

Review Article

Genetically Modified Crops and Public Health: Benefits, Risks, and Policy Debates

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Abstract

Genetically modified (GM) crops have become a prominent component of modern agricultural systems, offering potential solutions to food insecurity, malnutrition, and environmental stress. Through the application of genetic engineering techniques, crops can be enhanced for traits such as pest resistance, herbicide tolerance, improved nutritional composition, and resilience to climatic stressors. These innovations have significant implications for public health, particularly in addressing micronutrient deficiencies and improving food availability. However, the adoption of GM crops remains contentious due to concerns regarding food safety, environmental impacts, ethical considerations, and socioeconomic consequences. This review critically examines the role of genetically modified crops in shaping public health outcomes, with a balanced evaluation of their benefits, risks, and policy debates. The paper explores how GM crops can contribute to improved nutritional status, reduced pesticide exposure, and enhanced agricultural productivity. At the same time, it assesses potential risks, including allergenicity, unintended genetic effects, biodiversity loss, and the development of herbicide-resistant weeds. The review also addresses broader issues such as regulatory frameworks, public perception, intellectual property rights, and global disparities in technology access. By integrating evidence from agriculture, biotechnology, nutrition, and public health, this paper highlights the need for robust risk assessment, transparent governance, and science-based policymaking. It concludes that while GM crops hold considerable promise for advancing public health and food security, their successful integration into food systems requires careful management of risks, inclusive policy dialogue, and ongoing research to ensure safety, sustainability, and equitable benefits.

Keywords: *Genetically modified crops; Public health; Food safety; Biofortification; Biotechnology; Nutritional security; Risk assessment*

1. Introduction

Global food systems are under increasing pressure due to rapid population growth, climate change, land degradation, and evolving dietary demands. It is projected that the global population will exceed 9 billion by 2050, necessitating a substantial increase in food production without further exacerbating environmental degradation [1]. Conventional agricultural practices, while historically successful in boosting yields, are increasingly constrained by limited natural resources, pest resistance, declining soil fertility, and climatic variability. Within this context, modern biotechnology—particularly genetic modification—has emerged as a promising approach to enhance agricultural productivity, resilience, and nutritional quality [2]. Genetically modified (GM) crops are developed through advanced molecular techniques that enable the precise alteration of an organism's genetic material. Unlike traditional plant breeding, which relies on the selection and crossing of desirable traits over multiple generations, genetic engineering allows for the targeted insertion, deletion, or modification of specific genes. These genes may originate from the same species (cisgenic modification) or from entirely different organisms (transgenic modification), thereby expanding the range of traits that can be introduced into crops. Since their commercialization in the mid-1990s, GM crops have been adopted on millions of hectares globally, with major cultivation concentrated in countries such as the United States, Brazil, Argentina, India, and China [3-4]. The relevance of GM crops to public health is both direct and indirect. At a fundamental level, increased agricultural productivity contributes to improved food availability, thereby reducing the risk of hunger and undernutrition. More importantly, GM technology has enabled the development of biofortified crops with enhanced levels of essential nutrients, offering innovative solutions to micronutrient deficiencies—commonly referred to as “hidden hunger.” For instance, vitamin A deficiency remains a leading cause of preventable blindness among children in many developing regions, and GM crops enriched with provitamin A have been proposed as a sustainable intervention. In addition to nutritional benefits, GM crops can contribute to improved environmental and occupational health outcomes. Pest-resistant varieties, such as those expressing insecticidal proteins, can significantly reduce the need for chemical pesticides [5-6]. This reduction not only lowers production costs but also minimizes exposure to toxic substances among farmers and decreases environmental contamination. Similarly, crops engineered for drought tolerance or salinity resistance can enhance food security in regions affected by climate

stress, thereby stabilizing food systems and supporting population health [7]. Despite these potential advantages, the adoption of GM crops has been accompanied by considerable controversy and debate. Concerns regarding food safety, including potential allergenicity and unintended genetic effects, remain central to public discourse. Environmental risks, such as gene flow to wild species, development of resistant pests and weeds, and impacts on biodiversity, have also been widely discussed. Furthermore, socioeconomic issues—including corporate control over seed markets, intellectual property rights, and the marginalization of smallholder farmers—raise questions about equity and access. Public perception of GM crops varies significantly across regions and is influenced by cultural, ethical, and political factors. In some countries, strong regulatory frameworks and public skepticism have limited adoption, while in others, GM crops are widely cultivated and integrated into food systems. This divergence highlights the importance of transparent governance, effective risk communication, and inclusive policy processes. This paper aims to provide a comprehensive and balanced analysis of genetically modified crops from a public health perspective. It examines the scientific basis of GM technology, evaluates its potential benefits and risks, and explores the policy debates that shape its development and adoption [8]. By integrating insights from agriculture, biotechnology, nutrition, and public health, the review seeks to inform evidence-based decision-making and contribute to ongoing discussions on sustainable food systems.

