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Review

Global Overview of Genetically Modified Foods and Its Benefits: A Review

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ABSTRACT
Genetically modified (GM) foods have revolutionized agricultural biotechnology since their debut in the mid-1990s, sparking debates about their safety, environmental impact, and potential to solve global food security issues. This review offers a comprehensive look at the global status of GM foods, covering their development, various genetic modifications, and adoption rates across different regions. It delves into the regulatory frameworks that govern GM foods in major markets, noting the variations in regulatory approaches and strictness. The review highlights the benefits of GM foods, such as higher agricultural productivity, better environmental sustainability, improved food security, and enhanced nutritional value. It also addresses the ongoing controversies and challenges, including safety concerns, environmental risks, ethical questions, and public perception issues. Looking ahead, the paper considers the future of GM foods, focusing on advancements in biotechnology, possible changes in policies and regulations, and how GM crops can be integrated into sustainable agriculture practices. By providing a balanced perspective, this review aims to guide stakeholders in making informed, evidence-based decisions about the role of GM foods in addressing global food challenges.

Keywords: Genetically modified foods; GMOs; biotechnology; food security; regulation; global perspective

1. INTRODUCTION

The advent of genetically modified (GM) foods marks a pivotal development in agricultural biotechnology. Since the commercialization of the first GM crop in the mid-1990s, these innovations have ignited extensive discussions about their implications for food safety, environmental health, and global food security. The emergence of GM foods reflects humanity's continuous endeavor to enhance agricultural productivity, ensure food security, and address the nutritional needs of a growing population. Genetically modified foods are derived from organisms whose genetic material has been altered using genetic engineering techniques. This allows for the introduction of new traits or the enhancement of existing ones, which is not possible with traditional cross-breeding methods. For instance, crops can be engineered to resist pests, tolerate herbicides, endure harsh climatic conditions, or improve their nutritional profile. The goal is to create plants that are more robust, productive, and beneficial to human health and the environment.(1)

The global adoption of GM foods varies significantly. In the United States, GM crops like soybeans, corn, and cotton dominate agricultural production. Similarly, countries in South America, such as Brazil and Argentina, have embraced GM technology, primarily for soybean and maize cultivation. In contrast, European countries have been more cautious, with stringent regulations and limited cultivation of GM crops, although they import substantial quantities of GM animal feed. In Asia, the adoption is mixed; China and India are major producers of GM cotton, while other countries remain hesitant. Africa shows a slow but growing interest, with South Africa leading the way in GM crop production.[2]

Regulatory frameworks for GM foods differ around the world, reflecting varying levels of public acceptance and governmental oversight. In the United States, the Food and Drug Administration (FDA), the United States Department of Agriculture (USDA), and the Environmental Protection Agency (EPA) collectively oversee the regulation of GM crops, ensuring they meet safety and environmental standards. The European Union adopts a more precautionary approach, with the European Food Safety Authority (EFSA) conducting rigorous risk assessments and imposing strict labeling and traceability requirements. Internationally, the Cartagena Protocol on Biosafety and the Codex Alimentarius provide guidelines for the safe handling, transfer, and use of GM organisms.[3]

The potential benefits of GM foods are manifold. They can significantly boost agricultural productivity by increasing crop yields and reducing losses due to pests, diseases, and environmental stresses. This is particularly important in the context of global food security, as the world's population is projected to reach

2. DEVELOPMENT AND TYPES OF GENETICALLY MODIFIED FOODS

2.1 What are GMOs and GM Foods

GMOs (Genetically Modified Organisms) and GM foods are products where genetic material has been altered using biotechnological techniques, not occurring naturally through mating or recombination.[1] This contrasts with traditional selective breeding methods. Genes can be transferred between unrelated organisms using DNA recombinant technology. GM foods are those derived from genetically modified plants or animals. However, some argue that certain hybrids like Triticale, created through conventional breeding techniques but later modified for fertility using chemicals, also fall under the GMO umbrella, suggesting a need for a more precise term like "biotechnologically modified organism."

