over the same period (FAO, 2019). This progressive decline in banana productivity in the region is attributed to suboptimal management, declining soil fertility, increased moisture stress, postharvest losses, and biotic constraints (Kikulwe et al., 2022; Nyamamba et al., 2020). Banana Xanthomonas wilt (BXW) is the most severe and pervasive disease affecting bananas among East African farmers, resulting in up to 100% production losses in banana farms (Uwamahoro et al., 2019; Ocimati et al., 2019). Conventional preventive measures for the BXW disease, such as the removal of male buds to stop insect transmission, uprooting disease mats, have largely remained ineffective (Tripathi et al., 2017; Musabyemungu et al., 2025; Nakato et al., 2018). In addition, excessive use of chemicals remains harmful to the environment (Kikulwe et al., 2022; Nakato et al., 2018). The disease has continued to be a key challenge to the production of bananas, which is a key staple and cash crop in East Africa(Tripathi et al., 2017; Musabyemungu et al., 2025; Nakato et al., 2018). This is a classic case where genetic engineering could speed up the process of crop improvement, especially for bananas, which is a sterile seedless crop (Kikulwe et al., 2022; Tripathi et al., 2017).

Regulation and legal frameworks are important when introducing innovations, especially when it comes to sensitive areas such as food security which takes care of both safety and culture (Rozas et al., 2022). Some key steps have generally been made in the East African region as regards regulatory oversight, which is important for new breeding technologies (ISAAA, 2021). For instance, in Kenya, the National Biosafety Authority has developed guidelines that will distinguish the regulation of genome editing from that of GMOs (ISAAA, 2021). By June 2021, Kenya's Biosafety Authority had approved seven research projects applying genome editing, including banana resistant to Banana Streak Virus (BSV), nutritionally enhanced and disease-resistant yam, and the development of vaccines for the control of African Swine Fever in pigs, among others (ISAAA, 2021). The creation of some of these national guidelines, policies, and laws is an indication of progress made (Anami, 2024). However, these legal frameworks have not been sufficient to bolster significant adoption and acceptance of Gene

Modification Technologies in East Africa as compared to global progress over the past 30 years (Segawa, 2023; Musabyemungu et al., 2025) .

WHY IS THE ADOPTION AND ACCEPTANCE OF GENE MODIFICATION TECHNOLOGY FOR FOOD SECURITY LOW IN EAST AFRICA

Various authors have documented the global progress and benefits of GM crops and livestock, including improving yield, nutrition, adaptability to climate change-related challenges, and resistance to pests and diseases, among others (Kikulwe et al., 2022). Indeed, these would address some of the main challenges to agriculture and food security in East Africa (ISAAA, 2018; Musabyemungu et al., 2025; Massel, 2023) . However, the adoption and acceptance of Gene Modification Technology for agriculture, the main source of food in East Africa, has been relatively very low (Anami, 2024; Segawa, 2023). Below are some of the key issues that are not yet fully resolved and hinder the adoption of Gene Modification Technology for food security in the East African region (Mathur et al., 2017; Anami, 2024; Segawa, 2023).

Critics of Gene Modification Technology, including consumers and civil society bodies, argue that these GM foods could pose risks to human health and the environment (Mathur et al., 2017; Anami, 2024; Segawa, 2023). Additionally, evaluating the long-term effects of the use of GMOs is also of serious concern (Otim et al., 2023). Among the key points raised in the high court decision in Kenya to revoke to executive decision by the President of the Republic of Kenya to approve GM crops included the health risk posed by GMOs to the population, especially the most vulnerable (Wangui, 2022). In plant biotechnology, concerns of potential toxicity and allergenicity to human beings, potential environmental risks, such as chances of gene flow, adverse effects on non-target organisms, and evolution of resistance in weeds and insects, have hampered widespread adoption (Kumar et al., 2020). These GM crops rely on the use of said lab-made chemicals (Massel, 2023; Kumar et al., 2020). Although the government regulates them, ethical and safety debates continue, hence the potential long-term health impacts, impacts on biodiversity and ecosystems (Massel, 2023; Kumar et al., 2020). Moreover, there is limited to no sufficient evidence that approved GMOs are not harmful for human consumption (Otim et al., 2023) .