2. Overview of Genetically Modified Crops

Genetically modified crops are the product of advanced biotechnological interventions that enable precise manipulation of plant genomes to introduce desirable traits. These modifications are achieved through a range of molecular techniques, including recombinant DNA technology, gene transfer methods (such as *Agrobacterium*-mediated transformation and biolistic particle delivery), and more recently, gene-editing tools like CRISPR-Cas systems. These technologies allow scientists to overcome the limitations of conventional breeding by directly targeting specific genes responsible for agronomically or nutritionally important traits [9]. The primary objective of genetic modification in crops is to enhance their performance under various environmental and agronomic conditions. One of the most widely adopted traits is insect resistance, commonly achieved through the incorporation of genes derived from *Bacillus thuringiensis* (Bt), a soil bacterium that produces proteins toxic to certain insect pests. Bt crops have been successfully used in crops

Table 1. Major Types of Genetically Modified Crops and Their Traits

Crop Type	Genetic Modification	Key Trait	Public Health Relevance
Bt Maize	<i>Bacillus thuringiensis</i> gene	Insect resistance	Reduced pesticide exposure
Bt Cotton	<i>Bacillus thuringiensis</i> gene	Pest resistance	Improved farmer health, reduced chemical use
Herbicide-Tolerant Soybean	Herbicide resistance gene	Weed control efficiency	Increased productivity, food availability
Golden Rice	β -carotene biosynthesis genes	Vitamin A enrichment	Prevention of vitamin A deficiency
Iron-Enriched Rice	Iron metabolism genes	Increased iron content	Reduction of anemia
Drought-Tolerant Maize	Stress-response genes	Drought resistance	Food security under climate stress

Table 2. Public Health Benefits of GM Crops

Benefit Category	Mechanism	Health Outcome
Improved Food Security	Higher yields, reduced crop loss	Reduced hunger and undernutrition
Nutritional Enhancement	Biofortification (vitamins, minerals)	Reduced micronutrient deficiencies
Reduced Pesticide Exposure	Pest-resistant crops	Lower risk of poisoning and chronic illness
Environmental Health	Reduced chemical runoff	Cleaner water and ecosystems
Economic Improvement	Increased farmer income	Better access to healthcare and nutrition

such as maize and cotton to reduce crop losses and decrease reliance on chemical insecticides. Another trait is herbicide tolerance, which enables crops to withstand applications of specific herbicides, thereby simplifying weed management and improving yield efficiency. Beyond these first-generation traits, significant progress has been made in developing second- and third-generation GM crops with enhanced nutritional and functional properties. Biofortified crops, such as those enriched with vitamins, minerals, or essential amino acids, represent an advancement in addressing micronutrient deficiencies. For example, genetically engineered rice varieties containing elevated levels of provitamin A have been developed to combat vitamin A deficiency in populations that rely heavily on rice as a staple food. Similarly, efforts are underway to enhance iron and zinc content in staple crops to improve dietary quality [10]. Emerging traits also focus on improving crop resilience to abiotic stresses such as drought, salinity, and extreme temperatures. These stress-tolerant crops are particularly relevant in the context of climate change, which is expected to exacerbate environmental challenges and threaten agricultural productivity. By enhancing the adaptive capacity of crops, genetic modification can contribute to more stable food production systems and reduce vulnerability to climate-induced food insecurity [11-12]. Globally, the adoption of GM crops has expanded significantly