Genetic modification is a biological technique that alters the genetic makeup of organisms. According to the World Health Organization (WHO), GMOs are organisms whose genetic material (DNA) has been changed in a way that does not occur naturally through mating or natural recombination.[4] This definition distinguishes genetic manipulation from the long-established practice of improving genetic stock through selective breeding. Through DNA recombinant technology, genes from one organism can be inserted into another, typically unrelated, organism. Genetically modified foods come from organisms whose genetic material has been altered through genetic engineering techniques to introduce new traits or enhance existing ones, a process not achievable through traditional cross-breeding methods (Figure 1).

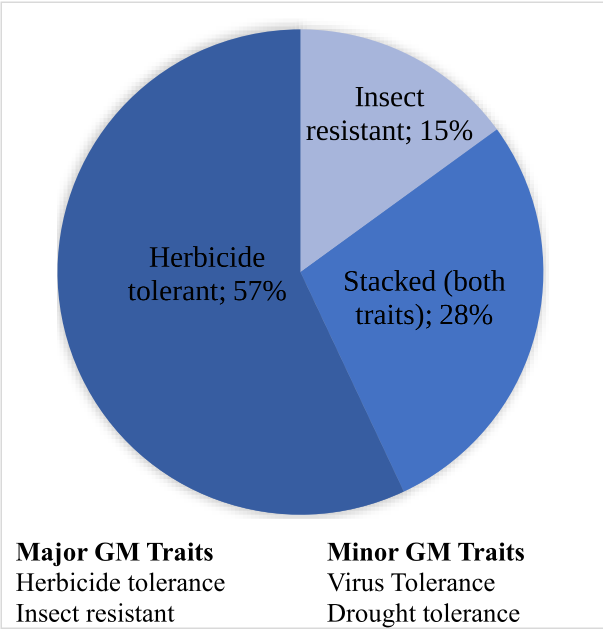

Figure 1. GM traits as percent of total GM area

Similarly, the Food and Agriculture Organization of the United Nations (FAO) and the European Commission define GMOs as products where genetic modifications do not occur naturally through mating or natural recombination.[5] GM foods refer to products made from genetically modified plants or animals.

However, Oliver[5] points out flaws in these definitions, highlighting Triticale as an example.

Triticale, a grain used in bread and pasta, was developed in the 19th century by crossing wheat with rye using traditional breeding methods. However, the resulting hybrid was sterile. In the 1930s, scientists used the chemical colchicine to induce fertility in the embryo cells of Triticale, making it fertile. Despite its primitive genetic modification compared to modern biotechnological standards, Triticale still fits the definition of a GMO. Oliver suggests the term "biotechnologically modified organism" as a more accurate descriptor.

2.2 Historical Background

The historical background of genetically modified foods begins in the early 1970s with the advent of recombinant DNA technology, which allowed scientists to manipulate genetic material in unprecedented ways.(6) This breakthrough set the stage for the development of genetically engineered crops. The first successful commercialization of a GM food product came in 1994 with the Flavr Savr tomato, designed to have a longer shelf life and better flavor compared to conventional tomatoes. This marked a significant milestone in biotechnology, demonstrating the practical benefits of genetic modification in agriculture. Following this, the mid-1990s saw the introduction of herbicide-tolerant soybeans and insect-resistant corn, which quickly gained popularity among farmers due to their improved agricultural performance and economic advantages. These early successes catalyzed further research and development, leading to a proliferation of GM crops with various beneficial traits.(7) The rapid adoption of GM foods in several countries underscored their potential to revolutionize agriculture, although it also sparked debates about their safety, environmental impact, and ethical implications, setting the stage for ongoing discussions that continue to shape the field today.

