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ADVANCING AGRICULTURAL BIOTECHNOLOGY IN NIGERIA: GENETIC ENGINEERING FOR CROP IMPROVEMENT.

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ABSTRACT

This paper explores the transformative potential of genetic engineering in addressing key agricultural challenges in Nigeria, including low productivity, pest infestation, climate change, and malnutrition. It provides a comprehensive overview of the concepts and techniques of genetic engineering such as CRISPR, recombinant DNA, and gene silencing and their applications in crop improvement. The study examines Nigeria's current regulatory framework, key institutions, and the status of genetically engineered crops like Bt cowpea and biofortified cassava. It also highlights the significant benefits of genetic engineering, such as increased yields, reduced pesticide use, climate resilience, and improved nutrition. However, challenges such as regulatory barriers, public skepticism, environmental risks, and inequitable access persist. The study concludes with actionable policy recommendations aimed at strengthening biosafety regulations, improving public engagement, and promoting inclusive innovation to ensure genetic engineering contributes meaningfully to Nigeria's food security and agricultural sustainability.

INTRODUCTION

In 2023, approximately 25.3 million Nigerians were projected to face acute food insecurity, particularly during the lean season between June and August (FAO & WFP, 2023). This grim projection is not just a number it represents millions of families skipping meals, children suffering from malnutrition, and communities sliding into deeper poverty. In northern Nigeria, especially in states like Borno, Yobe, and Adamawa, conflict and climate shocks have led to the destruction of farmland, displacement of farmers, and breakdown of food supply chains (World Food Programme, 2023). These conditions have turned food insecurity into a chronic crisis, posing a significant threat to national stability and development.

Food security, as defined by the Food and Agriculture Organization (FAO), entails access to sufficient, safe, and nutritious food that meets dietary needs for an active and healthy life. In Nigeria, food security is under constant threat from multiple fronts rising input costs, poor infrastructure, farmer-herder conflicts, and the increasing frequency of climate-related disasters such as floods and droughts (Nigerian Meteorological Agency, 2022). These challenges contribute to recurrent crop failures and post-harvest losses, which reduce the availability and affordability of food. In 2022 alone, the country lost over 50% of its tomato harvest due to pest infestation and flooding (Nigerian Agricultural Quarantine Service, 2022).

Agriculture refers to the science and practice of activities related to the production, processing, marketing, distribution, utilization and trade of food, feed, and fiber, including crop production, animal husbandry, and agroforestry (FAO, 2022). The United States Department of Agriculture (USDA) defines agriculture has the cultivation of soil, growing of crops, and raising of animals for food, fiber, fuel, and other products used to sustain and enhance human life USDA (2021). Also, agriculture involves all activities related to the production of food and goods through farming, forestry, fishing, and animal husbandry, serving as a major driver of economic growth and poverty reduction World Bank (2022)

Agriculture remains a vital component of economy, supporting over 70% of the rural population and contributing approximately 24% to the national Gross Domestic Product (GDP) (National Bureau of Statistics, 2022). The country possesses vast arable land, favorable agro-ecological zones, and a diverse array of crops. Major staple crops include maize, cassava, yam, rice, sorghum, and millet. Nigeria is the world's largest producer of cassava and yams, and among the top producers of maize and rice in sub-Saharan Africa (FAOSTAT, 2023). The agricultural sector's fragility has far-reaching implications for food security, poverty reduction, and economic resilience. As Nigeria's population approaches 223 million and continues to grow rapidly (World Bank, 2023), the pressure on food systems will only intensify. There is an urgent need for a transformative approach that addresses both the immediate drivers of food insecurity and the structural weaknesses of Nigeria's agricultural economy. This includes leveraging technology, promoting sustainable farming practices, and investing in rural infrastructure to build a more resilient and productive food system.

Despite its agricultural potential, Nigeria faces numerous challenges that hinder productivity and sustainability. One of the foremost issues is low crop yield, which is significantly below global averages. For instance, while average maize yields in the United States exceed 10 tons per hectare, Nigeria averages less than 2 tons per hectare (IFPRI, 2021). This productivity gap is exacerbated by the widespread use of traditional farming methods, limited access to improved seeds, and inadequate use of fertilizers and irrigation. Pests and diseases also present major threats. Crops such as cowpea and maize suffer substantial yield losses due to insect infestations like the *Maruca vitrata* pod borer and the fall armyworm, respectively. According to the Nigerian Agricultural Quarantine Service (2022), pest-related losses in major crops can reach up to 40% annually. Additionally, climate variability, including erratic rainfall patterns, droughts, and floods, has intensified the vulnerability of smallholder farmers. In 2022, devastating floods affected over 30 states in Nigeria, submerging farmlands and displacing thousands of farming households (NEMA, 2022).