since their introduction, with millions of farmers cultivating genetically modified varieties across diverse agroecological regions. The extent of adoption varies widely, influenced by factors such as regulatory frameworks, market demand, infrastructure, and public acceptance. In countries with supportive policies and strong agricultural sectors, GM crops have become integral to farming systems, while in others, regulatory restrictions and public opposition have limited their use. Despite their widespread adoption, GM crops remain subject to rigorous evaluation and oversight. Regulatory agencies typically require comprehensive risk assessments that examine potential impacts on human health, animal health, and the environment. These assessments include studies on toxicity, allergenicity, nutritional equivalence, and ecological effects [13-15]. Advances in molecular biology and genomics have further improved the ability to detect unintended changes and ensure the safety of GM products. It is also important to distinguish between genetically modified organisms (GMOs) and newer gene-editing technologies. While traditional GMOs often involve the introduction of foreign genes, gene editing can make precise modifications within an organism's existing genome without introducing external DNA. This distinction has important implications for regulation, public perception, and future applications. In summary, genetically modified crops represent a rapidly evolving field of

Table 3. Potential Risks Associated with GM Crops

Risk Category	Description	Public Health Concern
Allergenicity	Introduction of new proteins	Allergic reactions
Toxicity	Unintended metabolic changes	Long-term health effects
Environmental Impact	Gene flow, biodiversity loss	Ecosystem imbalance affecting food systems
Resistance Development	Pest and weed resistance	Increased chemical use
Socioeconomic Risks	Corporate control, seed dependency	Reduced farmer autonomy

agricultural biotechnology with significant potential to address global challenges related to food security, nutrition, and environmental sustainability. However, their development and deployment must be guided by robust scientific evidence, effective regulatory systems, and careful consideration of ethical and societal implications.

3. Benefits of Genetically Modified Crops for Public Health

Genetically modified (GM) crops offer a range of benefits that have direct and indirect implications for public health, particularly in the areas of food security, nutritional improvement, environmental health, and socioeconomic well-being. One of the most significant advantages is the enhancement of agricultural productivity. By incorporating traits such as pest resistance and herbicide tolerance, GM crops can reduce yield losses caused by biotic stressors, thereby increasing overall food production. This increase in food availability is critical in addressing hunger and undernutrition, especially in regions where agricultural productivity is constrained by environmental and biological factors. A major contribution of GM crops to public health lies in their potential for nutritional enhancement through biofortification [16]. Genetic engineering enables the development of crops with elevated levels of essential micronutrients, including vitamins and minerals that are often deficient in staple-based diets. For instance, crops enriched with provitamin A, iron, or zinc can help mitigate micronutrient deficiencies that lead to conditions such as anemia, impaired immune function, and developmental disorders. Unlike conventional supplementation or fortification programs, biofortified crops provide a sustainable, food-based solution that can reach populations with limited access to healthcare and nutritional interventions. Another benefit is the reduction in pesticide use associated with insect-resistant GM crops. Traditional farming often relies heavily on chemical pesticides to control pests, which can pose risks to both human health and the environment. Exposure to pesticides has been linked to acute poisoning, chronic health conditions, and en-

vironmental contamination. GM crops expressing insecticidal proteins can significantly reduce the need for such chemicals, thereby lowering occupational exposure among farmers and decreasing pesticide residues in food. This contributes to safer food systems and improved environmental quality. GM crops also offer potential benefits in adapting agriculture to climate change. The development of drought-tolerant, salinity-resistant, and heat-tolerant crop varieties can enhance resilience in regions affected by environmental stress. By stabilizing yields under adverse conditions, these crops can reduce the risk of food shortages and associated health impacts, such as malnutrition and food insecurity. Furthermore, improved crop efficiency can reduce pressure on natural resources, contributing to more sustainable food systems. Economic benefits associated with GM crop adoption also have important public health implications [17]. Increased productivity and reduced input costs can improve farmers' incomes, enabling greater access to healthcare, education, and nutritious food. In many developing regions, smallholder farmers constitute a significant proportion of the population, and improvements in agricultural income can have cascading effects on community health and well-being [18]. Finally, GM technology has the potential to reduce post-harvest losses and improve food quality. Crops engineered for delayed ripening or enhanced resistance to spoilage can extend shelf life and reduce food waste. This not only improves food availability but also contributes to food safety by reducing the risk of contamination and spoilage-related illnesses.