In 2023, the global area dedicated to GM crops increased by 1.9% from the previous year, reaching a record 206.3 million hectares (Figure 2). A total of 27 countries cultivated 11 different GM crops, with soybeans being the most widely planted at 100.9 million hectares, marking the first time this crop has surpassed 100 million hectares. Following soybeans, maize covered 69.3 million hectares, and cotton accounted for 24.1 million hectares. The number of countries growing GM crops has fluctuated since their introduction in 1996, influenced by factors such as the cessation of GM maize cultivation in several European countries and the discontinuation of GM cotton planting in Burkina Faso. Since 2020, 27 countries have consistently cultivated GM crops, a number that was also reached in 2015.(8)

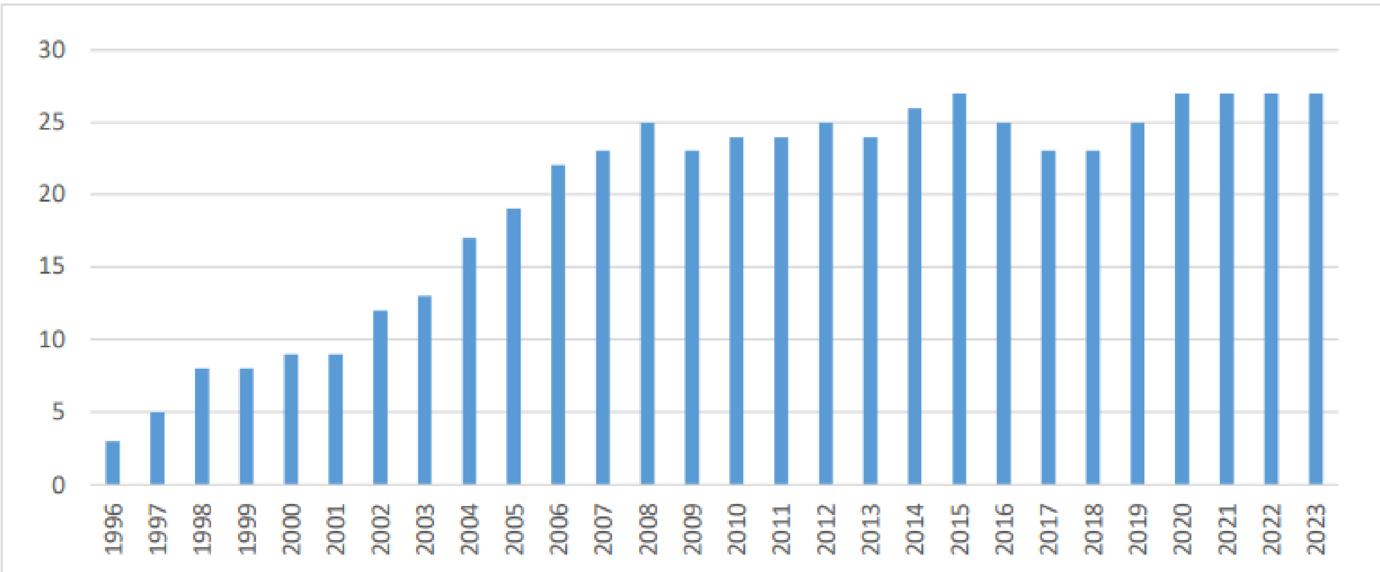

Figure 2. Number of GM crop cultivating countries by year (adopted from GM Monitor)(8)

2.2 GM Stats

Genetically modified foods, dominated by four crops—soy, corn, canola, and cotton—constitute 99% of global GM crop production (Figure 3). Nearly all GM crops are designed with herbicide tolerance, present in 85% of them, and insect resistance as their primary traits. Despite the potential benefits, the cultivation of GM crops is concentrated in a few regions; ten countries account for 98% of the global GM crop acreage, with the vast majority of nations opting not to grow GM crops. This results in only 3.7% of the world's agricultural land being used for GM crops, and less than 1% of the world's farmers engaged in GM farming.

