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REVIEW

GMOs and Africa's food security: safety and potential for sustainable development

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ABSTRACT

BACKGROUND:
Genetically modified organisms (GMOs) are promoted as tools to strengthen food security in Africa, yet their adoption varies across countries due to regulatory diversity, infrastructural challenges, and cultural perceptions. Understanding these dynamics is essential for evidence-based policymaking.

OBJECTIVE:
This review aimed to assess the current status of GMO adoption in Africa, evaluate its impacts on food production and livelihoods, and analyze the roles of stakeholders in shaping regulatory approaches and public acceptance.

METHODS:
A narrative review of peer-reviewed literature published from June 2024 to July 2025 was performed using PubMed, Scopus, and Google Scholar. Papers were included if they were in English, Africa-focused, empirically grounded, and addressed agriculture, food security, biodiversity, regulation, or socioeconomic outcomes. From 245 articles screened, 73 met inclusion criteria after title/abstract and full-text review. Data extracted covered geographical scope, crop type, outcomes (e.g., yield, pesticide use, biodiversity), regulatory settings, and stakeholder influence. Findings were synthesized thematically, with attention to cross-regional variation.

RESULTS:
The evidence shows that South Africa, Kenya, Ethiopia, and Sudan have progressed in GMO commercialization, while many other countries remain cautious due to biosafety concerns, regulatory uncertainty, and cultural resistance. GMOs demonstrate potential to increase yields, reduce pesticide dependence, and improve drought resilience. However, benefits are uneven and shaped by infrastructure, policy quality, and societal acceptance.

CONCLUSION:
Compared with agroecology and conventional breeding, GMOs provide significant but context-dependent advantages. Achieving sustainable adoption in Africa will require coherent policy frameworks, investment in rural infrastructure, and inclusive engagement with diverse public perspectives to ensure equitable benefits and protection of biodiversity.

KEYWORDS:
Adoption Rates, Agricultural Biotechnology, Biosafety Regulations, Drought Tolerance, Misconception, Myth, Public Perception, Sustainable Agriculture, Technology Acceptance

INTRODUCTION

Africa faces major food security challenges despite vast agricultural potential. Although the continent holds about 25% of the world's fertile soil, it contributes only 10% of global agricultural output. This underutilization stems from limited access to modern farming technologies and underinvestment in critical infrastructure[1]. Nearly one-third of the world's chronically malnourished population lives in Africa[2], underscoring persistent food insecurity.

Factors such as widespread agricultural pests, plant diseases, and increasingly harsh climatic conditions exacerbate these challenges[3]. Rapid population growth, especially in Sub-Saharan Africa with an annual rate near 3%, further strains food systems[4]. In 2022, about 61% of Africans faced moderate to severe food insecurity, well above the global average[5]. Addressing this requires targeted investment in pest control, irrigation, and biotechnologies[1,5]. Biotechnology, particularly genetic engineering, has become a key tool to improve crop resilience. Genetically Modified Organisms (GMOs) are organisms whose DNA is altered by introducing genes from unrelated species, creating traits such as pest resistance, drought tolerance, or improved nutrition[6,7]. Since their commercial debut in 1996, biotech crops expanded from 1.7 million hectares in six countries to nearly 192 million hectares in 70 countries by 2018, the fastest adoption of any agricultural technology[11]. GMOs can increase yields, reduce pesticide use, and improve nutrition[12,13]. In Sub-Saharan Africa, they are seen as part of wider food security and sustainability strategies[14]. Yet, public perception remains mixed due to cultural, ethical, and socioeconomic concerns, requiring a balance between innovation and caution [9,15].

GMOs development was driven by environmental concerns from the 1970s Green Revolution and advances in recombinant DNA technologies[16-19]. Their main goals are higher yields, pest- and disease-resistant crops, and improved nutrition, to address hunger, resource scarcity, and climate change[20,21]. High-income countries lead in transgenic adoption, while many African nations face financial and technical barriers [22,23]. Countries such as South Africa, Ethiopia, Sudan, Eswatini, and Kenya have biosafety laws permitting GM crop release[24]. Yet, adoption remains uneven, with only about 3 million hectares under cultivation by 2021[25].