4. Potential Risks and Concerns

Despite the potential benefits of genetically modified crops, several risks and concerns must be carefully considered to ensure their safe and sustainable use. One of the primary concerns relates to food safety, particularly the possibility of allergenicity and unintended health effects. Genetic modification may introduce new proteins into crops, raising questions about whether these proteins could trigger allergic reactions in susceptible individuals. Although regulatory agencies require rig-

Table 4. Comparison of GM Crops and Conventional Crops

Parameter	GM Crops	Conventional Crops
Yield Stability	High (stress-resistant)	Variable
Pesticide Use	Reduced	Higher
Nutritional Enhancement	Possible (biofortified)	Limited
Environmental Impact	Potentially lower (if managed)	Often higher
Cost of Seeds	Higher	Lower
Regulation	Strict	Less stringent

Table 5. Global Regulatory Approaches to GM Crops

Region/Country	Regulatory Approach	Key Features
United States	Product-based	Focus on end-product safety
European Union	Process-based	Strict approval, labeling required
India	Precautionary	Controlled approvals, field trials
Brazil	Science-based	Rapid adoption, strong regulatory body
China	Government-regulated	Gradual commercialization

orous testing to assess allergenic potential, long-term health effects remain a subject of public debate and scientific inquiry. Another important issue is the possibility of unintended genetic changes resulting from the modification process [19]. While modern biotechnological techniques are highly precise, there is still a risk of off-target effects that could alter metabolic pathways or lead to the production of unexpected compounds. Continuous monitoring and post-market surveillance are therefore essential to ensure the safety of GM foods over time [20]. Environmental concerns also play a central role in the debate surrounding GM crops. One risk is the development of resistance among target pests and weeds. For example, prolonged exposure to insect-resistant crops may lead to the evolution of resistant insect populations, reducing the effectiveness of the technology and potentially requiring increased use of chemical controls. Similarly, the widespread use of herbicide-tolerant crops has been associated with the emergence of herbicide-resistant weeds, which can complicate weed management and increase production costs. Gene flow from GM crops to wild relatives or non-GM crops represents another environmental concern. The transfer of modified genes through pollen can lead to unintended ecological consequences, including the spread of traits such as herbicide tolerance into wild plant populations. This may affect biodiversity and disrupt ecosystem dynamics. Additionally, the impact of GM crops on non-target organisms, such as beneficial insects and soil microorganisms, remains an area of ongoing research. Socioeconomic issues are equally important in assessing the risks associated with GM crops. The commercialization of GM technology is often dominated by large multinational corporations, which hold patents on genetically modified seeds [21]. This concentration of market power can limit access to technology for smallholder farmers and increase dependency

on proprietary inputs. High seed costs and restrictions on seed saving may place financial burdens on farmers, particularly in developing countries. Ethical and cultural concerns further contribute to public skepticism. Questions about the “naturalness” of genetically modified organisms, as well as concerns about transparency and labeling, influence consumer acceptance. In many regions, consumers demand clear labeling of GM foods to make informed choices, reflecting broader issues of trust in scientific and regulatory institutions. While GM crops offer significant potential benefits, their risks must be addressed through comprehensive risk assessment, ongoing research, and effective regulatory oversight. A precautionary yet evidence-based approach is essential to balance innovation with safety and public confidence.

5. Policy and Regulatory Frameworks

The governance of genetically modified crops is a critical factor in determining their impact on public health and their acceptance within society. Regulatory frameworks are designed to ensure that GM crops are safe for human consumption, environmentally sustainable, and socially acceptable. These frameworks vary considerably across countries, reflecting differences in scientific capacity, political priorities, cultural values, and levels of public trust. Most regulatory systems are based on science-driven risk assessment processes that evaluate the safety of GM crops before their commercialization. These assessments typically include studies on toxicity, allergenicity, nutritional equivalence, and environmental impact. Regulatory authorities also examine the stability of inserted genes and the potential for unintended effects. In many countries, GM crops must undergo multi-stage approval processes, including laboratory testing, field trials, and post-market monitoring. Two regulatory approaches

