علم او فن- علمي څېړنيزه مجله

Role of Genetically Modified Crop in Engineering Food Security

Farid Ahmad Sherzai[1]*, Sayeed Qadir Danishiar[1], Mohammad Modaser Tawfeed[1]
[1]Department of Biotechnology and Seed Production, Agriculture Faculty, Kabul University, Kabul, Afghanistan
*Corresponding Author Email: faridahmadsherzai@gmail.com

Abstract

Global food security is increasingly threatened by population growth, climate change, and declining natural resources. Genetically modified and genome-edited crops have emerged as important tools to enhance agricultural productivity, improve stress tolerance, and increase the nutritional quality of staple foods. This narrative review synthesizes current evidence on the contributions of genetically modified plants to yield improvement, pest and disease resistance, abiotic stress tolerance, and biofortification, with particular emphasis on recent advances in CRISPR-based genome editing technologies. While genetically modified crops offer significant potential to support sustainable food systems, their effective deployment depends on supportive regulatory frameworks, public acceptance, and equitable access for smallholder farmers. Overall, plant biotechnology represents a key component of integrated strategies aimed at achieving global food and nutritional security.

Keywords: Genetically modified crops; Genome editing; CRISPR/Cas; Abiotic and biotic stress tolerance; Biofortification

نقش محصولات اصلاح شده جنتیکی در تأمین امنیت غذایی

فرید احمد شیرزی[۱]، سید قدیر دانشیار[۱]، محمد مدثر توفیق[۱]
[۱]دیپارتمنت بایوتکنالوژی و تولید تخم های بذری، پوهنځی زراعت، پوهنتون کابل، کابل، افغانستان

خلاصه

امنیت غذایی جهانی به طور فزاینده ای به وسیله رشد جمعیت، تغییرات اقلیمی و کاهش منابع طبیعی تهدید می شود. محصولات اصلاح شده جنتیکی و نباتات دستکاری شده جینومی به عنوان ابزارهای مهمی برای افزایش محصولات زراعتی، بهبود تحمل به تنش ها و افزایش کیفیت تغذیه ای غذاهای اساسی مطرح شده اند. این مرور روایتی، شواهد موجود درباره نقش نباتات اصلاح شده جنتیکی در بهبود عملکرد (حاصل دهی)، مقاومت در برابر آفات و امراض، تحمل به تنش های غیر زنده و غنی سازی زیستی را با تاکید ویژه بر پیشرفت های اخیر در فناوری های ویرایش جین مبتنی برCRISPR ، ترکیب و خلاصه می کند. با وجود اینکه محصولات اصلاح شده جنتیکی ظرفیت قابل توجهی برای حمایت از سیستم های غذایی پایدار دارند، استفاده موثر از آنها وابسته به چارچوب های قانونی حمایتی، پذیرش عمومی و دسترسی عادلانه برای دهقانان خرد می باشد. در مجموع، بایوتکنا لوژی نباتی یکی از اجزای کلیدی در راهبردهای یکپارچه برای دستیابی به امنیت غذایی و تغذیه ای جهانی محسوب می شود.

کلیمات کلیدی: محصولات اصلاح شده جنتیکی؛ امنیت غذایی؛ ویرایش جینوم؛ CRISPR/Cas؛ تحمل به تنش های زنده و غیر زنده.

1. Introduction

The global food security challenge represents one of the most pressing issues of our time, with the world population projected to exceed 9.7 billion by 2050 (WijerathnaYapa & Pathirana, 2022). Rapid population growth is increasing the demand for food, feed, and agricultural resources. At the same time, agricultural systems face growing pressure from climate change, land degradation, water scarcity, and limited arable land. Food insecurity already affects billions of people worldwide. Approximately 820 million individuals experience chronic hunger, while more than two billion people suffer from micronutrient deficiencies, often referred to as hidden hunger (Christou & Twyman, 2004).

In response to these challenges, genetically modified (GM) plants have emerged as an important technological approach for improving agricultural productivity and food quality. Genetic engineering enables scientists to introduce specific traits into crops in a targeted manner, thereby accelerating the development of improved plant varieties. Genetically modified crops are plants whose DNA has been altered using modern molecular techniques to introduce traits that provide agronomic or nutritional advantages (Aziz et al., 2022).

Since their commercial introduction in 1996, transgenic crops have experienced rapid global adoption. Cultivation expanded from 1.7 million hectares to more than 190 million hectares by the early 2010s, reflecting strong acceptance in several major agricultural economies (James, 2003). More recent global agricultural assessments indicate that the cultivation of biotechnology crops has continued to expand in many regions, highlighting their increasing importance in modern farming systems. These developments illustrate how biotechnology has become a central component of contemporary strategies aimed at improving agricultural productivity and sustainability.