Discussions about GMOs bring in the issue of food sovereignty (Segawa, 2023). The seeds for the GMOs would replace the traditional, affordable, and easily accessible seed systems, on which several rural peasants rely, hence questioning the sustainability of the GMOs and overall longer-term food security of especially the most vulnerable populations in East Africa (Wangui, 2022). David Kabanda, the Executive Director of a local Non-Governmental Organization (NGO) in Uganda, Center for Food and Adequate Living Rights, argues that the promotion of GMOs will promote seed dependency, a form of neo-colonialism in Africa (Segawa, 2023). Ayebare Prudence Aijuka, the policy research manager at Uganda National Farmers Federation, continues to emphasize against GMOs in East Africa to ensure food sovereignty, that buying seeds every season will be challenging for many farmers in Uganda. Ayebare further suggests that what Ugandan farmers need is various technologies to combat pests and diseases for better yield, rather than getting trapped in what will destroy food sovereignty (Segawa, 2023). In Kenya, the President of the Republic of Kenya lifted a ban on the cultivation or importation of GM crops except for conducting confined research trials in 2022, in interest to remodel the national textile industry, hence contributing to economic growth.

However, the Kenya High Court later revoked the executive decision upon request from anti-GM activists (Wangui, 2022). Among the key points raised in the high court decision are the risk of loss of indigenous seeds, which would be replaced by commercialized and patent-protected GMO seeds (Anami, 2024; Wangui, 2022).

East African countries did not reach an agreement on GMOs, with the disagreements stemming from benefits and risks associated with the GMOs and relevant technology, hence sending the discussion to the regional bloc's legislature to come up with harmonized policies and laws for the region (Anami, 2024). Incoherencies and a lack of polices and laws are an issue slowing the adoption of GMOs for food security in East Africa (Tripathi et al., 2017; Anami, 2024). For instance, Burundi argued that they are signatory to the Cartagena Protocol on Biosafety, which seeks to protect biological diversity from the potential risks posed by GMOs, while on the other hand, Uganda and Rwanda have had national guidelines or policies in place since 2003 and 2023, respectively (Anami, 2024). However, for Uganda, despite the policies in place, there are still several disagreements internally (Segawa, 2023; Anami, 2024). In 2012 and 2017, the president declined to sign into law the National Biotechnology and Biosafety Bill. In 2022, the parliament of Uganda planned to introduce a bill prohibiting GMOs. However, this has not happened since (Segawa, 2023). By 2017, genetically modified (GM) BXW-resistant bananas had already been developed and field-tested in Uganda.

However, a lack of policies to release them was an issue (Tripathi et al., 2017).

There has not been sufficient sensitization and information sessions on GM foods and respective technologies among the East African population (Otim et al., 2023; Anami, 2024; Segawa, 2023). Despite new breeding technologies presenting great opportunities in improving agricultural production, communication approaches will either hamper or facilitate their uptake (ISAAA, 2021). In this case for East Africa, insufficient investment has been made to sensitize the population on the benefits and how to handle the challenges related to the GM foods (Otim et al., 2023; Wangui, 2022). Misinformation is one of the key challenges on the current impasse on GM related technologies, according to Dr Njagi a senior researcher at the Tegemeo Institute of Technology in Kenya (Anami, 2024). Further, regulatory approval for GM crops is often delayed due to poor communication and awareness, which fosters consumer mistrust (Mustapa et al., 2021). In Kenya, another key reason the high court suspended the executive decision was that the government lifted the ban on GMOs without public consultation, reiterating the need for information sharing on GMOs among the masses in East Africa (Wangui, 2022; Anami, 2024). This calls for governments, research institutions, civil society organizations and relevant stakeholders such as consumers to take up the information and communication sessions (Anami, 2024; Otim et al., 2023; Wangui, 2022). .