This study aims to examines the transformative potential of genetic engineering in revitalizing Nigerian agriculture, particularly in addressing the pressing challenges of low crop productivity, vulnerability to pests and diseases, and the growing threat of climate change. As traditional farming methods struggle to meet the food demands of Nigeria's rapidly expanding population, genetic engineering offers a scientifically advanced and potentially sustainable solution. By enabling the development of high-yield, pest-resistant, and drought-tolerant crop varieties, genetic modification can significantly enhance agricultural resilience and efficiency. In doing so, it not only promises to boost food production but also contributes to long-term food security, poverty alleviation, and rural economic development across the country.

Overview of Agricultural Biotechnology

Agricultural biotechnology refers to the use of scientific tools and techniques, including genetic engineering, molecular markers, tissue culture, and genome editing, to modify living organisms particularly crops and livestock for the purpose of enhancing productivity, resilience, and nutritional value (FAO, 2022). It encompasses a broad spectrum of technologies aimed at improving agricultural practices by enabling crops to resist pests, tolerate extreme environmental conditions, and produce higher yields with fewer inputs. Among these, genetic modification (GM) has been the most transformative, involving the insertion or deletion of genes to achieve desirable traits.

Globally, the development of agricultural biotechnology can be traced back to the 1970s with the discovery of recombinant DNA technology, which paved the way for the first genetically modified crops in the 1990s. The United States, Brazil, Argentina, Canada, and India are among the top adopters of GM crops, with millions of hectares planted annually (ISAAA, 2021). GM crops such as Bt cotton, herbicide-tolerant soybeans, and insect-resistant maize have demonstrated significant improvements in productivity and reductions in pesticide use (Brookes & Barfoot, 2020).

In Africa, progress in agricultural biotechnology has been uneven, constrained by regulatory, political, and socio-cultural factors. However, countries like South Africa, Burkina Faso (prior to a temporary suspension), and Sudan have made notable strides. South Africa, for example, has cultivated GM maize, soybean, and cotton since the early 2000s, becoming a regional leader in biotech agriculture. More recently, Nigeria has emerged as a promising frontier, with the approval of genetically modified Bt cotton in 2018 and GM cowpea in 2019 Africa's first genetically modified food crop approved for commercialization (NBMA, 2019). These developments suggest a growing recognition of biotechnology's potential to address food insecurity in Africa.

Current Status of Agricultural Biotechnology in Nigeria

Nigeria has made notable strides in creating a policy and institutional framework to support agricultural biotechnology. Central to these efforts is the National Biotechnology Development Agency (NABDA), established in 2001 under the Federal Ministry of Science, Technology and Innovation. According to NABDA (2022), the agency's mandate includes promoting, coordinating, and implementing biotechnology policies in various sectors, including agriculture. NABDA collaborates with international organizations and national institutions to drive research and adoption of genetically modified organisms (GMOs) aimed at increasing food productivity and sustainability. The enactment of the National Biosafety Management Agency (NBMA) Act in 2015 marked a turning point in Nigeria's regulatory landscape. As stated by the NBMA (2019), this law ensures that biotechnology activities are conducted in a safe and environmentally responsible manner. The agency evaluates GMOs before release into the environment and oversees compliance with global biosafety standards. According to the research by Ayoade and Mohammed (2023), the NBMA's regulatory oversight has helped build public trust and facilitated the introduction of crops such as Bt cowpea. Additionally, Nigeria's National Biotechnology Policy, updated in 2020, emphasizes innovation-driven agriculture and encourages public-private partnerships to commercialize genetically engineered crops. As observed by Ogunbanwo and Olanrewaju (2021), these policies reflect Nigeria's commitment to leveraging biotechnology to achieve food and nutritional security in line with its broader economic diversification goals.

Figure 1: Agricultural Biotechnology (Naija Scholar, 2024).

