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A Narrative Review of Genetically Modified Organisms and Public Health in Nigeria: Balancing Benefits, Concerns, and Regulatory Challenges

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Abstract

Background: Genetically modified organisms (GMOs) are one of the most debated scientific innovations, sitting at the intersection of agriculture, biotechnology, ethics, and public health. They offer potential benefits such as improved yields, enhanced nutrition, and reduced pesticide use, but concerns about safety, biodiversity, and socio-economic inequities persist. This debate is particularly significant in low- and middle-income countries, where food insecurity and weak regulatory systems amplify both opportunities and risks. This review aims to define GMOs and outline the biotechnology tools used in their development, examine Nigeria's regulatory and policy context, synthesize evidence on documented benefits and major concerns, and explore public health implications.

Methods: Evidence was drawn from peer-reviewed articles, international reports, and regulatory documents. Thematic synthesis was applied to categorize findings into biotechnology tools, regulatory approaches, benefits, concerns, and public health implications.

Results: GMOs developed through biotechnology tools have enabled traits such as pest resistance, herbicide tolerance, and bio-fortification. Documented benefits include higher yields, improved farmer income, reduced pesticide-related health risks, and nutrition enhancement through crops. However, potential allergenicity, ecological disruption, herbicide overuse, and seed dependency remain concerns. Indirect implications include socio-economic inequities, public mistrust, and cultural opposition. Nigeria's regulatory framework progress but faces challenges of capacity, transparency, and public engagement.

Conclusion: GMOs hold promise for food security and public health but raise unresolved scientific, ecological, and equity concerns and dilemmas. Strengthening transparent regulation, post-release monitoring, and participatory dialogue is essential for balancing benefits and risks, ensuring that GMO adoption contributes sustainably to health and development.

Keywords: Genetically Modified Organisms, Biotechnology, Genome Editing, Food Security, Public Health, Nigeria

Background

Genetically modified organisms (GMOs) remain one of the most debated innovations in modern science, straddling the interface of agriculture, biotechnology, ethics, and public health. Since the commercial introduction of genetically engineered crops in the mid-1990s, proponents have highlighted their potential to improve crop yields, enhance nutritional value, reduce reliance on pesticides, and address food insecurity.[1,2,3] Critics, however, argue that GMOs pose risks to human health, biodiversity, and socio-economic equity, fuelling public scepticism and regulatory tensions across regions.[4] This divergence of opinion underscores the importance of interrogating concerns, clarifying scientific evidence, and understanding the public health implications of GMOs in a rapidly evolving food landscape.

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The significance of this discussion is particularly acute for low- and middle-income countries (LMICs), where malnutrition, food insecurity, and agricultural vulnerabilities intersect with limited regulatory capacity. For instance, the adoption of bio fortified crops such as Golden Rice has been presented as a public health intervention to combat Vitamin A deficiency, a major contributor to childhood morbidity and mortality in parts of Asia and Africa.[6] Conversely, concerns over corporate control of seed systems, potential allergenicity, and unintended ecological consequences have contributed to resistance against GMO adoption in many parts of Europe and Africa.[7] This global divide highlights the need for balanced, evidence-based assessments that acknowledge both the scientific truths and the socio-cultural concerns surrounding GMOs. Such an approach can enable policymakers, health professionals, and the public to make informed decisions about biotechnology and its role in promoting health and development. The aim of this study, therefore, is to critically review the scientific evidence, regulatory landscape, and public health implications of genetically modified organisms (GMOs) in Nigeria, with a view to balancing documented benefits, concerns, and governance challenges.

Methodology

This study adopted a narrative review design to examine genetically modified organisms (GMOs) and their public health implications in Nigeria. A narrative approach was chosen to integrate diverse evidence spanning biotechnology, regulation, socio-economic factors, and public health. Relevant literature was identified through searches of PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar, supplemented by grey literature from international organizations (WHO, FAO), regulatory bodies (National Biosafety Management Agency), and government publications. Search terms included combinations of "genetically modified organisms," "biotechnology," "public health," "food safety," "biosafety," "regulation," "Nigeria," and "Africa." Peer-reviewed articles, reviews, policy documents, and authoritative reports published in English were included if they addressed GMO development, regulatory frameworks, benefits, risks, public perception, or public health implications. Non-credible sources and materials without relevance to public health or policy were excluded.