Adoption depends on policy frameworks, infrastructure, and public attitudes, shaped by cultural perceptions [26-29]. Kenya shows that sound policy, education, and public engagement improve GMOs acceptance [30]. Still, high seed costs, dependence on proprietary seeds, and herbicide-resistant pests hinder sustainable adoption[31,32]. Initiatives like SABIMA (Sustainable Agricultural Biotechnology for Smallholder Farmers) aim to help smallholder farmers integrate GMOs sustainably [33]. GMOs offer benefits such as higher yields, pest and drought resistance, and reduced pesticide use[34-36]. Concerns include biodiversity loss, health risks, and socio-economic impacts like market monopolies that disadvantage smallholders [15, 37, 38]. Addressing these issues requires robust regulatory systems, public education, and equitable policies[15]. Social, political, and economic realities in Africa shape GMOs adoption and demand context-specific strategies[25,39-42].

This review explored GMOs adoption across Africa, focusing on regional differences in Southern, Eastern, Western, and Northern Africa. It also analyzed national case studies to identify drivers and barriers such as public attitudes, policy gaps, and infrastructure limitations. The review also assessed GMOs' impact on smallholders, considering yields, production costs, and income, and examined the roles of governments, researchers, farmers, and NGOs in shaping policy and fostering regional coordination. It further evaluated biosafety and regulatory frameworks and compared GMOs with other innovations such as agroecology and conventional breeding under climate stress.

METHODS

A narrative review method was employed to synthesize peer-reviewed literature on GMOs adoption, benefits, drawbacks, and governance in Africa. Unlike systematic reviews or meta-analyses, this approach as shown in Fig. 1 allows flexible summarization of heterogeneous sources to identify common themes and insights. A systematic search of PubMed, Scopus, and Google Scholar was conducted, using keywords such as

"Genetically modified organisms," "GMOs and food security," "Africa and agriculture," "biodiversity and rural development," and "poverty in farming communities." Inclusion criteria required articles to be (1) English-language, peer-reviewed, (2) focused on GMOs in the African context with relevance to agriculture, food security, biodiversity, policy, or socioeconomics, and (3) presenting empirical findings or case studies involving African populations. Grey literature, opinion pieces, and studies outside Africa were excluded. Of 245 initially identified articles, 73 met the inclusion criteria after title, abstract, and full-text screening. Data extracted included geographic location, crop type, reported outcomes (yield changes, pesticide use, biodiversity impacts), regulatory context, funding, and conflict of interest declarations. Risk of bias was assessed based on methodological transparency and reporting clarity.