Nigeria's progress in agricultural biotechnology has been largely supported by robust research institutions. The International Institute of Tropical Agriculture (IITA), headquartered in Ibadan, plays a leading role in genetic improvement of staple crops. IITA, in collaboration with organizations such as the African Agricultural Technology Foundation (AATF) and NABDA, has been instrumental in the development and field testing of Bt cowpea, improved maize, and other GMOs suited for the African environment (IITA, 2022). In addition, several Nigerian universities—including Ahmadu Bello University, Obafemi Awolowo University, and the University of Ibadan—have established biotechnology departments and participate in national and regional biotech research programs. These universities often collaborate with government agencies and international partners to conduct trials and train the next generation of scientists in molecular biology and genetic engineering techniques (Anaduaka et al., 2020). For example, the Biotechnology Centre at Ahmadu Bello University has been involved in molecular characterization of improved sorghum and cowpea varieties (Akinwale et al., 2022). Furthermore, platforms like the Open Forum on Agricultural Biotechnology in Africa (OFAB)—Nigeria chapter—serve as advocacy and stakeholder engagement networks, helping to bridge the gap between scientists, policymakers, farmers, and the general public. According to the work of Eniola and Salako (2021), such collaborations are essential for dispelling myths about GMOs and promoting evidence-based policy decisions.

Among the most successful examples of genetically engineered crops in Nigeria is the Bt cowpea, which was officially approved for commercial release in 2019. This variety is engineered to resist the *Maruca vitrata* pod borer, a pest responsible for significant yield losses in conventional cowpea farming. As reported by the NBMA (2020), Bt cowpea has shown up to 80% reduction in insect-related damage during field trials and is now being distributed to farmers in multiple states. Another major area of innovation involves the development of biofortified cassava with enhanced levels of vitamin A, zinc, and iron. As highlighted in the research by Okafor and Olawale (2022), this initiative addresses widespread micronutrient deficiencies in Nigeria, especially among children and pregnant women. These cassava varieties are being developed through collaborations involving IITA, HarvestPlus, and Nigerian universities, and are undergoing performance evaluations across agroecological zones. In addition, genetically improved maize varieties, such as TELA maize, are under trial and development. TELA maize combines insect resistance and drought tolerance traits, and is tailored to the needs of African farmers. According to the African Agricultural Technology Foundation (AATF, 2023), Nigeria is among the leading countries involved in testing these varieties, with positive preliminary results showing increased yields and reduced reliance on chemical pesticides. These efforts are collectively positioning Nigeria as a biotechnology leader in sub-Saharan Africa. As stated by Juma (2016), the combination of political will, institutional support, and farmer-centered innovation is crucial for translating laboratory breakthroughs into real-world agricultural transformation.

Genetic Engineering in Agriculture

Genetic engineering, also referred to as genetic modification or gene editing, is the intentional alteration of an organism's DNA using advanced biotechnological tools to introduce, enhance, or remove specific traits. As defined by the National Human Genome Research Institute (2023), genetic engineering enables scientists to directly manipulate the genetic material of crops in order to increase yield, confer resistance to pests and diseases, improve tolerance to abiotic stressors such as drought and salinity, and enhance nutritional content. According to Ogunbanwo and Olanrewaju (2021), this technology holds particular promise for improving food security in developing nations such as Nigeria, where conventional agriculture faces mounting challenges due to climate change, population growth, and pest pressures.

The distinction between genetic engineering and traditional breeding is critical to understanding the technology's novelty and precision. As stated by Juma (2016) in his work *Innovation and Its Enemies*, traditional breeding relies on the natural cross-pollination of plants with desirable traits, a process that is often laborious and limited by species compatibility. In contrast, genetic engineering allows for the targeted insertion or removal of genes—even those derived from entirely unrelated organisms. For instance, in genetically modified maize, a gene from the bacterium *Bacillus thuringiensis* (Bt) is inserted to produce a protein that is lethal to specific insect pests. This level of specificity and control is not achievable through conventional breeding methods.

Figure 2: Genetic Engineering (National Human Genome Research Institute, 2023).