Several interconnected factors have driven the development of genetically modified crops. The global population continues to grow while available agricultural land per capita is steadily declining. Climate change also places additional pressure on crop production through increased drought, heat stress, and unpredictable weather patterns. Furthermore, agriculture must reduce excessive pesticide use while simultaneously improving the nutritional quality of staple foods consumed by large populations (Tabassum et al., 2021). Together, these challenges have accelerated scientific efforts to develop crops that are more resilient, productive, and nutritionally enhanced.

Agricultural biotechnology therefore represents a crucial component of the broader set of tools available to address global food security. It works alongside conventional breeding, improved agronomic management, and emerging agricultural technologies to increase crop performance and stability (Tripathi et al., 2022). Among the most important targets for genetic improvement are major staple crops such as rice, wheat, and maize, which collectively provide approximately 60 percent of the world's caloric intake (Shiferaw et al., 2011). Enhancing the productivity and resilience of these crops is therefore essential for sustaining global food supplies.

Although conventional plant breeding significantly increased agricultural production during the Green Revolution, it faces important limitations in addressing rapidly evolving environmental challenges. Traditional breeding programs often require many years to develop new varieties, particularly when multiple complex traits must be combined. These constraints highlight the value of modern biotechnology, which enables more precise and efficient modification of plant genomes (Qaim, 2020).

Genetically modified organisms offer several distinctive advantages in crop improvement. Scientists can introduce beneficial traits more efficiently, including resistance to pests and diseases, tolerance to environmental stresses such as drought and salinity, improved nutrient-use efficiency, and enhanced nutritional composition. In many cases, these improvements can be achieved within shorter timeframes compared with traditional breeding approaches (Ahmad, 2023).

As biotechnology continues to evolve, new genome-editing technologies are further expanding the possibilities for crop improvement. These advances are increasingly shaping the future of plant breeding and strengthening the role of biotechnology in achieving sustainable global food security.

2. Methodology

This study uses a narrative literature review to explore the role of genetically modified and genome-edited crops in global food security. Unlike systematic reviews, this approach allows integration of diverse studies, highlighting major trends, technological advances, and research gaps in plant biotechnology. Relevant peer-reviewed studies published between 2000 and 2025 were identified from Scopus, Web of Science, PubMed, and Google Scholar using keywords such as genetically modified crops, food security, stress tolerance, biofortification, and CRISPR/Cas. Studies were included if they were in English, published in scientific journals, and directly related to crop improvement or food security. After removing duplicates, titles and abstracts were screened, followed by full-text review of relevant studies. Literature was grouped thematically around yield improvement, stress tolerance, nutritional enhancement, and genome-editing technologies, providing an up-to-date overview of advances and remaining research needs. Although narrative reviews involve some interpretive judgment, this approach offers valuable insights by synthesizing diverse perspectives and highlighting the broader impact of biotechnology innovations on agriculture.

3. Resutls and Discussion

3.1. Crop yield enhancement and productivity improvements

Enhancing crop yields represents a fundamental strategy for ensuring food security under conditions of expanding global population and constrained land resources (Tabassum et al., 2021). Genetically modified crops have demonstrated substantial capacity to increase agricultural productivity through multiple mechanisms. First-generation transgenic crops have primarily focused on introducing herbicide tolerance and insect resistance traits that reduce production costs and losses while simplifying crop management (Barrows et al., 2014). The economic impacts of these first-generation GM crops have been well-documented, with studies demonstrating that adopting farmers achieved higher net returns per hectare through reduced pesticide expenses, lower labor requirements, and decreased crop losses compared to conventional farming systems (James, 2010).

Beyond herbicide tolerance and Bt-based pest resistance, emerging transgenic crops are being engineered to directly enhance yield through improved physiological characteristics. The expression of alternative photorespiratory pathways in C3 crops such as wheat, rice, and soybean represents a significant innovation, as these crops lose substantial productivity at elevated temperatures due to photorespiration, wherein the enzyme responsible for fixing CO2 fixes O2 instead (Cavanagh et al., 2021). Under heated field conditions, plants engineered with alternative photorespiratory pathways sustained 19 percent less yield loss compared to non-engineered plants, suggesting that such technologies could help maintain or improve yields in a warming climate. Similarly, genetic manipulation of gibberellin metabolism through overexpression of specific GA2 oxidase mutants in rice has yielded combinations of beneficial traits including reduced height, more productive tillers, expanded root systems, and increased photosynthesis rates, resulting in 10-30 percent increases in grain yield under field trial conditions (Lo et al., 2016).