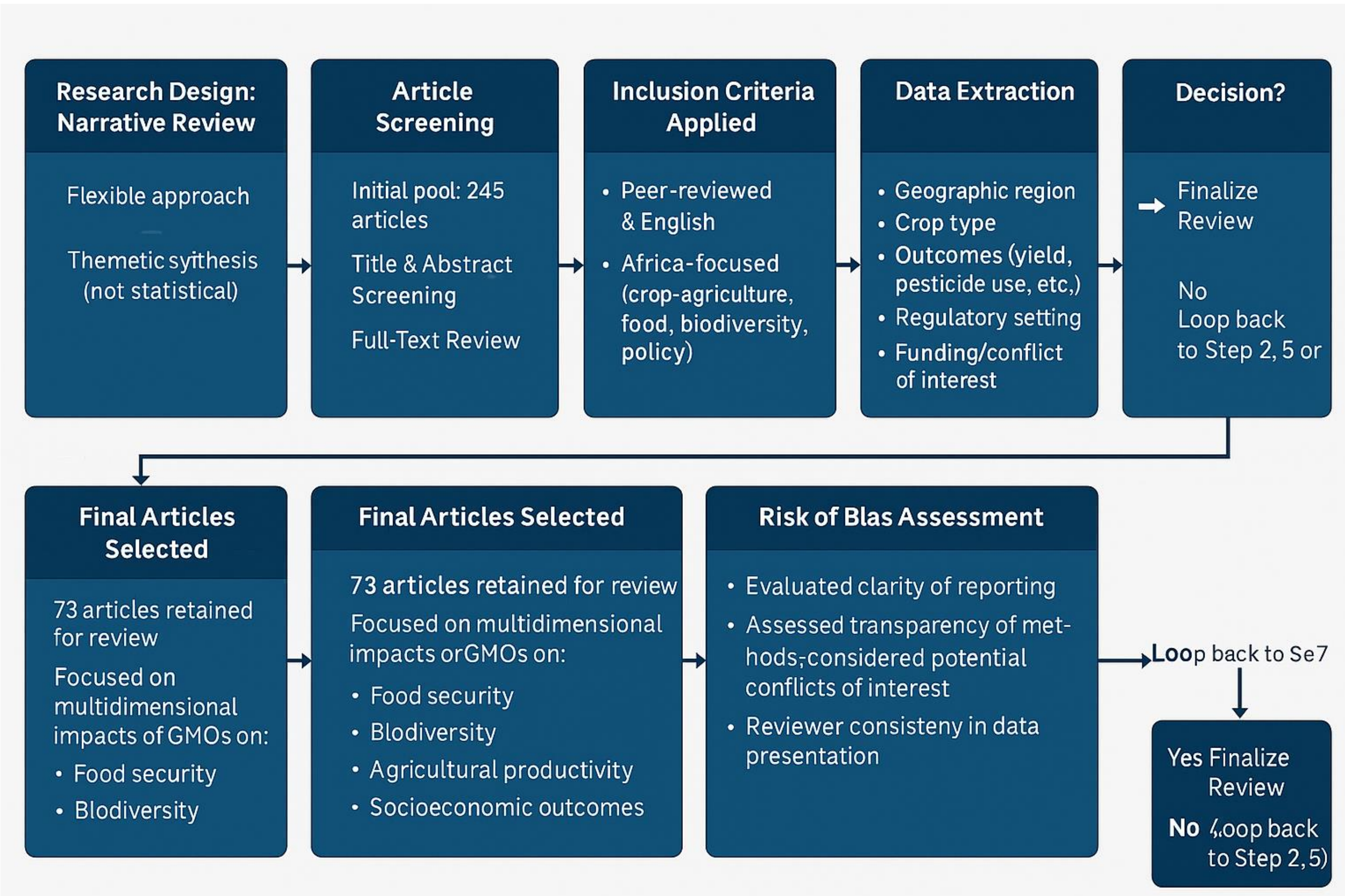

Figure 1. Methodological Flow of the Narrative Review: Green boxes show the main process phases; arrows indicate sequence. Step 9 is a decision checkpoint that can loop back to earlier phases if refinement is needed.

RESULTS

Africa's GMOs Situation:

GMOs adoption in Africa is slow and contested, balancing agricultural needs against food safety concerns. While GMOs could address water scarcity, pest outbreaks, and land degradation, doubts remain about impacts on health, biodiversity, and ecosystems [13,43,44]. Ethical debates, weak regulation, and public skepticism hinder acceptance. Overcoming these barriers requires inclusive dialogue, evidence-based policy, and context-sensitive innovation [45].

Table 1 summarizes adoption trends across selected nations. South Africa and Sudan report yield gains and reduced pesticide use, while Uganda and Tanzania remain at trial stage due to regulatory barriers. This highlights both the potential benefits of GMOs and the policy and implementation gaps shaping adoption [46].

Barriers and Opportunities for GMOs Adoption: Misconceptions, cultural beliefs, and safety concerns slow GMOs adoption. Many still view GMOs as harmful despite limited scientific evidence [22]. Addressing these concerns requires comprehensive biosafety regulations, rigorous environmental and health risk assessments, and targeted public education to improve understanding of GMOs science. Harmonized biosafety laws across Africa could strengthen regional cooperation and biotechnology trade, boosting food security [47,48]. GMOs can improve productivity, food security, and economic growth, but integration must account for socioeconomic realities, legal frameworks, and public attitudes. Policies must reflect sociopolitical contexts and cultural values, while staying adaptable to evolving science and public attitudes [49, 50].