One of the most revolutionary tools in genetic engineering is the CRISPR-Cas9 system. According to Doudna and Charpentier (2014), who were instrumental in developing the technology, CRISPR allows for precise and efficient editing of DNA sequences at designated sites within the genome. This has enabled the development of crops with improved traits such as drought resistance, early maturation, and disease resistance. In Nigerian research, Akinwale et al. (2022) emphasize that CRISPR has the potential to transform staple crop production, especially in addressing challenges such as cassava mosaic virus and rice blast disease, which are prevalent in the country.

Recombinant DNA (rDNA) technology, another foundational technique, involves splicing genes from different organisms and inserting them into host genomes to express desired traits. As described by Brookes and Barfoot (2020), this technology has been extensively used in creating herbicide-resistant soybean, insect-resistant cotton, and other transgenic crops. The research by Anaduaka et al. (2020) on the Nigerian agricultural sector highlights how recombinant DNA has been pivotal in the development of Bt cowpea, a genetically engineered variety resistant to *Maruca vitrata*, a major pest affecting legume crops in West Africa.

Gene silencing techniques, such as RNA interference (RNAi), have also shown promise in crop protection and quality enhancement. In the work of Baulcombe (2004), RNAi is shown to suppress undesirable gene expression, enabling the development of virus-resistant or allergen-free crops. In Nigeria, researchers like Ojo and Adebayo (2019) have explored the use of gene silencing to combat plant viruses that significantly reduce cassava yield—a staple crop vital to the country's food security and economy.

A notable application of genetic engineering is the development of drought-resistant crops. According to Nelson et al. (2019), genetically modified crops like drought-tolerant maize can help mitigate the effects of erratic rainfall and water scarcity, which are becoming increasingly severe across sub-Saharan Africa. Nigerian agronomist Bello (2020) reports that the introduction of drought-tolerant maize varieties in northern Nigeria has improved yields in water-stressed areas, providing resilience against climate variability and stabilizing farmer incomes.

As stated by the National Biosafety Management Agency (NBMA, 2020), genetic engineering also plays a crucial role in pest resistance. Nigeria's approval and commercialization of Bt cowpea represents a landmark achievement. This legume, genetically modified to express insecticidal proteins, showed an 80% reduction in yield losses due to *Maruca vitrata* in field trials. This breakthrough was highlighted in the research by Eniola and Salako (2021), who argue that the adoption of genetically engineered pest-resistant crops can reduce dependence on chemical pesticides, thereby lowering production costs and environmental harm. Furthermore, genetic engineering is being used to address nutritional deficiencies through biofortification. One prominent example is Golden Rice, which is engineered to produce beta-carotene, a precursor of vitamin A. According to Tang et al. (2009), consuming Golden Rice can significantly improve vitamin A intake in populations where rice is a dietary staple. While Nigeria has not yet commercialized Golden Rice, local researchers like Okafor and Olawale (2022) are advocating for the development of biofortified variants of local staples such as cassava and maize to combat malnutrition, particularly among children in rural areas. As emphasized by the Food and Agriculture Organization (FAO, 2022), gene editing technologies can contribute to sustainable food systems by reducing input use, increasing resilience to climate change, and improving crop nutritional profiles. With proper regulatory oversight and public awareness, as noted by Ayoade and Mohammed (2023), Nigeria can harness these innovations to achieve food self-sufficiency and reduce the burden of food insecurity across the country.

Potential Benefits of Genetic Engineering in Nigerian Agricultural Sector

One of the foremost advantages of genetic engineering in agriculture is the potential to significantly boost crop yield and productivity. This is particularly vital for Nigeria, where agriculture provides employment for over 70% of the rural population and contributes about 25% to the Gross Domestic Product (GDP) (National Bureau of Statistics, 2022). According to the research by Qaim and Zilberman (2003), countries like India experienced a notable increase in cotton yield following the introduction of Bt cotton. Farmers in India saw up to 50% increases in yield along with a decline in pesticide use a model that demonstrates the transformative potential for similar crops in Nigeria. In Nigeria, field trials of genetically modified Bt cowpea have reported yield increases of over 20% compared to traditional varieties, primarily due to reduced insect damage (National Biosafety Management Agency, 2020). As noted by AATF (2023), such productivity gains are critical for reducing food import dependence and increasing domestic food availability, especially in staple crops like maize, cowpea, and cassava.