Extracted information was thematically analysed and organized into key domains: biotechnology tools, regulatory approaches, benefits, concerns, public trust and communication challenges, adoption patterns, and direct and indirect public health implications. As this review relied solely on published literature, ethical approval was not required.

Defining GMOs

Genetically modified organisms (GMOs) are living organisms—plants, animals, or microorganisms—whose genetic material has been altered using modern biotechnology in ways that do not occur naturally through conventional breeding or natural recombination.[8] These modifications are achieved using molecular tools.[9,10] The purpose of genetic modification is typically to enhance desirable traits—such as pest and disease resistance, herbicide tolerance, improved nutritional value, or faster growth—while reducing undesirable ones.[7]

Thus, GMOs represent a diverse and evolving category of organisms developed to meet agricultural, medical, and industrial needs, while simultaneously raising regulatory, ethical, and public health considerations.

Biotechnology Tools in GMO Development

The development of genetically modified organisms (GMOs) relies on a variety of biotechnology tools designed to introduce, remove, or modify genetic material with precision. These biotechnology tools underpin modern GMOs across agriculture and medicine. Their evolution toward more precise genome editing has expanded benefits for food security, nutrition, disease prevention, and therapeutic innovation, while also shaping regulatory and biosafety debates relevant to public health (see Table 1 below).

Regulatory Approaches of GMOs

Regulatory approaches differ: the European Union emphasizes a process-based framework, whereas the United States employs a product-based approach[33] These differences influence global governance, labelling, and consumer acceptance. The process-based framework for regulating genetically modified organisms (GMOs) emphasizes the methods used to

Table 1: Overview of Biotechnology Tools Used in GMO Development

Biotechnology Tool	Basic Description	Key Applications (Examples)	Public Health Relevance
Recombinant DNA (rDNA) Technology	Introduction of specific genes into organisms using bacterial vectors (e.g., *Agrobacterium tumefaciens*, *Bacillus thuringiensis*).	**Plants:** Bt cotton and Bt maize for pest control,[11] Golden Rice enriched with β-carotene to reduce vitamin A deficiency,[12] herbicide-tolerant soybean.[13] **Animals:** AquAdvantage salmon (enhanced growth); transgenic goats producing antithrombin,[14] experimental disease-resistant poultry.[15] **Healthcare:** Recombinant insulin,[16] hepatitis B vaccine,[17] monoclonal antibodies and clotting factors.	Improves food security, nutrition, and access to essential medicines; long history of safe use in healthcare supports risk communication.
Gene Gun (Biolistics)	Physical delivery of DNA into cells using DNA-coated particles.	**Plants:** Bt maize, herbicide-tolerant soybean,[1,2] rice and wheat with disease resistance,[18,19] virus-resistant papaya.[20] **Animals:** Transgenic mice,[21] poultry research.[22] **Healthcare:** DNA vaccines for influenza, hepatitis B, HIV,[23] cancer immunotherapy,[24] gene therapy research.[25]	Supports crop resilience and vaccine research; relevant for infectious disease control and food system stability.
CRISPR-Cas9 Genome Editing	Precise editing of specific DNA sequences without random gene insertion.	**Plants:** Disease-resistant rice,[26] GABA-enriched tomato,[27] drought-tolerant wheat and maize.[28] **Animals:** PRRSV-resistant pigs,[29] hornless cattle,[30] improved growth and disease resistance in fish.[31] **Healthcare:** Gene-editing trials for sickle cell disease and β-thalassemia,[32] CAR-T cancer therapies.	Enables targeted interventions with potential safety advantages; major implications for nutrition, animal welfare, and treatment of genetic diseases.
Other Gene-Editing Tools (TALENs & ZFNs)	Targeted gene editing tools that preceded CRISPR; more complex and costly.	**Plants:** Disease-resistant rice and wheat. **Animals:** Hornless cattle (TALENs),[30] PRRSV-resistant pigs via CD163 knockout (ZFNs).[29] **Healthcare:** Early human trials (ZFNs for HIV via CCR5 disruption); TALEN-based universal CAR-T cells.	Foundational tools for modern gene therapy; contributed to early clinical translation and biosafety frameworks.