Table 1. GMO Adoption Trends, Crop Types, and Benefits Across Selected African Countries [46]

Country	GMO Crop(s)	Adoption Status	Notes	GMO Crop(s)_2	Benefits Experienced	Adoption Status_2
South Africa	Maize, Cotton, Soybean	Full Commercial Adoption	First African country to adopt GM crops; well-regulated sector.	Maize, Cotton	Yield ↑, Pesticide ↓, Profit ↑	Commercialized
Sudan	Bt Cotton	Commercial since 2012	Significant reduction in pest-related losses.	Bt Cotton	Pest resistance, Income ↑	Commercialized (since 2012)
Burkina Faso	Bt Cotton (withdrawn)	Initial Adoption, Later Halted	Withdrawn due to fiber quality issues despite yield benefits.			
Nigeria	Bt Cotton, Bt Cowpea	Approved for commercial release	Bt Cowpea released as first GM food crop in Africa (2019).	Cowpea, Cotton	Yield ↑, Food security ↑	Approved and Adopted
Kenya	Maize, Cotton	Regulatory approval granted	Commercialization ongoing; biosafety authority active.	Maize, Cotton	Drought resistance, Yield ↑	Regulatory Approval
Uganda	Banana, Cassava, Maize	Field Trials	Delays due to lack of biosafety legislation.	Banana, Cassava	Virus resistance, Yield potential ↑	Field Trials Ongoing
Ghana	Bt Cowpea	Confined Field Trials	Public-private partnerships active.	Bt Cowpea	Field performance promising	Confined Trials
Tanzania	Drought-tolerant maize	Trials Only	Limited adoption due to biosafety policy hesitancy.			

Table 2 summarizes biotech crop implementation in Africa (2012–2018), including cultivation scale, GFSI (Global Food Safety Initiative) changes, economic outcomes (notably Bt cotton), approval status, and prevailing legal frameworks[51]-[53]. Despite skepticism, integrating GMOs with agroecological practices requires science-based decision-making. Benefits for farmers, consumers, and the environment depend on dialogue among governments, scientists, and stakeholders. This includes combating misinformation, educating the public on GMOs safety and advantages, and establishing transparent, strong regulatory systems [21,54,55].

Table 2. Integrated Summary of Biotech Crop Distribution, Food Security Trends, Agronomic Performance, Regulatory Approvals, and Legal Context in Africa (2012–2018)

Country	Burkina Faso	South Africa	Sudan	Egypt	eSwatini	Ethiopia	Ghana	Kenya
Total Area of Biotech Crops (2012–2018)	0.3	2.9, 2.9, 2.7, 2.3, 2.7, 2.7, 2.7	<0.1, 0.1, 0.1, 0.1, 0.1, 0.2, 0.2	-	-	-	-	-
Share in Agricultural Land 2018 (%)	0	22.5	1	-	-	-	-	-
Change 2012–2018 (2012=100.0)	0	93.1	200	-	-	-	-	-
Approved Crops	Cotton	Argentine Canola, Cotton, Maize, Rice, Soybean	Cotton	Maize	Cotton	Cotton	Cowpea	Cotton, Maize
Scientific Names	Gossypium hirsutum L.	Brassica napus, Gossypium hirsutum L., Zea mays L., Oryza sativa L., Glycine max L.	Gossypium hirsutum L.	Zea mays L.	Gossypium hirsutum L.	Gossypium hirsutum L.	Vigna unguiculata	Gossypium hirsutum L., Zea mays L.
Events Approved	1	75	1	1	2	2	1	2
Biosafety Laws and GM Commercial Crops	YES	YES	YES	YES	YES	YES	YES	YES
GFSI 2012	33.2	61.5	34.4					
GFSI 2018	37.9	65.5	36.4					
Change in GFSI (%)	0.142	0.065	0.058					
Change in Biotech Area	++	+	+++					
Bt Yield (kg/ha)		1178						
Conventional Yield (kg/ha)		997						