Table 6. Policy Debates Surrounding GM Crops

Issue	Proponents' View	Critics' View
Food Security	Essential for feeding growing population	Alternative methods available
Safety	Scientifically proven safe	Long-term effects uncertain
Environment	Reduces chemical use	Risk of biodiversity loss
Economics	Increases farmer income	Corporate monopolies
Ethics	Technological advancement	Concerns about naturalness

can be identified globally: the product-based approach and the process-based approach [22]. The product-based approach, adopted by countries such as the United States, focuses on the characteristics of the final product rather than the method used to produce it. If a GM crop is deemed substantially equivalent to its conventional counterpart, it may be approved with relatively fewer restrictions. In contrast, the process-based approach, commonly used in the European Union, emphasizes the method of genetic modification itself and often involves stricter regulations, including mandatory labeling and traceability requirements. International agreements and organizations play an important role in harmonizing biosafety standards and facilitating global trade. The Cartagena Protocol on Biosafety, under the Convention on Biological Diversity, provides a framework for the safe handling, transport, and use of living modified organisms. It emphasizes the precautionary principle and allows countries to make decisions based on risk assessment and national priorities. Similarly, guidelines from international bodies such as the Codex Alimentarius Commission contribute to the development of food safety standards for GM products. Public participation and transparency are increasingly recognized as essential components of effective governance. Engaging stakeholders—including scientists, policymakers, farmers, industry representatives, and consumers—in decision-making processes can enhance trust and legitimacy [24]. Clear communication of scientific evidence, risks, and benefits is necessary to address public concerns and counter misinformation. Policy debates surrounding GM crops also encompass issues related to intellectual property rights, trade, and equity. Patent protection for genetically modified seeds can incentivize innovation but may also restrict access and increase costs for farmers. Balancing the interests of technology developers with those of farmers and consumers is a key policymakers. Additionally, disparities in regulatory capacity between developed and developing countries can create barriers to technology adoption and international trade, regulatory frameworks must adapt to emerging biotechnologies such as gene editing, which blur the distinction between conventional breeding and genetic modification. Policymakers face the challenge of developing flexible, science-based regulations that can accommo-

date technological advances while ensuring safety and public confidence, robust and transparent policy and regulatory frameworks are essential for maximizing the public health benefits of genetically modified crops while minimizing potential risks. Effective governance requires a balance between innovation, safety, and societal values, supported by ongoing research and international collaboration [25]. International organizations play a role in harmonizing regulatory standards and facilitating global trade. Agreements such as the Cartagena Protocol on Biosafety provide guidelines for the safe handling, transport, and use of living modified organisms. However, disparities in regulatory frameworks can create challenges for international trade and technology transfer. Public engagement and transparency are essential components of effective governance. Policymakers must address public concerns, provide clear information, and ensure that decision-making processes are inclusive and evidence-based.

6. Policy Debates and Future Directions

The discourse surrounding genetically modified (GM) crops is characterized by diverse and often conflicting perspectives regarding their role in agriculture, public health, and sustainable development. Proponents argue that GM technologies are essential for addressing global challenges such as food insecurity, climate change, and malnutrition. They emphasize the capacity of GM crops to increase yields, enhance nutritional quality, and reduce dependence on chemical inputs. From this perspective, biotechnology represents a critical tool for achieving global food security and improving public health outcomes, critics raise concerns about the long-term safety, environmental sustainability, and socioeconomic implications of GM crop adoption [26]. Questions regarding corporate control over seed systems, intellectual property rights, and the marginalization of smallholder farmers are central to these debates. There is also ongoing discussion about the adequacy of existing regulatory frameworks and the need for more precautionary approaches in evaluating potential risks. Ethical considerations, including consumer autonomy and the right to informed choice, further contribute to the complexity of policy debates. One of the key areas of discussion is the role of alterna-

tive agricultural approaches, such as agroecology and organic farming, in comparison to GM technologies. While these approaches prioritize ecological sustainability and biodiversity, they may face limitations in terms of scalability and productivity. Policymakers are therefore challenged to balance technological innovation with sustainable agricultural practices, ensuring that different approaches can coexist and complement one another, emerging biotechnologies such as gene editing offer new opportunities and challenges [27]. Techniques such as CRISPR-Cas9 enable precise modifications to plant genomes without necessarily introducing foreign DNA, potentially addressing some of the concerns associated with traditional genetic modification. These technologies have the potential to accelerate crop improvement, enhance resilience to environmental stress, and improve nutritional quality. However, they also raise new regulatory and ethical questions, particularly regarding classification, safety assessment, and public acceptance. Future directions in this field also include strengthening research and monitoring systems to evaluate long-term health and environmental impacts. Investments in public-sector research can help ensure that the benefits of biotechnology are accessible to a broader range of stakeholders, including smallholder farmers. Capacity building, knowledge transfer, and infrastructure development are essential for enabling equitable adoption of GM technologies across different regions, policy debates surrounding GM crops reflect broader tensions between innovation and precaution, efficiency and equity, and global and local priorities. A balanced and inclusive approach, grounded in scientific evidence and ethical considerations, is necessary to guide future developments in this field.