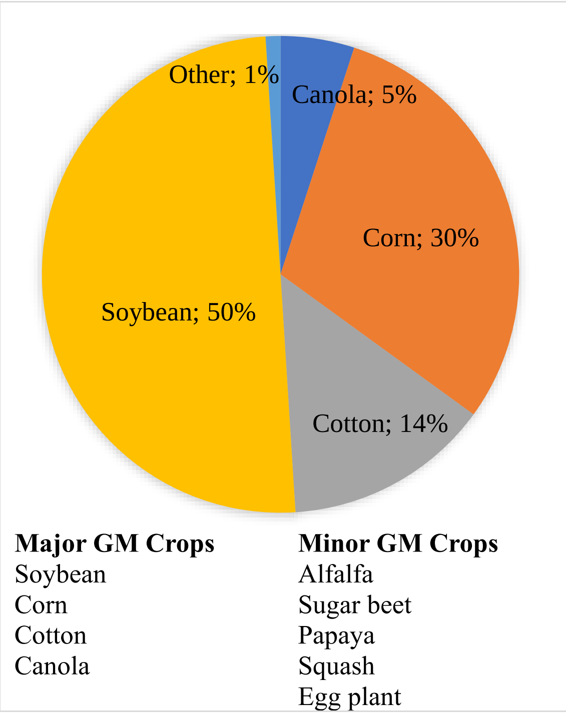

Figure 3. GM crops as percent of total GM area

Regions such as the European Union and several African countries have stringent regulations that restrict or ban the cultivation of GM crops, reflecting ongoing debates and varied acceptance levels worldwide (Table 1). The concentrated adoption highlights both the technological promise of GM foods and the significant regulatory, ethical, and public perception challenges that shape their global use.

Table 1. GM Restricted Countries

Continent or Region	Country
Africa	Algeria, Egypt
Asia	Sri Lanka, Thailand, Japan, Philippine
Europe	Norway, UK, Spain, Italy, France
Middle East	Saudi Arabia
Pacific	Fiji, Australia, New Zealand

2.3 Types of Genetic Modifications

Different genetic modifications are following:

- Herbicide Tolerance: Crops modified to withstand specific herbicides, allowing farmers to control weeds without harming the crop.
- Insect Resistance: Crops engineered to produce toxins that are harmful to specific insects, reducing the need for chemical pesticides.
- Disease Resistance: GM crops resistant to viruses, fungi, and bacteria.
- Nutritional Enhancement: Biofortification of crops to increase their nutritional value, such as Golden Rice enriched with Vitamin A.
- Climate Resilience: Development of crops that can tolerate abiotic stresses like drought, salinity, and extreme temperatures.

Some of the GM foods are listed in the Table 2.

Table 2. Example of GM foods

Crop	GMO (Tentative Imported Items)	GM Trait(s)
Canola	GMO	Herbicide tolerant
Corn	GMO	Insect resistant & herbicide tolerant
Soy	GMO	Herbicide tolerant
Sugar Beat	GMO	Herbicide tolerant
Papaya	GMO	Virus resistant
Squash	GMO	Virus resistant
Cotton	GMO	Insect resistant
Alfalfa	GMO	Herbicide tolerant & low lignin
Apple	GMO	Non-browning
Potato	GMO	Insect resistant
Rice	GMO	Herbicide tolerant (not grown anywhere in the world)
Flax	GMO	Herbicide tolerant
Tomato	GMO	Delayed ripening Insect resistant
Lantis	Product of chemically induced seed mutagenesis	Herbicide tolerant
Sunflower	Product of conventional plant breeding	Herbicide tolerant
Wheat	Product of chemically induced seed mutagenesis	Herbicide tolerant

3. BENEFITS OF GENETICALLY MODIFIED FOODS

3.1 Agricultural Benefits

From 1996 to 2012, GM crops contributed to an increase of over 370 million tons of food crops globally, with one-seventh of this increase attributed to GM crops in the U.S. Achieving the same yield increase with conventional crops would have required over 300 million additional acres, likely involving land needing more fertilizer or irrigation, or converting tropical forests, leading to severe ecological stress. Between 1996 and 2013, biotechnology added 138 million tons of soybeans, 274 million tons of corn, 21.7 million tons of cotton lint, and 8 million tons of canola globally. Without these technologies, maintaining production levels would have required 11% more arable land in the U.S. or 32% more cereal area in the EU.[9,10]