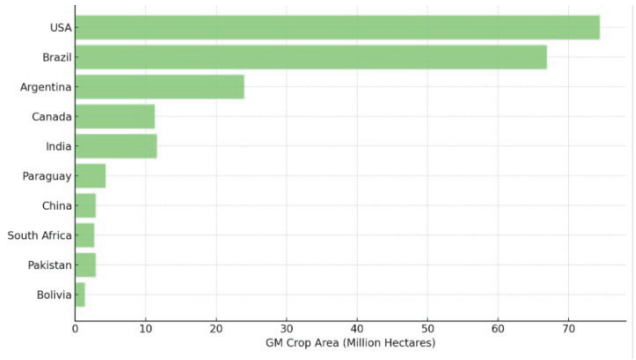
Another key reason for the relatively low adoption of GMOs in East Africa is that despite the food insecurity levels in East Africa, not the whole region or countries are food insecure (Segawa, 2023; Anami, 2024). This pauses the question on whether the region needs GMOs now amidst the ongoing controversies around them (Segawa, 2023; Anami, 2024). Tanzania, for instance, argues that they simply do not need GMOs because they produce more than enough food (Anami, 2024). South Sudan agrees that food insecurity remains a challenge, however, they mention that the risks associated with the GMOs are high (Anami, 2024). The context of Uganda is like Tanzania, both relatively food secure (Segawa, 2023; Anami, 2024). Segawa (2023) quotes the World Food Programme that about in Uganda, about 40% of vegetables and fruits are lost to pests, disease, and spoilage. More than 12% of maize grain produced in the country is wasted on the field due to prolonged field drying and late harvests, and another

18% is lost during transportation, processing, drying and poor storage. Segawa (2023) further quotes the Food Agriculture Organization which notes that about 89% of people in Uganda are food secure and can afford three meals a day, apart from the Karamoja sub-region where harvests are relatively low as a result of dry weather, as compared to the rest of the country. This suggests that East Africa may not necessarily need the introduction of GMOs whose safety for the population is still doubted, with GM policy and technological infrastructure not yet fully in place (Anami, 2024; Segawa, 2023). Rather, what East Africa currently needs as a solution to food insecurity is to fix the gaps in food systems including quality inputs and infrastructure such as extension services and irrigation schemes, post-harvest handling (Abdullahi et al., 2024; Anami, 2024; Segawa, 2023). Further, the region should strengthen the social protection schemes to ensure food accessibility throughout the year for the most vulnerable people (Aryal et al., 2021; Abdullahi et al., 2024).

RESULTS AND DISCUSSION

The literature reviewed indicates that GMOs have increased over 100-fold in the past 30 years (ISAAA, 2021; Mathur et al., 2017). However, the adoption and acceptance has only been in a few countries globally, with the East African countries among those with the low adoption of GMOs and respective technology towards food security (Anami, 2024; Tripathi et al., 2017). The significant GM food production is only in a few countries led by the USA, then Brazil, Argentina, and to a medium extent Canada and India among the main GMO producers (Reportlinker, 2020; ISAAA, 2018)

Table 1: Top 10 Countries by Genetically Modified Crop Acreage (2023)



Adapted from Statista (2024)

Many countries in Europe and the Middle East have imposed full or partial restrictions on the commercialization of GM crops (Mustapa et al., 2021). Europe, which is Africa's leading export market (36% of Africa's agricultural exports) has significant restrictions and trade controls on GM crops. The European Union set a threshold system of tracing and tracking GM, 0.9% for approved crops and 0% for crops assessed by the European Food Safety Authority (EFAS) for the import to EU market, which opens the possibility of import ban from countries cultivating GM crops (Purnhagen & Wesseler, 2021). This implies that the low rate to no adoption of the Gene Modification Technology for food security is not only unique to East African countries but also majority countries around the world (Mustapa et al., 2021; Purnhagen & Wesseler, 2021).