7. Discussion

The integration of genetically modified crops into food systems presents a complex set of opportunities and challenges for public health. On one hand, GM crops have demonstrated potential to enhance food availability, improve nutritional quality, and reduce exposure to harmful agricultural inputs. On the other hand, concerns regarding safety, environmental sustainability, and socioeconomic equity continue to shape public discourse and policy decisions. A critical issue in this discussion is the balance between technological advancement and risk management. While extensive scientific evidence supports the safety of approved GM crops, uncertainties regarding long-term effects and ecological interactions persist. These uncertainties necessitate a precautionary approach that includes rigorous pre-market assessment, post-market monitoring,

and adaptive regulatory frameworks. Ensuring that risk assessment processes remain transparent and scientifically robust is essential for maintaining public trust [29]. Another important consideration is the role of GM crops within broader food systems. The effectiveness of these technologies in improving public health outcomes depends on their integration with complementary interventions, such as nutrition education, healthcare access, and social protection programs. GM crops alone cannot address the multifaceted determinants of malnutrition and health disparities; rather, they must be part of a comprehensive strategy that includes both technological and social solutions. Equity and access are also central to the discussion. While GM crops can provide economic benefits through increased productivity and reduced input costs, these benefits are not uniformly distributed. Smallholder farmers may face barriers related to seed costs, access to information, and market constraints. Addressing these disparities requires policies that promote inclusive access to technology, support local agricultural systems, and protect the interests of vulnerable populations. Public perception and acceptance play an role in determining the adoption and impact of GM crops [30]. Misinformation, lack of awareness, and distrust in institutions can hinder acceptance, even in the presence of scientific evidence supporting safety and benefits. Effective communication strategies that engage stakeholders, address concerns, and provide clear and accurate information are essential for fostering informed decision-making. Environmental sustainability is another key dimension. While GM crops can reduce pesticide use and improve resource efficiency, their long-term ecological impacts must be carefully monitored. Integrating GM technologies with sustainable agricultural practices, such as crop rotation and integrated pest management, can help mitigate potential risks and enhance overall system resilience, the discussion highlights the need for a holistic and interdisciplinary approach to the evaluation and implementation of GM crops [31]. Collaboration among scientists, policymakers, industry stakeholders, and communities is essential for ensuring that the benefits of biotechnology are realized while minimizing potential risks.

8. Conclusion

Genetically modified crops represent a significant advancement in agricultural biotechnology with far-reaching implications for public health, food security, and environmental sustainability. Their capacity to enhance crop productivity, improve nutritional content, and reduce reliance on chemical inputs positions them as valuable tools in addressing global challenges. In

particular, the potential of biofortified crops to combat micronutrient deficiencies offers a promising pathway toward improving population health in resource-limited settings. However, the successful integration of GM crops into food systems requires careful consideration of associated risks and challenges. Food safety concerns, environmental impacts, and socioeconomic issues must be addressed through comprehensive and transparent regulatory frameworks. Continuous research and monitoring are essential to ensure that GM technologies remain safe, effective, and responsive to emerging challenges. Policy approaches must strike a balance between promoting innovation and safeguarding public health and environmental integrity. This includes fostering inclusive governance, supporting public engagement, and ensuring equitable access to technological advancements. International cooperation and harmonization of regulatory standards can further facilitate the safe and efficient use of GM crops across different regions. Looking forward, advances in biotechnology, including gene editing, offer new opportunities for crop improvement and sustainable agriculture. These innovations must be guided by ethical considerations, scientific evidence, and societal values to ensure that their benefits are widely shared. Strengthening public-sector research, investing in capacity building, and supporting smallholder farmers are critical for achieving equitable outcomes. In conclusion, genetically modified crops have the potential to contribute significantly to improved public health and sustainable development. Realizing this potential requires a balanced, evidence-based approach that integrates technological innovation with robust governance, environmental stewardship, and social equity. Such an approach will be essential for ensuring that biotechnology serves as a positive force in shaping the future of global food systems.

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