The application of transgenic approaches to improve nitrogen use efficiency exemplifies how genetic modification can address a critical agricultural input limitation. Nitrogen is quantitatively the most essential nutrient for plants and the major factor limiting crop productivity; however, crops utilize only approximately 50 percent of applied nitrogen, with the remainder lost through various environmental pathways (Govindasamy et al., 2023). Transgenic rice expressing tissue-specific alanine aminotransferase driven by a root-specific promoter demonstrated significantly increased biomass and grain yield compared to control plants when supplied with adequate nitrogen, while simultaneously showing increased nitrogen uptake efficiency and modified key metabolite profiles indicative of enhanced nutrient assimilation (Shrawat et al., 2008). The development of such nitrogen-efficient crop varieties could substantially reduce fertilizer application rates, lower production costs while simultaneously reducing environmental externalities associated with nitrogen runoff and emissions.

3.2. Disease and Pest Resistance Development

Biotic stresses, encompassing both pest and pathogenic infections, represent major constraints to global crop production, causing yield losses frequently exceeding 30 percent annually (Pandit et al., 2022). Genetically modified approaches to disease and pest resistance have proven particularly valuable in addressing these challenges, especially in developing countries where access to chemical pesticides may be limited or economically prohibitive. The development of Bacillus thuringiensis (Bt) crops, which express insecticidal crystal proteins derived from this soil bacterium, has revolutionized insect pest management for numerous crops (Prasanna et al., 2022). Bt crops function through the production of proteinaceous toxins that selectively target lepidopteran (butterfly and moth) pests while exhibiting minimal toxicity to non-target organisms, thereby reducing reliance on broad-spectrum chemical insecticides.

In rice, the commercialization of insect-resistant genetically modified varieties in China represents a significant milestone in GM crop adoption for addressing major agricultural pests (Chen et al., 2010). These Bt rice lines, possessing cry1Ab/Ac genes for expression of insecticidal proteins, have demonstrated effective economic control of the lepidopteran pest complex affecting rice production, with laboratory and field tests confirming that the transgenic lines provide superior pest control compared to existing practices while presenting minimal environmental risk. The reduction in chemical pesticide applications associated with Bt crop adoption has resulted in documented decreases in insecticide costs and primary pesticide applications while simultaneously reducing occupational exposure among agricultural workers.

Beyond insect resistance, CRISPR/Cas9-based genome editing has emerged as a powerful technology for developing disease-resistant crops. The precision of CRISPR systems enables targeted modifications that enhance resistance to viral, fungal, and bacterial pathogens without the integration of foreign DNA, thus creating transgene-free plants (Erdoan et al., 2023). Recent applications have included the development of disease-resistant banana varieties targeting both banana bunchy top virus and banana streak viruses, and disease-resistant maize varieties resistant to maize lethal necrosis through CRISPR-mediated editing approaches (Tripathi et al., 2022). Furthermore, CRISPR/Cas-based strategies for controlling plant viruses have demonstrated tremendous potential through targeted engineering of either host susceptibility factors or direct resistance mechanisms, offering novel opportunities for reducing losses to viral diseases while improving food security (Robertson et al., 2022).

3.3. Abiotic stress tolerance for climate resilience

Climate change and increasing environmental variability pose profound threats to agricultural productivity, with abiotic stresses including drought, salinity, extreme temperatures, and waterlogging potentially reducing crop yields by more than 50 percent in severely affected regions (Rahman et al., 2022). The development of transgenic crops with enhanced abiotic stress tolerance has emerged as a critical adaptation strategy for maintaining food production under adverse environmental conditions. Drought stress represents perhaps the most widespread abiotic constraint affecting agriculture, particularly in rainfed systems characteristic of most developing countries (Turner et al., 2014). Genetic engineering approaches to drought tolerance have focused on manipulating genes involved in osmotic adjustment, antioxidant production, and water uptake, with successful examples including transgenic crops expressing osmoprotectants or enzymes involved in the synthesis of protective compounds.

Transgenic tomatoes developed for abiotic stress tolerance have been modified through expression of genes such as DREBs, Osmotin, and BADH2, which encode proteins involved in stress signaling, transcriptional control, and compatible solute synthesis (Krishna et al., 2019). These modifications have enabled tomato varieties to manage stress at the cellular level through modulation of downstream genes, ultimately improving growth and supporting more sustainable agricultural production. Similarly, transgenic maize plants overexpressing the Thellungiella halophila vacuolar H+-pyrophosphatase gene demonstrated enhanced tolerance to low phosphate availability stress, a common limitation in many agricultural soils, through development of more robust root systems that facilitated improved nutrient uptake (Pei et al., 2012).