The key reason for the low adoption Gene Modification Technology for food security around East African countries, as the rest of the world is the risk and lack of clarity on health and safety both for humans and environment (Otim et al., 2023; Massel, 2023; Kumar et al., 2020). The risks include the

potential to create new allergens, unintended consequences for ecosystems. However, through regulatory frameworks and responsible research, these risks these can be addressed (Massel, 2023). Additionally, despite the global increment in production of GMOs, only a few crops have significantly been grown through Gene Modification Technology including maize, cotton, soya bean and canola (Statista, 2024; FAO, 2025). Most of the crop being grown so far under the Gene Modification Technology has been mainly for non-human consumption especially animal consumption and making ethanol (Aldemita et al., 2015). For instance, of total GM maize produced globally, 55% was used for animal feed, 20% for other non-food applications, and merely 12% for human consumption (FAO, 2025). The fact that fewer of the GMOs are used for direct human consumption is a sign of lack of trust or sufficient evidence to qualify GMO consumption human beings in East Africa and other parts of the world, requiring more research to be done on the impact of the GM food on human health and environment over a longer period (Mustapa et al., 2021) .

International collaboration and constant communication between scientists, decision-makers, and the public regarding Gene Modification Technology and food security in East Africa and other parts of the world will be necessary to address the risks associated with GMOs and build trust among the public (Otim et al., 2023). It is necessary to encourage stakeholder involvement along the entire value chain, from the laboratory to the field, and collaboration among different regional networks to ensure that the best practices and lessons learned are shared widely (Otim et al., 2023). Ultimately, the development of future foods must be guided by a commitment to sustainability, social justice, and scientific rigour (Massel, 2023).

Away from the skepticism of the East African public, combined with the health risks not clarified, GMOs are not yet welcome in the region despite some parts of the region being food insecure (Panzarini et al., 2015). The literature reviewed indicates that even in countries such as Kenya and Uganda where laws and policies have been developed, limited adoption of GM technologies for food security has taken place; GMOs are not yet welcome (Segawa, 2023; Anami, 2024). The civil society, such as those who went to court against the Kenyan government decision on the same, feel the region is simply not ready for the discussion on GMOs (Anami, 2024; Wangui, 2022). One of the key stakeholders not supporting the adoption of GMOs is the Executive Director of the Southern and East African Trade Information and Negotiations institute in Uganda, who remarks that the region is not ready for GMOs because hunger in the region is because of lack of water for production, climate change, degraded soils and farmers not getting the right seed (Anami, 2024). On the other hand, one may also argue that these are the real issues as to why the region needs the GMOs. However, as it stands, the lack of sufficient clarity on health risks and food sovereignty overrides all the would-be potential benefits of Gene Modification Technology for food security in East Africa and the rest of the world facing food insecurity.

REFERENCES

Abdullahi, A. M., Kalengyo, R. B., & Warsame, A. A. (2024). The unmet demand of food security in East Africa: Review of the triple challenges of climate change, economic crises, and conflicts. Discover Sustainability, 5(1), 244. https://doi.org/10.1007/s43621-024-00381-5

Africa Development Bank. (2024). EAST AFRICA ECONOMIC OUTLOOK 2024 Driving East Africa's Transformation: The Reform of the Global Financial Architecture. https://www.afdb.org/sites/default/files/documents/publications/reo_east_africa_english_2024.pdf

Aldemita, R. R., Reaño, I. M. E., Solis, R. O., & Hautea, R. A. (2015). Trends in global approvals of biotech crops (1992–2014). GM Crops & Food, 6(3), 150–166. https://doi.org/10.1080/21645698.2015.1056972

Anami, L. (2024, September). GMO push sows discord in regional bloc. https://www.theeastafrican.co.ke/tea/news/east-africa/gmo-push-sows-discord-in-regional-bloc- 4769528

Aryal, J. P., Sapkota, T. B., Rahut, D. B., Marenya, P., & Stirling, C. M. (2021). Climate risks and adaptation strategies of farmers in East Africa and South Asia. Scientific Reports, 11(1), 10489. https://doi.org/10.1038/s41598-021-89391-1

Batista, R., Fonseca, C., Planchon, S., Negrão, S., Renaut, J., & Oliveira, M. M. (2017). Environmental stress is the major cause of transcriptomic and proteomic changes in GM and non-GM plants. Scientific Reports, 7(1), 10624. https://doi.org/10.1038/s41598-017-09646-8