Genetic engineering also offers a sustainable solution to one of Nigeria's most persistent agricultural challenges: crop losses due to pests and diseases. Currently, Nigerian farmers lose up to 40% of their harvests to pests such as the fall armyworm, stem borers, and the Maruca vitrata pod borer (FAO, 2021). These losses not only reduce income for smallholder farmers but also drive-up food prices. As stated by Brookes and Barfoot (2020), genetically modified crops like Bt maize and Bt cowpea produce proteins from the *Bacillus thuringiensis* bacterium, which are toxic to specific insects but safe for humans. This technology reduces the need for synthetic pesticides, thereby cutting costs and lowering environmental contamination. In the work of Eniola and Salako (2021), it is shown that Bt cowpea reduced the need for pesticide application by 75% in trial locations across Nigeria, significantly benefiting both farmers' health and the environment.

Climate change has intensified the need for resilient agricultural systems, particularly in regions like Nigeria that are prone to erratic rainfall, drought, and flooding. Genetic engineering allows the development of crops that can tolerate drought, heat, salinity, or waterlogging, thus offering a buffer against the adverse effects of climate variability. For instance, drought-tolerant maize varieties developed through the Water Efficient Maize for Africa (WEMA) project have been introduced in several African countries, including Nigeria. As reported by the African Agricultural Technology Foundation (2022), these varieties maintain stable yields even in seasons with below-average rainfall. According to a study by Nelson et al. (2019), such traits can help stabilize food supply and farmer incomes in the face of unpredictable weather patterns. Furthermore, future research in Nigeria is exploring salt-tolerant rice and flood-resistant yam varieties, which will be particularly useful in regions like the Niger Delta and semi-arid Northern Nigeria.

Beyond yield and resilience, genetic engineering can play a key role in addressing malnutrition, which remains a public health challenge in Nigeria. According to UNICEF (2022), about 33% of Nigerian children under the age of five suffer from stunting due to chronic malnutrition. Biofortified crops developed using genetic engineering techniques are being promoted as a solution to improve the nutritional content of staple foods. One of the most well-known examples globally is Golden Rice, engineered to produce beta-carotene, a precursor of vitamin A. As shown in the work of Tang et al. (2009), consumption of Golden Rice can significantly reduce the incidence of vitamin A deficiency, which is a leading cause of blindness and mortality among children. Nigeria is also engaged in developing and promoting pro-vitamin A cassava and iron-enriched beans, crops aimed at populations that depend heavily on carbohydrate-rich but nutrient-poor staples (Okafor & Olawale, 2022). In the words of Juma (2016), "genetic modification not only addresses the 'quantity' of food produced but also the 'quality' a dual approach necessary for tackling both hunger and hidden hunger in Africa." The integration of these biofortified crops into school feeding programs and rural food systems can lead to measurable improvements in public health.

Challenges to the Adoption of Genetic Engineering in Nigeria

Despite the promising potential of genetic engineering, regulatory and institutional challenges remain significant barriers in Nigeria. The National Biosafety Management Agency (NBMA), established under the National Biosafety Management Agency Act of 2015, serves as the primary institution responsible for regulating genetically modified organisms (GMOs). While the NBMA has made notable progress such as the approval of Bt cowpea it faces limitations in enforcement capacity, inter-agency coordination, and technical expertise (Oyekale, 2020). As noted by Adebayo et al. (2021), inconsistencies in policy implementation and the absence of clear protocols for GMO labeling and post-commercialization monitoring weaken regulatory trust and hinder adoption. Moreover, conflicting roles among agencies such as NBMA, the Nigerian Agricultural Quarantine Service (NAQS), and the Ministry of Environment often create bureaucratic delays. For Nigeria to fully leverage biotechnology, regulatory frameworks must be harmonized and strengthened to ensure safe and timely release of innovations.

One of the most pressing obstacles to the adoption of genetic engineering in Nigeria is negative public perception, driven largely by misinformation, cultural beliefs, and mistrust of new technologies. As stated by the research of Adenle (2011), many Nigerians associate GMOs with health hazards or foreign manipulation, despite scientific evidence confirming their safety. Religious leaders and civil society groups have also voiced ethical objections, citing concerns about "tampering with nature." In the work of Oladele and Ayoola (2022), surveys indicated that less than 30% of Nigerian farmers had accurate knowledge about GM crops, while a significant proportion expressed reluctance to grow them due to fear of unknown side effects. The lack of widespread public education campaigns further exacerbates skepticism. Addressing these concerns will require proactive engagement strategies, including transparent communication, inclusive consultations, and the involvement of trusted community leaders and agricultural extension workers.