Salt tolerance represents another critical trait for expanding agriculture into marginal lands and sustaining production in regions where soil salinization threatens traditional farming systems. Genetic approaches to salt tolerance have involved introducing genes encoding ion transporters, protective proteins, and osmoprotectants that enable plants to maintain cellular function despite elevated sodium or chloride concentrations (Carillo et al., 2011). The development of climate-smart crop varieties capable of withstanding multiple simultaneous stresses remains a priority for future food security, requiring integrated approaches combining conventional breeding, marker-assisted selection, and precise genome editing technologies (Razzaq et al., 2021). Furthermore, emerging technologies including nanotechnology-mediated genome editing and speed breeding platforms offer accelerated pathways for developing climate-resilient cultivars suited to anticipated future growing conditions (Raza et al., 2023).

3.4. Nutritional Enhancement and Biofortification

Hidden hunger, characterized by micronutrient deficiencies despite adequate caloric intake, affects over two billion people worldwide, with particularly severe impacts in low and middle-income countries where populations depend heavily on staple grains deficient in essential minerals and vitamins (Lowe, 2021). Biofortification, the process of breeding or engineering nutritional enhancements into food crops, has emerged as a cost-effective and sustainable approach to deliver micronutrients to vulnerable populations with limited access to dietary diversity or commercial fortification (Garg et al., 2018). The development of transgenic crops enriched with critical micronutrients represents a significant innovation, exemplified by the famous "Golden Rice" initiative aimed at providing provitamin A carotenoids through genetic modification (Welch & Graham, 2004).

Recent advances in CRISPR/Cas-based genome editing have substantially accelerated the development of biofortified crop varieties, enabling precise targeting of nutritional traits without the limitations associated with transgenic approaches (Kumar et al., 2022). CRISPR-based genome editing has been utilized to impart both qualitative enhancement—such as improvements in aroma, shelf life, sweetness, and texture—and quantitative improvement in nutritional components including starch, protein, gamma-aminobutyric acid (GABA), oleic acid, anthocyanin, and phytic acid contents in cereals, vegetables, and other crop species. The development of quality protein maize (QPM) represents a significant achievement in conventional breeding for nutritional improvement, with successful introgression of genes conferring higher protein content and improved amino acid balance, particularly enhanced lysine and tryptophan content, creating cereals with nutritional profiles more aligned with human dietary requirements (Prasanna et al., 2020).

Iron and zinc biofortification has received substantial research attention due to the global prevalence of deficiencies in these critical micronutrients. Transgenic rice lines incorporating barley genes involved in mugineic acid family phytosiderophore synthesis have demonstrated increased tolerance to iron deficiency stress in calcareous paddy soils, thereby improving agricultural productivity while simultaneously increasing iron and zinc concentrations in grain (Suzuki et al., 2008). Biofortified crops developed through breeding have been released in over 26 countries across Africa, Asia, and Latin America through initiatives such as HarvestPlus, with biofortified staple crops now being grown and consumed by millions of farmers and consumers in developing regions (Andersson, 2017). These crops combine enhanced micronutrient content with acceptable agronomic performance and consumer acceptability, demonstrating the practical application of nutritional improvement in addressing food and nutritional security, particularly in regions where cereal-based diets predominate (Palacios-Rojas et al., 2020).

3.5. Advanced genome dditing technologies: CRISPR and beyond

The CRISPR/Cas9 system has revolutionized the field of genetic modification by providing a rapid, efficient, and accessible tool for precise genome editing across diverse plant species (Zegeye et al., 2022). Unlike conventional genetic transformation approaches that require insertion of foreign DNA sequences, CRISPR-based methods enable targeted modifications through site-specific cleavage followed by either deletion or precise insertion of genetic material, frequently resulting in transgene-free edited plants (El-Mounadi et al., 2020). The advantages of CRISPR-based genome editing are substantial: the technology is simpler and less expensive than earlier site-specific nuclease approaches, exhibits high efficiency and reproducibility, and accelerates the breeding cycle by condensing the time required to develop improved varieties (Ahmad, 2023).