Columbia University. (2024). Content Analysis. https://www.publichealth.columbia.edu/research/population-health-methods/content-analysis

FAO. (2025). FAOSTAT. https://www.fao.org/faostat/en/#data/RP

ISAAA. (2018). Brief 54: Global Status of Commercialized Biotech/GM Crops. https://www.isaaa.org/resources/publications/briefs/54/

ISAAA. (2021a). Biotech Crop Highlights in 2019. 16. https://www.isaaa.org/resources/publications/pocketk/16/#:~:text=The%20most%20planted%20biotech%20crops,crops%20or%2091.9%20million%20hectares ISAAA. (2021b). Breaking Barriers with Breeding: A Primer on New Breeding Innovations for Food Security. 56, 43–56.

Kavhiza, N. J., Zargar, M., Prikhodko, S. I., Pakina, E. N., Murtazova, K. M.-S., & Nakhaev, M. R. (2022). Improving Crop Productivity and Ensuring Food Security through the Adoption of Genetically Modified Crops in Sub-Saharan Africa. Agronomy, 12(2), 439. https://doi.org/10.3390/agronomy12020439

Kikulwe, E., Asindu, M., Ocimati, W., Ajambo, S., Tinzaara, W., Iradukunda, F., & Blomme, G. (2022). Scaling Banana Bacterial Wilt Management Through Single Diseased Stem Removal in the Great Lakes Region. In G. Thiele, M. Friedmann, H. Campos, V. Polar, & J. W. Bentley (Eds.), Root, Tuber and Banana Food System Innovations (pp. 289–317). Springer International Publishing. https://doi.org/10.1007/978-3-030-92022-7_10

Kumar, K., Gambhir, G., Dass, A., Tripathi, A. K., Singh, A., Jha, A. K., Yadava, P., Choudhary, M., & Rakshit, S. (2020). Genetically modified crops: Current status and future prospects. Planta, 251(4), 91. https://doi.org/10.1007/s00425-020-03372-8

Massel, K. (2023). What's the latest on GMOs and gene-edited foods – and what are the concerns? An expert explains. https://theconversation.com/whats-the-latest-on-gmos-and-gene-edited-foods-and- what-are-the-concerns-an-expert-explains-204275

Mathur, V., Javid, L., Kulshrestha, S., Mandal, A., & Reddy, A. A. (2017). World Cultivation of Genetically Modified Crops: Opportunities and Risks. In E. Lichtfouse (Ed.), Sustainable Agriculture Reviews (Vol. 25, pp. 45–87). Springer International Publishing. https://doi.org/10.1007/978-3-319- 58679-3_2

Musabyemungu, A., Tripathi, J. N., Muiruri, S. K., Gaidashova, S. V., Rukundo, P., & Tripathi, L. (2025). Genetic Improvement of Banana for Resistance to Xanthomonas Wilt in East Africa. Food and Energy Security, 14(1), e70048. https://doi.org/10.1002/fes3.70048

Mustapa, M. A. C., Batcha, M. F. N., Amin, L., Arham, A. F., Mahadi, Z., Yusoff, N. A. M., Yaacob, M., Omar, N. A., & Hussain, W. H. W. (2021). Farmers' attitudes towards GM crops and their predictors. Journal of the Science of Food and Agriculture, 101(13), 5457–5468. https://doi.org/10.1002/jsfa.11194

Nakato, V., Mahuku, G., & Coutinho, T. (2018). Xanthomonas campestris pv. musacearum: A major constraint to banana, plantain and enset production in central and east Africa over the past decade. Molecular Plant Pathology, 19(3), 525–536. https://doi.org/10.1111/mpp.12578

N.I. Lokuruka, M. (2021). Food and Nutrition Security in East Africa (Kenya, Uganda and Tanzania): Status, Challenges and Prospects. In B. Mahmoud (Ed.), Food Security in Africa. IntechOpen. https://doi.org/10.5772/intechopen.95036