3.2 Economic Benefits

From 2006 to 2012, GM foods increased global farm income by $116 billion, nearly triple the increase of the previous decade. Approximately 42% of this economic gain came from higher yields due to advanced genetics and pest and weed resistance, while reduced production costs (e.g., less pesticide and herbicide use) accounted for the remaining 58%.[9,10]

3.3 Nutritional Benefits

GM technology has enhanced the nutritional content of foods, adding beneficial nutrients like vitamins A, C, E, unsaturated fatty acids, dietary fiber, and probiotics. Notable examples include "Golden Rice," which addresses malnutrition economically, and sweet lupine with enriched methionine. The Amflora potato, modified for higher amylopectin content by gene silencing, illustrates how GM can improve food composition for industrial use.[11]

3.4 Food Processing Improvements

GM technology has improved food processing. The "Flavr Savr" tomato, introduced by Calgene in 1992, uses an antisense gene to slow ripening, extending shelf life. Genetic modifications in potatoes, such as introducing bacterial genes, enhance brightness and appearance. GM also extends to animal products, with the FDA approving the fast-growing "AquAdvantage" salmon, which requires less time and fewer resources to reach full size, alleviating pressure on wild fish populations.[12]

3.5 Therapeutic Products

Genetic engineering enables the production of viral or bacterial antigens in edible plant cells, potentially creating oral vaccines that stimulate mucosal immunity. Research is underway on crops like rice, maize, soybeans, and potatoes to develop edible vaccines against infections such as E. coli toxins, rabies virus, Helicobacter pylori, and type B viral hepatitis.[13,14]

4. GLOBAL ADOPTION AND REGULATORY FRAMEWORKS

The global adoption of genetically modified (GM) foods varies widely, influenced by regional policies, public perception, and agricultural needs. As of recent years, only a small fraction of the world's agricultural land—about 3.7%—is dedicated to GM crops, with just under 1% of farmers cultivating them. This is largely concentrated in a few countries, with ten nations accounting for 98% of the global GM crop acreage. The primary GM crops include soybeans, corn, canola, and cotton, which together constitute 99% of the world's GM crop production. These crops are predominantly engineered for herbicide tolerance (85%) and insect resistance.

Regulation of GM foods involves rigorous assessment of safety, environmental impact, and labeling requirements: In United States, the FDA, USDA, and EPA share responsibility for regulating GM crops, focusing on substantial equivalence and environmental safety. The European Food Safety Authority (EFSA) conducts comprehensive risk assessments, with stringent labeling and traceability requirements (Table 3). The Cartagena Protocol on Biosafety and Codex Alimentarius provide frameworks for international regulation and trade of GM foods.

One of the main challenges to adopting GMOs in Africa is the regulatory system. Effective policies and regulations are crucial for the acceptance, application, and commercialization of GMOs. These frameworks are necessary to protect human and environmental health while supporting research, development, and trade. However, regulating GMOs is knowledge-intensive and expensive. A 2014 report by the International Food Policy Research Institute (IFPRI) and African Development Bank (AfDB) highlighted that many existing regulatory frameworks in Africa are costly, inefficient, and lack transparency, with systems being overly cautious. Currently, many African countries lack the capacity to establish effective policies, regulations, and monitoring systems for GMOs.[16-17]

Table 3. The adoption of GM crops varies significantly across different regions (Mmbando, 2024)[15]

Region	Adoption of GM crops
North America	The United States and Canada are leading adopters of GM crops, with high percentages of GM maize, soybean, and cotton cultivation
South America	Countries like Brazil and Argentina have rapidly embraced GM technology, particularly for soybean and maize
Asia	Adoption is mixed, with China and India cultivating GM cotton extensively, while other countries remain cautious
Europe	The European Union has stringent regulations and limited GM crop cultivation, although GM imports are allowed for animal feed
Africa	Adoption is slow, with a few countries like South Africa and Burkina Faso cultivating GM crops, while others are hesitant due to regulatory and public acceptance issues