develop the organism rather than the final product. Under this approach, regulatory scrutiny is triggered by the use of recombinant DNA technology or any form of genetic engineering, regardless of the traits expressed in the final organism. For instance, the European Union (EU) adopts a process-based framework in which GM crops such as Bt maize are subject to strict authorization, labelling, and traceability requirements because of the genetic modification techniques employed.[34] Critics argue that this approach can stifle innovation, as it does not consider that conventionally bred crops may also carry genetic risks.[5]

By contrast, the product-based approach evaluates the characteristics of the final organism rather than the process used in its creation. The focus is on the safety, composition, and intended use of the product, irrespective of whether it was developed through genetic engineering or conventional breeding. Countries like the United States and Canada follow this approach, regulating GMOs through existing food and environmental safety frameworks, such as the Coordinated Framework for Regulation of Biotechnology in the U.S.[35] For example, if a genetically engineered tomato has the same safety profile as a conventionally bred tomato, it is regulated similarly. Proponents of this model argue that it is more scientifically defensible and promotes innovation while ensuring public safety.[4]

GMO Introduction in Nigeria: Public Trust, Adoption, Health Communication, and Governance

Nigeria has emerged as one of the most active African countries in the research, regulatory approval, and early commercialization of genetically modified (GM) crops. The national regulatory framework is anchored in the National Biosafety Management Agency (NBMA) Act of 2015 and its 2019 amendment, which designate NBMA as the authority responsible for risk assessment, approval, and post-release oversight of modern biotechnology products.[39] Under this framework, several GM crops have received approval for environmental release and commercialization, including Bt cotton for fibre production, Bt cowpea (pod-borer–resistant cowpea) approved in 2019 as Nigeria's first commercialized GM food crop, and more recently, insect-resistant and drought-tolerant maize varieties (TELA maize).[36–38] The NBMA maintains that approvals are science-based and include pre-market risk assessment and post-release monitoring requirements.[39]

Despite this regulatory structure, public trust remains a major challenge. Public understanding of GMOs in Nigeria is generally low, and risk communication has often been perceived as top-down, technical, and insufficiently inclusive.[40] Civil society organizations, faith-based groups, and environmental advocates have expressed concerns about long-term health effects, environmental contamination, seed sovereignty, and multinational corporate influence.[40,43] Media narratives have sometimes amplified fears around herbicide use, bio-fortification ethics, and perceived loss of traditional farming systems, contributing to scepticism and polarized public discourse.[43] These dynamics highlight a persistent gap between regulatory assurances and public confidence, underscoring the importance of transparent, culturally sensitive health communication strategies.

Adoption rates and farmers' perceptions of GM crops in Nigeria appear mixed but generally cautious. Early reports suggest that Bt cowpea adoption has been gradual, with higher uptake among farmers who experienced significant yield losses from pod-borer infestations, while others remain hesitant due to seed cost, access concerns, and uncertainty about market acceptance.[36,38] Studies across sub-Saharan Africa indicate that farmers' acceptance of GM crops is strongly influenced by perceived economic benefit, trust in government institutions, and access to reliable extension services—factors that remain uneven in Nigeria.[3,42] Where extension and demonstration trials are effective, perceptions tend to improve, suggesting that farmer-facing communication plays a critical role in adoption.

From a public health surveillance perspective, Nigeria currently lacks a robust, integrated system for long-term monitoring of human health outcomes associated with GM food consumption. While NBMA mandates post-release environmental monitoring, systematic dietary exposure assessment and population-level health surveillance linked specifically to GM crops remain limited.[39] Existing oversight focuses more on environmental biosafety than on epidemiological follow-up, reflecting broader capacity constraints in food safety surveillance systems. This gap has fuelled public concern, as the absence of visible health monitoring is sometimes interpreted as absence of precaution rather than a lack of evidence of harm.

Governance of GMOs in Nigeria thus reflects a tension between innovation-driven food security goals and unresolved public trust and communication challenges. Strengthening laboratory capacity, improving post-market environmental and health surveillance, institutionalizing participatory risk communication, and integrating public health agencies more explicitly into GMO oversight could enhance credibility and legitimacy.[3,39,42] Without these measures, regulatory approvals alone may be insufficient to achieve broad societal acceptance or sustainable adoption.