Ntiamoah, E. B., Chandio, A. A., Yeboah, E. N., Twumasi, M. A., Siaw, A., & Li, D. (2023). How do carbon emissions, economic growth, population growth, trade openness and employment influence food security? Recent evidence from the East Africa. Environmental Science and Pollution Research, 30(18), 51844–51860. https://doi.org/10.1007/s11356-023-26031-3

Nyamamba, K. A., Tom O. Ouna, Hellen Kamiri, & Erwin Pane. (2020). Effects of Land Use Change on Banana Production: A Case Study of Imenti South Sub-County of Meru County in Kenya. Britain International of Exact Sciences (BIoEx) Journal, 2(3), 640–652. https://doi.org/10.33258/bioex.v2i3.303

Ocimati, W., Bouwmeester, H., Groot, J. C. J., Tittonell, P., Brown, D., & Blomme, G. (2019). The risk posed by Xanthomonas wilt disease of banana: Mapping of disease hotspots, fronts and vulnerable landscapes. PLOS ONE, 14(4), e0213691. https://doi.org/10.1371/journal.pone.0213691

Otim, G., Matinyi, S., Busuulwa, I. P., Mweine, P., Baluku, E., Magoola, G. P., Chimulwa, I. S. G., Mukuze, S., Aber, P. P., Babigumira, P. A., Katumba, A., & Opiyo, S. O. (2023). Addressing Gene Modified Technology for Emerging Risks Through Regional Networks. Current Genetic Medicine Reports, 11(1–2), 1–7. https://doi.org/10.1007/s40142-023-00207-2 Panzarini, H., Bittencourt, M., De Aville Mantos, S., & Wosaick, A. (2015). Biotechnology in agriculture: The perceptions of farmers on the inclusion of Genetically Modified Organisms (GMOs) in agricultural production. Afr J Agric Res, 631–636.

Purnhagen, K., & Wesseler, J. (2021). EU Regulation of New Plant Breeding Technologies and Their Possible Economic Implications for the EU and Beyond. Applied Economic Perspectives and Policy, 43(4), 1621–1637. https://doi.org/10.1002/aepp.13084

Raman, R. (2017). The impact of Genetically Modified (GM) crops in modern agriculture: A review. GM Crops & Food, 8(4), 195–208. https://doi.org/10.1080/21645698.2017.1413522

Reportlinker. (2020). Global Agricultural Biotechnology Industry. https://www.prnewswire.com/news-releases/global-agricultural-biotechnology-industry-301092902.html

Rozas, P., Kessi-Pérez, E. I., & Martínez, C. (2022). Genetically modified organisms: Adapting regulatory frameworks for evolving genome editing technologies. Biological Research, 55(1). https://doi.org/10.1186/s40659-022-00399-x

Segawa, N. (2023). GMOs in East Africa: Food Security Boon or Seed Stealing Ploy? https://globalpressjournal.com/africa/uganda/gmos-east-africa-food-security-boon-seed-stealing-ploy/

Statista. (2024). Top 10 countries growing genetically modified (GM) crops. https://geneticliteracyproject.org/2024/10/07/top-10-countries-growing-genetically-modified-gm-crops/

Statista. (2025). Adoption of GM technology among selected major crops worldwide in 2019, by type. https://www.statista.com/statistics/262288/global-adoption-rate-major-biotech-crops-worldwide/

Tripathi, L., Atkinson, H., Roderick, H., Kubiriba, J., & Tripathi, J. N. (2017). Genetically engineered bananas resistant to Xanthomonas wilt disease and nematodes. Food and Energy Security, 6(2), 37–47. https://doi.org/10.1002/fes3.101

Uwamahoro, F., Berlin, A., Bylund, H., Bucagu, C., & Yuen, J. (2019). Management strategies for banana Xanthomonas wilt in Rwanda include mixing indigenous and improved cultivars. Agronomy for Sustainable Development, 39(2), 22. https://doi.org/10.1007/s13593-019-0569-z

Wangui, J. (2022). Kenya's High Court puts the brakes on plans to import GMOs. The East African. https://www.theeastafrican.co.ke/tea/news/east-africa/kenyan-court-stops-gmo-imports-4036516