5. CONTROVERSIES AND CHALLENGES

5.1 Human Health

The impact of genetically modified organisms (GMOs) on human health has been a topic of extensive research and debate. Studies have focused on assessing the effects of GMO consumption on various aspects of health, including blood chemistry, reproductive potential, and organ health. While most studies have not shown significant adverse effects, concerns remain regarding potential allergenicity, antibiotic resistance, and gene transfer from GM foods to the human body.[18,19]

5.2 Ecosystem and Biodiversity

The cultivation of genetically modified crops can have far-reaching effects on ecosystems and biodiversity. Concerns arise from the potential reduction in farmland diversity, the development of herbicide-resistant weed species, and disruptions to soil microbiota. The monoculture practices associated with GM crops can lead to a loss of insect and plant species diversity in agricultural landscapes. Additionally, gene flow from GM crops to wild relatives raises concerns about genetic diversity and ecosystem stability.[20,21]

5.3 Resistance to Antibiotic

Antibiotic resistance is a well-documented issue in medical science, primarily resulting from the overuse of therapeutic antibiotics in both medicine and agriculture. During genetic modification processes, antibiotics are frequently used as selection markers to differentiate successfully transformed bacteria from those that were not. This practice poses a risk of transferring antibiotic resistance genes to the benign bacteria in the human and animal gastrointestinal tracts, or even worse, to pathogenic bacteria consumed through GM foods. This is concerning because both beneficial and harmful bacteria can exchange genes, including those that provide antibiotic resistance, through horizontal gene transfer between species.[22-24]

5.4 Others

Ethical concerns revolve around tampering with nature, corporate control of the food supply, and socio-economic impacts on smallholder farmers and traditional farming practices. Public perception of GM foods varies widely, influenced by cultural, social, and political factors. Effective communication and education are essential to address misconceptions and build trust.[25]

6. FUTURE PROSPECTS

The future prospects of genetically modified (GM) crops are promising, with advancements in genetic engineering techniques offering new opportunities for crop improvement. One of the key areas of focus is the development of genetically engineered crop varieties with multiple favorable traits. Alternative technologies, such as cisgenesis, intragenesis, and genome editing, are being explored to address concerns related to transgenic crops and to facilitate the development of crops that are free from any foreign genes.

Genome editing techniques, such as CRISPR/Cas system, have enabled precise and targeted modifications in crop genomes with unprecedented ease, accuracy, and precision. These tools have the potential to address regulatory issues associated with transgenic crops and contribute to the development of improved varieties through interventions like targeted mutagenesis, precise editing of endogenous genes, and site-specific insertion of trait genes.[26]

The development of genome-edited (GEd) crops has already shown promising results, with examples like Sulfonylurea herbicide-tolerant canola variety and bacterial blight-resistant rice. These crops have been de-regulated in some countries, indicating a shift towards faster regulatory approvals for non-transgenic GEd crops. The potential benefits of GEd crops include increased crop yields, climate resilience, and addressing consumer concerns and nutritional needs. However, the future prospects of GM crops also face challenges, such as regulatory uncertainties in many countries. The Intellectual Property landscape related to genome editing technologies, like CRISPR/Cas, also needs to be considered to ensure the commercialization of GEd crops without infringing on patent rights. Governments around the world need to support the development of an appropriate and updated regulatory framework to facilitate the widespread adoption of engineered crops developed using genome editing tools.[27]

7. CONCLUSION

Genetically modified foods have revolutionized agriculture, offering solutions to enhance crop yields, reduce pesticide use, and improve nutritional content, essential for feeding a growing global population under climate stress. Despite their benefits, GM foods face significant controversies, including safety concerns, environmental risks, ethical questions, and varied public acceptance. Regulatory responses differ globally, with countries like the U.S. and Brazil adopting GM crops widely, while the EU enforces stringent regulations. Advances in biotechnology, such as CRISPR, promise further innovations, potentially increasing the precision and benefits of GM crops. To fully realize their potential, it is crucial to balance these innovations with rigorous safety assessments, ethical considerations, and effective public communication, ensuring that GM foods contribute to a secure and sustainable global food system.