Documented Benefits of GMOs

Agricultural Productivity and Food Security

One of the most significant benefits of GMOs is their contribution to increased agricultural productivity. GM crops such as Bt maize and Bt cotton, engineered to produce Bacillus thuringiensis toxins, provide inherent resistance to insect pests, reducing crop losses and decreasing the need for chemical insecticides.[37] Similarly, herbicide-tolerant soybean and maize varieties allow farmers to control weeds more efficiently, improving yields.[1] These advances are particularly valuable in regions facing food insecurity, where GM crops can enhance food availability and resilience against pests and environmental stresses.

Environmental Benefits

GM crops can also generate environmental advantages. Reduced reliance on chemical pesticides not only lowers production costs but also minimizes environmental contamination and risk to non-target species.[44] In some cases, GM crops contribute to conservation agriculture, as herbicide-tolerant varieties enable low- or no-tillage farming, reducing soil erosion and greenhouse gas emissions.[1] This positions GMOs as a potential tool in climate change mitigation strategies within agriculture.

Health and Nutrition Improvements

In addition to agricultural benefits, some GMOs are designed to directly improve human health and nutrition. A notable example is Golden Rice, engineered to produce beta-carotene, a precursor of vitamin A, to address vitamin A deficiency—a major cause of childhood blindness and mortality in developing countries.[45] Bio fortified crops with enhanced iron, zinc, or folate content are under development and could reduce micronutrient deficiencies that affect billions worldwide.[46] GM crops can also reduce exposure to harmful mycotoxins, as insect-resistant maize suffers less fungal contamination.[47]

Economic Benefits to Farmers

Economic studies consistently show that GM crop adoption has delivered substantial economic gains, especially for smallholder farmers in developing countries. Farmers adopting GM cotton in India, for example, experienced significant increases in income due to higher yields and reduced pesticide costs.[48] Globally, GM crop adoption between 1996 and 2018 is estimated to have provided over $225 billion in economic benefits to farmers.[1]

Major Concerns with the Adoption of GMOs

Despite the potential benefits of genetically modified organisms (GMOs) in addressing food insecurity, improving agricultural productivity, and enabling biomedical innovation, their adoption has sparked significant debate globally and locally. For instance, in Nigeria, despite the approvals by NBMA, the introduction of GMOs in Nigeria has generated substantial public debate that spans scientific, socio-economic, ethical, and public-health dimensions. Advocates — including parts of the scientific community, agricultural research institutes, and some government agencies — argue that GM traits such as insect resistance and drought tolerance can reduce pesticide use, raise yields, enhance farmer incomes, and improve food security.[37,41] For example, trials of Bt cowpea documented large reductions in pod borer damage and pesticide spraying, suggesting direct benefits for farmer health and environmental exposures.[41] Conversely, civil-society groups, some farmer organizations, and public interest NGOs have raised concerns about corporate control of seeds, potential ecological harms (e.g., gene flow, resistance evolution), food sovereignty, and incomplete assessment of long-term human health effects. These critics have pushed for stronger precautionary provisions in national law and have called for more transparent stakeholder engagement and mandatory labelling.[49]

Concerns discussed in the Nigerian debate and indeed globally often cut across several overlapping categories comprising of human health, environmental sustainability, socio-economic impacts, and ethical considerations.

Human Health Concerns

One of the most widely debated issues relates to the safety of GM foods. Critics argue that genetic modification may introduce new allergens or toxins into food products, or result in unintended effects due to gene insertion.[50] Although regulatory bodies like the World Health Organization (WHO) and Food and Agriculture Organization (FAO), international reviews and case-by-case risk assessments generally find no evidence that currently approved GM foods are inherently more hazardous than their conventional counterparts,[3,51] skepticism persists, particularly around the long-term health impacts of consumption.[52] Also, there are indirect, systems-level concerns — for example, how seed market concentration, intellectual property, and changes in cropping systems could affect smallholder livelihoods, nutrition, and resilience, which in turn influence population health.[7,53] In Nigeria these public-health angles are debated not only on scientific grounds but also through the lens of equity and food sovereignty, with calls that any biotech deployment be accompanied by robust surveillance, farmer training, and access safeguards.[39,40]

Environmental Concerns

GMOs also raise environmental issues. there are exposure and poisoning concerns linked to the agrochemical regimes associated with some GM traits (e.g., herbicide-tolerant crops can change herbicide use patterns with the emergence of herbicide-resistant weeds, leading to concerns about biodiversity loss); these changes affect farmworker and community pesticide exposures and require monitoring of chemicals and biomarkers to quantify public-health impacts.[41,42,54] Similarly, the release of genetically modified plants may affect non-target species, disrupt ecological balance, and reduce genetic diversity within crop populations.[55] These ecological risks remain a central argument against widespread GMO adoption.