Yield Difference (kg/ha)		181						
Bt Income ($/ha)		3.17						
Conventional Income ($/ha)		-22.89						
Income Difference ($/ha)		26.06						
Insecticide Cost Bt ($/ha)		6.29						
Insecticide Cost Conv ($/ha)		58						
Cost Difference ($/ha)		-51.71						
Revenue Bt ($/ha)		419.83						
Revenue Conv ($/ha)		354.32						
Net Income Bt ($/ha)		39						
Net Income Conv ($/ha)		-22.89						
Net Income Difference ($/ha)		61.89						
Genetically Modified Crops								Maize, Sorghum, Sweet Potato, Cassava, and Cotton

* Low-Income Food-Deficit Countries (LIFDCs) FAOSTAT 2019] Source: James 2012, 2013, 2014, 2016, 2017, 2018, FAOSTAT 2019], [51,52]

* Global Food Security Index Source: The Economist 2018]

*Increase or decrease: ≥ 1.0-9.9% +, 10.0-19,9% ++, ≥ 20.0% +++ [53]

Implications of GMOs Adoption:

GMOs and food innovations may enhance smallholder productivity, rural value chains, and community resilience by improving food access, safety, and health [56]. Yet impacts on livelihoods are complex. High seed costs and intellectual property rules limit access, favoring wealthier farmers and widening inequalities. This can marginalize smallholders and increase dependence on multinational seed companies [57]. Market-driven GMOs systems often prioritize profits over equity, raising sustainability concerns. Short-term gains from Bt cotton are offset by recurring seed and chemical costs, while seed monopolies threaten local innovation and self-reliance[57]. Thus, GMOs' contribution to sustainable development depends on robust policies, regulatory oversight, equity focus, capacity building, and support for agroecological alternatives[56].

Socioeconomic studies show GM crops often help smallholders raise yields and cut pest control costs. Bt cotton, for example, increased yields by about 18% over conventional cotton, improving farmer incomes [45]. Such results are notable in South Africa, Burkina Faso, and Egypt, where GM crops improved rural livelihoods and reduced poverty[53]. However, benefits are uneven. Smallholders face high seed costs and limited extension support, reducing their ability to benefit fully. Thorough evaluation and sound policy are needed to manage socioeconomic impacts, including trade dynamics, non-GMOs market access, and wider economic effects[43].

Challenges to Traditional Farming and Seed Sovereignty:

GM crops challenge traditional farming and seed sovereignty. Patented seeds and restrictive licenses prevent seed saving, undermining independence, biodiversity, and resilience [57]. They also weaken farmer-led breeding and distribution of locally adapted varieties, accelerating biodiversity loss and eroding indigenous knowledge. Replacing diverse crops with GM monocultures reduces resilience to environmental and cultural needs[58]. Top-down GMOs introduction often excludes community input, limiting smallholder agency and weakening traditional practices[22]. Food sovereignty and resilience require farmer control of seed systems, through community seed banks and participatory breeding that protect biodiversity and heritage [22].

Cultural Acceptance and Indigenous Knowledge:

Cultural acceptance of GMOs is closely linked to indigenous knowledge and local traditions, especially in African contexts where farming is deeply connected to cultural identity and social life. GMOs are often introduced via top-down approaches that overlook indigenous ecological knowledge, weakening their cultural relevance and contributing to skepticism and resistance [57]. Industrialized food systems shaped by GM technologies often prioritize yield and efficiency at the expense of cultural and spiritual values attached to indigenous crops [57]. Traditional farming knowledge, essential for biodiversity promotion and sustainable land management, is frequently ignored in biotechnology-centered models, risking alienation of local populations and undermining the credibility and sustainability of agricultural development strategies [58]. For GMOs adoption to be equitable and sustainable, it must be grounded in community participation, respect cultural values, and protect indigenous knowledge systems to sustain food sovereignty and resilience [58].