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Conflict of Interest

The authors declare no conflict of interest

REFERENCES

1. Zhang C, Wohlhueter R, Zhang H. Genetically modified foods: A critical review of their promise and problems. Food Science and Human Wellness. 2016;5(3):116–23. http://dx.doi.org/10.1016/j.fshw.2016.04.002
2. Singh RB, Mishra S, Saxena P, Saxena M, Priya, Smail MMA, et al. Genetically modified organisms and foods: perspectives and challenges. Functional Foods and Nutraceuticals in Metabolic and Non-Communicable Diseases. 2022;493–505. http://dx.doi.org/10.1016/b978-0-12-819815-5.00041-0
3. National Academies of Sciences, Engineering, and Medicine; Division on Earth and Life Studies; Board on Agriculture and Natural Resources; Committee on Genetically Engineered Crops: Past Experience and Future Prospects. Genetically Engineered Crops: Experiences and Prospects. Washington (DC): National Academies Press (US); 2016 May 17. 9, Regulation of Current and Future Genetically Engineered Crops. Available from: https://www.ncbi.nlm.nih.gov/books/NBK424533/
4. WHO. Food, genetically modified. World Health Organization. 2014. Available from: https://www.who.int/news-room/questions-and-answers/item/food-genetically-modified (Accessed on 10 June 2024)
5. Oliver MJ. Why we need GMO crops in agriculture. Missouri Medicine. 2014;111(6):492-507. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6173531/
6. Cohen SN, Chang ACY, Boyer HW, Helling RB. Construction of Biologically Functional Bacterial Plasmids In Vitro. Proceedings of the National Academy of Sciences. 1973;70(11):3240–4. http://dx.doi.org/10.1073/pnas.70.11.3240
7. Lombardo L, Grando MS. Genetically Modified Plants for Nutritionally Improved Food: A Promise Kept? Food Reviews International. 2019;36(1):58–76. http://dx.doi.org/10.1080/87559129.2019.1613664
8. GM Monitor. Global GM Crop Area review. 2024. https://gm.agbioinvestor.com/downloads (Accessed on 10 June 2024)
9. Brookes G, Barfoot P. Economic impact of GM crops. GM Crops & Food. 2014;5(1):65–75. http://dx.doi.org/10.4161/gmcr.28098
10. James C. Global Status of Commercialized Biotech/GM

Crops: 2013. ISAAA Brief No. 46. 2013. Available from: https://www.isaaa.org/resources/publications/briefs/46/executivesummary/ (Accessed on: 16 June 2024)