Socio-Economic Concerns

Socio-economic issues further complicate GMO adoption. Patents and intellectual property rights held by multinational biotech companies often limit farmers' autonomy and create dependency on expensive seeds.[58] Smallholder farmers in developing countries may face economic disadvantages, as they cannot save or exchange patented GMO seeds. Additionally, concerns exist that GM crop production could contribute to the corporate monopolization of food systems, reducing diversity in farming practices and exacerbating inequities between large-scale and small-scale farmers.[56]

Ethical and Cultural Concerns

Finally, ethical and cultural considerations play a role in GMO debates. Critics argue that genetic modification may constitute an "unnatural" interference in life forms, raising moral objections. Religious and cultural beliefs may also shape opposition, as seen in some African countries where GMO adoption is rejected on moral and spiritual grounds.[57] The lack of transparent labelling of GM foods in many regions also fuels mistrust among consumers who wish to make informed choices.

Public Health Implications of GMOs

The adoption of genetically modified organisms (GMOs) in agriculture and food systems has raised significant debate regarding their public health implications. These implications can be categorized into direct and indirect effects on population health.

Direct Public Health Implications

Direct public health implications relate to the safety and nutritional quality of GMO-derived foods. Studies have shown that most commercially approved GMOs are substantially equivalent in safety and nutrition to conventional crops.[2] Nonetheless, concerns persist regarding potential allergenicity, toxicity, and unintended health effects from novel proteins expressed in GMO foods.[50] For example, transgenic crops that express insecticidal proteins (such as Bt toxins) are scrutinized for possible allergenic reactions, though no confirmed cases have been reported in humans.[52]

On the positive side, GMOs hold potential to improve nutrition and prevent micronutrient deficiencies. For instance, Golden Rice enriched with beta-carotene provides a sustainable strategy to combat vitamin A deficiency—a major cause of preventable childhood blindness and mortality in developing countries.[45] Similarly, bio fortified GMO crops are being developed to enhance iron, zinc, and folate content, offering direct nutritional benefits.

Indirect Public Health Implications

Indirect implications stem from the broader ecological, economic, and social consequences of GMO adoption that eventually influence public health. Environmentally, herbicide-tolerant crops may encourage excessive herbicide use, leading to the emergence of herbicide-resistant weeds and higher chemical residues in food and the environment.[54] These practices may contribute to chronic exposure risks for farming communities and consumers. Additionally, pest-resistant crops like Bt maize reduce reliance on chemical insecticides, indirectly lowering occupational pesticide poisoning and associated health risks.[44]

Socio-economically, the dependency on patented GMO seeds raises equity issues, particularly for smallholder farmers in low- and middle-income countries. Farmers' economic vulnerability may indirectly affect household food security and nutrition, thereby influencing public health.58 Furthermore, public mistrust and lack of transparent labelling of GMO foods can cause anxiety, erode confidence in food systems, and contribute to risk perception-driven dietary choices.[57]

Taken together, the public health implications of GMOs are complex and context-specific. While GMOs present opportunities for nutritional enhancement and reduced pesticide exposure, challenges such as long-term safety uncertainties, ecological impacts, and socio-economic inequities must be carefully managed through transparent regulation, monitoring, and public engagement.

Conclusion and Recommendation

Genetically modified organisms sit at the crossroads of science, health, and society. They embody both the promise of biotechnology—greater food security, improved nutrition, and reduced pesticide dependence—and the anxieties of modern agriculture, from ecological disruption to socio-economic inequity. The debate is not merely scientific but deeply ethical, cultural, and political. For public health, the implications are twofold: directly influencing what people eat and indirectly shaping the environments and economies that determine population health.

The way forward requires more than polarized debates. It calls for transparent regulation, inclusive dialogue, and investments in independent researches to address long-term safety, environmental sustainability, and equity concerns. By moving beyond myths and misconceptions, societies can engage in evidence-based decision-making that respects both innovation and precaution. In doing so, GMOs can shift from being symbols of controversy to tools for advancing health, sustainability, and development in a world that urgently needs solutions to hunger, malnutrition, and climate stress.

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