Environmental Impacts:

Widespread GMOs monocultures threaten biodiversity by replacing diverse local varieties with uniform ones, accelerating genetic erosion and vulnerability to pests and climate shocks[22,56]. This reduces ecosystem resilience and disrupts balances. Gene flow between GM and non-GM plants risks genetic contamination and loss of local biodiversity [22]. This reduces ecosystem resilience and disrupts balances. Gene flow between GM and non-GM plants risks genetic contamination and loss of local biodiversity[22]. GM crops may increase herbicide and fertilizer use, degrading habitats and simplifying landscapes[57].

Direct soil impacts of GM crops are limited, but herbicide-tolerant varieties often lead to heavier herbicide use, disturbing soil microbes, reducing biodiversity, and lowering fertility[57]. GMOs-linked intensification, reliant on synthetic inputs, can reduce soil organic matter, damage structure, and lower biological activity[57]. Bt crops reduced pesticide use initially, but prolonged exposure has accelerated pest resistance, reducing effectiveness[57]. This forces a return to chemicals and triggers secondary pest outbreaks[58]. In the Global South, long-term GMOs sustainability is uncertain. Gene transfer, pest resistance, and ecosystem disruption need further study, especially under weak regulation[55,59]. Seed market concentration threatens food sovereignty, increases dependency, and sidelines traditional practices[22, 56]. Critics warn high-input GMOs systems may conflict with agroecology and reduce adaptability to climate change[57].

Gender and Equity Considerations in GMO Adoption: Women provide a major share of agricultural labor, though recent data from six Sub-Saharan countries shows variation, about 24% in Niger to 56% in Uganda, with an average near 40% [59]. This highlights the need for gender-sensitive policies. Women remain vital in agriculture, but GMOs policies often ignore barriers they face in accessing inputs, training, and innovation. Ignoring these gaps risks marginalizing rural women and deepening inequality[59]. Limited access to land, credit, and extension services further hinders equitable GMOs adoption. Targeted, gender-responsive interventions are essential to ensure women's participation in decision-making and access to benefits from biotechnology [59,60].

Public concerns center on health, environment, and biodiversity. Although science shows GM crops are as safe as conventional ones, critics cite risks such as allergies, cancer, and ecological damage[61,43]. Concerns also include herbicide-resistant weeds and gene flow. Balancing these risks against benefits is essential. Perceptions are shaped by misinformation, cultural beliefs, and fears of corporate dominance[50, 62]. Building public trust requires transparent communication, education, and evidence-based dialogue [63–65]. Southern Africa, led by South Africa, has advanced GMOs adoption, while Eastern, Western, and Northern Africa face economic, regulatory, and public skepticism challenges[66,67]. Egypt, an early adopter, halted GMOs cultivation in 2012 over public opposition and regulatory issues, despite potential benefits[67,68]. Sustainable adoption requires harmonized, context-specific strategies that reflect cultural, socioeconomic, and environmental realities[64, 67].

DISCUSSION

Over three decades, no confirmed harm has been linked to approved GM crops. More than 4,485 risk assessments confirm GMOs are as safe as conventional crops, with no credible evidence of higher health or environmental risks[68]. International bodies (FAO, WHO, Codex Alimentarius, OECD (Organisation for Economic Co-operation and Development), EFSA (European Food Safety Authority)) provide harmonized biosafety frameworks with strict safety standards[68]. Despite scientific consensus, skepticism persists in Africa, driven by concerns about allergens, residues, gene transfer, and biodiversity. Misinformation, politics, and lack of trusted data reinforce these doubts [69]. Effective risk management requires strong food safety systems, context-specific risk assessments, and transparent communication. Although the Cartagena Protocol promotes precautionary case-by-case reviews, many African stakeholders see them as donor-driven and poorly aligned with local realities, fostering mistrust [70]. Strengthening science-based monitoring, supporting long-term ecological and health studies, and fostering inclusive governance are critical for rebuilding trust[69]. Many African countries have biosafety laws consistent with international standards, but enforcement is weak due to limited capacity, poor transparency, inadequate funding, and fragmented governance[68]. South Africa and Nigeria have stronger systems, but elsewhere progress is slowed by bureaucracy, political interference, and European-style precautionary models such as the African Model Law [68]. Weak inter-agency coordination, slow approvals, and inconsistent laws undermine governance. Donor-driven agendas and limited scientific literacy among policymakers worsen these gaps[68]. Regional harmonization efforts exist but remain uneven. Stronger scientific capacity, coordination, and transparency are urgently needed[68]. Public mistrust is fueled by fears of foreign corporate dominance, seed ownership, and intellectual property, seen as threats to autonomy and traditional practices[70]. Erosion of indigenous knowledge and ecological risks further deepen mistrust among scientists, policymakers, and farmers [70]. Legitimacy requires GMOs innovation to respect socio-cultural realities, food sovereignty, and ethics, supported by participatory and African-led regulation [70].