11. Kramkowska M, Grzelak T, Czyżewska K. Benefits and risks associated with genetically modified food products. Ann Agric Environ Med. 2013;20(3):413-9. Available from: https://pubmed.ncbi.nlm.nih.gov/24069841/
12. Nicolia A, Manzo A, Veronesi F, Rosellini D. An overview of the last 10 years of genetically engineered crop safety research. Critical Reviews in Biotechnology. 2013;34(1):77–88. http://dx.doi.org/10.3109/07388551.2013.823595
13. Schafer MG, Ross AA, Londo JP, Burdick CA, Lee EH, Travers SE, et al. The Establishment of Genetically Engineered Canola Populations in the U.S. Herrera-Estrella A, editor. PLoS ONE. 2011;6(10):e25736. http://dx.doi.org/10.1371/journal.pone.0025736
14. Aggarwal S (Rob). What's fueling the biotech engine—2011 to 2012. Nature Biotechnology. 2012;30(12):1191–7. http://dx.doi.org/10.1038/nbt.2437
15. Mmbando GS. The Adoption of Genetically Modified Crops in Africa: the Public's Current Perception, the Regulatory Obstacles, and Ethical Challenges. GM Crops & Food. 2024;15(1):185–99. http://dx.doi.org/10.1080/21645698.2024.2345401
16. Chambers JA, Zambrano P, Falck-Zepeda J, Gruère G, Sengupta D, Hokanson K. GM agricultural technologies for Africa - a state of affairs. International Food Policy Research Institute (IFPRI). 2014. Available from: https://www.afdb.org/fileadmin/uploads/afdb/Documents/Generic-Documents/IFPRI_-_AFDB_Agric_Biotech_Report_-_EN_-_04.07.2014.pdf (Accessed on: 25 May 2024)
17. Gbashi S, Adebo O, Adebiyi JA, Targuma S, Tebele S, Areo OM, et al. Food safety, food security and genetically modified organisms in Africa: a current perspective. Biotechnology and Genetic Engineering Reviews. 2021;37(1):30–63. http://dx.doi.org/10.1080/02648725.2021.1940735
18. Zhou XH, Dong Y, Xiao X, Wang Y, Xu Y, Xu B, et al. A 90-day toxicology study of high-amylose transgenic rice grain in Sprague–Dawley rats. Food and Chemical Toxicology. 2011;49(12):3112–8. http://dx.doi.org/10.1016/j.fct.2011.09.024
19. Song H, He X, Zou S, Zhang T, Luo Y, Huang K, et al. A 90-day subchronic feeding study of genetically modified rice expressing Cry1Ab protein in Sprague–Dawley rats. Transgenic Research. 2014;24(2):295–308. http://dx.doi.org/10.1007/s11248-014-9844-6
20. Tsatsakis AM, Nawaz MA, Kouretas D, Balias G, Savolainen K, Tutelyan VA, et al. Environmental impacts of genetically modified plants: A review. Environmental Research. 2017;156:818–33. http://dx.doi.org/10.1016/j.envres.2017.03.011
21. Nawaz MA, Golokhvast KS, Tsatsakis AM, Lam HM, Chung G. GMOs, Biodiversity and Ecosystem Processes. Topics in Biodiversity and Conservation. 2020;3–17. http://dx.doi.org/10.1007/978-3-030-53183-6_1
22. Gilbert N. Case studies: A hard look at GM crops. Nature. 2013;497(7447):24–6. http://dx.doi.org/10.1038/497024a
23. Ray DK, Ramankutty N, Mueller ND, West PC, Foley JA. Recent patterns of crop yield growth and stagnation. Nature Communications. 2012;3(1). http://dx.doi.org/10.1038/ncomms2296
24. Ricroch AE, Bergé JB, Kuntz M. Evaluation of Genetically Engineered Crops Using Transcriptomic, Proteomic, and Metabolomic Profiling Techniques. Plant Physiology. 2011;155(4):1752–61. http://dx.doi.org/10.1104/pp.111.173609
25. Binimelis R, Myhr AI. Socio-economic considerations in GMO Regulations: opportunities and challenges. Know your food. 2015;61–7. http://dx.doi.org/10.3920/978-90-8686-813-1_8
26. Ansori AN, Antonius Y, Susilo RJ, Hayaza S, Kharisma VD, Parikesit AA, Zainul R, Jakhmola V, Saklani T, Rebezov M, Ullah ME, Maksimiuk N, Derkho M, Burkov P. Application of CRISPR-Cas9 genome editing technology in various fields: A review. Narra J. 2023;3(2):e184. http://dx.doi.org/10.52225/narra.v3i2.184
27. Kumar K, Gambhir G, Dass A, Tripathi AK, Singh A, Jha AK, Yadava P, Choudhary M, Rakshit S. Genetically modified crops: current status and future prospects. Planta. 2020;251(4):91. http://dx.doi.org/10.1007/s00425-020-03372-8