Genetically engineered crops also raise legitimate environmental concerns, which must be carefully managed. One of the key issues is gene flow, or the unintended transfer of modified genes to wild relatives or non-GMO crops, which may affect biodiversity. According to the work of Losey et al.

(1999), there is potential for unintended ecological consequences, including disruptions in local ecosystems or harm to non-target organisms. Another concern is the development of resistance in pests and weeds. As observed in parts of India and the United States, overuse of Bt crops has led to the emergence of pest populations resistant to Bt toxins and herbicide-tolerant weeds (Tabashnik et al., 2013). In Nigeria, a poorly coordinated resistance management strategy could undermine the long-term effectiveness of genetic technologies. As suggested by Ojo and Afolabi (2020), integrated pest management (IPM) approaches and refugia planning must be incorporated into GMO deployment strategies to mitigate these risks.

A crucial, yet often overlooked challenge, is the issue of access and equity, especially among smallholder farmers, who make up over 80% of Nigeria's farming population (FAO, 2021). High costs of genetically engineered seeds, licensing fees, and limited rural distribution networks restrict access to those who need these innovations the most. Furthermore, dependence on multinational seed companies has raised concerns about farmer autonomy and seed sovereignty. According to Akinbo et al. (2015), equitable access requires public investment in research, local seed production, and fair intellectual property rights frameworks. In Nigeria, partnerships between universities, government institutions like the National Biotechnology Development Agency (NABDA), and international bodies can play a crucial role in making the technology affordable and locally adapted. As noted by Ogundele and Iliyasu (2023), policies that promote inclusive innovation—ensuring participation by marginalized communities are essential for biotechnology to benefit all layers of society.

Conclusion

Genetic engineering presents a powerful opportunity for Nigeria to overcome some of the most persistent constraints in its agricultural sector. With the ability to precisely enhance crop traits such as pest resistance, drought tolerance, and nutritional value, biotechnology stands as a viable tool to improve food production and tackle malnutrition. Evidence from both global and Nigerian case studies such as the successful deployment of Bt cowpea demonstrates that genetically modified crops can enhance yield, reduce chemical use, and support climate change adaptation efforts.

Nevertheless, realizing these benefits fully will require Nigeria to address several systemic challenges. Regulatory and institutional bottlenecks, public distrust fueled by misinformation, environmental concerns, and issues of equitable access continue to hinder wider acceptance and adoption. Without robust, transparent, and inclusive governance, the promise of genetic engineering could remain out of reach for many Nigerian farmers, particularly smallholders.

Thus, while the science of genetic engineering is advancing rapidly, its deployment in Nigeria must be underpinned by strong ethical considerations, sound policy frameworks, and inclusive outreach strategies. The path forward must ensure that biotechnology is not only safe and effective but also socially accepted and equitably distributed.

Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance the integration of genetic engineering and agricultural biotechnology in tracking crop development, improving agricultural performance, and ensuring sustainable food security within Nigeria's agricultural governance framework:

1. The Nigerian government should reinforce the operational and technical capacity of the National Biosafety Management Agency (NBMA) to ensure robust risk assessment, post-approval monitoring, and public accountability.

2. Public education campaigns involving local leaders, agricultural extension agents, scientists, and media should be launched to dispel myths, explain the science, and build trust around genetic engineering. Special attention should be given to local languages and cultural contexts.

3. Government and research institutions must prioritize the development and dissemination of genetically engineered seeds that are affordable, locally adapted, and suitable for smallholder

farmers. Public-private partnerships should ensure seed access is not monopolized by multinational corporations.

4. Increased funding for universities and agricultural research institutes such as IITA and NABDA will encourage home-grown innovations. Capacity-building programs for scientists, regulators, and extension workers are also crucial to sustain the sector.

5. Biotechnology should be formally incorporated into national development strategies, such as the Agricultural Transformation Agenda and the Nigeria Economic Sustainability Plan. This includes establishing clear roadmaps for GM crop development, approval, and commercialization.

6. Adoption of GM crops should be paired with sound environmental risk management practices, such as integrated pest management (IPM), gene flow mitigation strategies, and monitoring of resistance development in pests.

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