Effective GMOs policy demands transparent, science-based governance to counter misinformation and mistrust. Priorities include culturally relevant education, independent biosafety authorities with expert staff, and regional harmonization under the African Union[69,71]. Participation by farmers, researchers, civil society, and policymakers ensures technologies reflect local needs and agroecological realities[71]. Responsible GMOs adoption must combine science with respect for African food traditions and sovereignty. Context-specific approaches should complement, not replace, local agriculture. South, South cooperation and Africa-specific solutions can strengthen food security and equity across the continent [71]. Recent advances, including drought-tolerant maize, Bt brinjal, and Golden Rice, show GMOs' potential to improve yields, nutrition, and climate resilience[68]. International frameworks call for case-by-case risk assessments on allergenicity and environmental impacts. Global GM crop cultivation expanded 113-fold between 1996 and 2019, underscoring their rising importance[72]. Public–private partnerships and regional collaborations (e.g., AATF (African Agricultural Technology Foundation), AU (Astronomical Unit), ABNE (African Biosafety Network of Expertise)) support technology transfer, capacity building, and harmonized governance[48,13]. For real acceptance, innovation must be co-created with communities to ensure cultural and ecological compatibility. Participatory models involving farmers, policymakers, and civil society foster sustainability better than top-down approaches [73]. Field experiences reveal on-the-ground realities. Bt maize trials in Kenya improved yields and reduced pesticide use, but seed costs and reuse restrictions raised concerns. In Sudan, Bt cotton benefited large farms, but smallholders lacked technical and biosafety support. In Nigeria, trust improved through local engagement and extension officers[48,13]. Long-term success requires farmer education, localized support, and equitable access.

Study Limitations:

This review only considered English-language, peer-reviewed sources, potentially excluding relevant non-English or grey literature. The lack of meta-analysis restricts quantitative insights and statistical comparisons. Only studies published up to July 2025 were included; later developments were not captured. Data gaps in some African countries limited geographical representation and generalizability. Socio-cultural impacts, including gender roles, indigenous knowledge, and cultural values, require deeper research.

Weaknesses of the Study:

Reliance on secondary data may not fully reflect on-the-ground realities. Excluding non-English and grey literature may have omitted key regional perspectives. The absence of original field data and limited country coverage reduce the depth and generalizability of findings.

CONCLUSION

African agriculture stands at a pivotal juncture. GMOs can address food insecurity, climate stress, malnutrition, and economic marginalization, but success requires scientific rigor alongside ethical, social, and political alignment. This review underscores the need for evidence-based and context-specific GMOs adoption. Although global evidence affirms GMOs safety, public trust in Africa remains fragile due to historical inequities, corporate dominance fears, and cultural concerns. Innovation alone is insufficient; inclusive dialogue, participatory policies, and respect for indigenous knowledge are essential. Governments, researchers, and civil society must ensure transparent, locally grounded regulatory frameworks. Investment in education, biosafety infrastructure, and harmonized governance is vital to rebuild trust. Equitable access, particularly for marginalized groups, will decide whether biotechnology empowers communities or widens inequalities. Africa's challenge is not whether to adopt GMOs, but how to align them with its values, priorities, and traditions. Inclusive approaches can make GMOs tools of resilience that support sovereignty, sustainability, and food security.

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CONFLICT OF INTEREST

None declared.

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