Recent technological advances beyond the original CRISPR/Cas9 system have further expanded the scope and precision of genome editing possibilities. Prime editing and base editing represent novel approaches that enable more complex and precise genetic modifications without generating double-strand breaks, thereby reducing off-target effects and improving editing accuracy (Vats et al., 2024). The availability of diverse Cas protein variants, including Cas12, Cas13, and Cas14 with alternative targeting specificities and operational characteristics, has expanded the toolkit available for crop improvement (Razzaq et al., 2021). Furthermore, the integration of nanotechnology with CRISPR systems through nanoparticle-mediated delivery approaches offers enhanced efficiency for both transient and stable genetic modifications across various plant species, potentially overcoming some limitations of conventional gene delivery methods (Ahmar et al., 2021).

A significant distinction between CRISPR-edited and conventionally transgenic crops relates to regulatory classification and public acceptance. Genome-edited plants developed through CRISPR approaches without foreign gene integration are increasingly regarded as non-GMOs in several countries, including Argentina, Japan, and others, thus potentially facilitating more rapid commercialization and public acceptance (Ahmad et al., 2023). This regulatory distinction reflects recognition that CRISPR-edited plants are phenotypically and genetically indistinguishable from plants that might arise through mutagenesis or conventional breeding, thereby potentially reducing regulatory burdens while maintaining rigorous safety considerations (Mushtaq et al., 2021). The potential for CRISPR technology to produce transgene-free plants with desirable traits similar to those developed through mutagenesis but with greater precision and efficiency has been identified as a pathway toward achieving widespread adoption of genome-edited crops in regions where transgenic crops face regulatory or public acceptance challenges.

3.6. Implementation challenges, policy framework, and future directions

Despite the substantial potential of genetically modified crops for enhancing food security, numerous implementation challenges remain, spanning regulatory, socioeconomic, and institutional domains (Qaim, 2020). The regulatory landscape governing GM crops varies substantially across different regions, with the United States and Canada regulating crops based on product characteristics, while the European Union, India, China, and other countries employ process-based regulation focused on whether the product was developed through genetic modification, regardless of the final characteristics (Ewa et al., 2022). This regulatory heterogeneity creates substantial complexity for international trade in agricultural products and may impede the adoption of beneficial technologies in regions with stringent regulatory requirements (Ewa et al., 2022).

Public perception represents a critical factor influencing GM crop adoption, with substantial regional variation in acceptance and familiarity with genetic modification technologies (Ewa et al., 2022). In North America and increasingly in other regions, public understanding of genome editing technologies has expanded, with CRISPR systems receiving greater recognition than earlier genetic engineering approaches. Conversely, public skepticism regarding GM foods persists in Europe and remains significant in many developing countries, often driven by concerns regarding environmental impacts, food safety, and corporate control of agricultural technology (Altieri & Rosset, 1999). Addressing public concerns requires transparent communication of scientific evidence regarding the safety and benefits of GM crops, coupled with inclusive dialogue involving diverse stakeholders including farmers, consumers, civil society organizations, and researchers.

Adoption of GM crops in developing countries faces multiple additional constraints beyond regulatory frameworks and public perception. Smallholder farmers, who constitute the majority of agricultural producers in Africa, South Asia, and parts of Latin America, often lack access to improved seed varieties, financial resources for purchasing agricultural inputs, extension services for technical guidance, and functional input and output markets (Shiferaw et al., 2011). The economic structure of seed systems and intellectual property regimes governing GM crops may further limit access for resource-poor farmers, particularly in regions where informal seed systems predominate. Addressing these constraints requires integrated approaches combining technology development, institutional innovation, policy reform, and investment in agricultural extension and farmer education (Wigboldus et al., 2016).

The integration of genetically modified crops within broader sustainable agriculture frameworks remains essential for optimizing their contributions to food security while maintaining environmental sustainability (Ronald, 2011). While GM crops have demonstrated capacity to reduce pesticide applications in herbicide-tolerant systems, concerns persist regarding the development of herbicide-resistant weeds and potential ecological impacts of reduced agricultural biodiversity. Future crop development must emphasize stacking multiple desirable traits—including yield improvement, stress tolerance, enhanced nutrition, and disease resistance—within single varieties to maximize their contributions to food security while supporting more sustainable farming systems (Aziz et al., 2022). The emergence of advanced molecular tools, including high-throughput phenotyping, genomic prediction, and artificial intelligence-assisted breeding, offers unprecedented opportunities to accelerate crop improvement while reducing the time and resources required to develop farmer-preferred varieties suited to diverse agroecological contexts (Razzaq et al., 2021).

Regional approaches to GM crop adoption and development must carefully consider the specific needs, constraints, and opportunities present in particular agroecological and socioeconomic contexts. In sub-Saharan Africa, where food insecurity remains acute and climate variability poses increasing challenges, the development and deployment of GM crops offering enhanced drought and disease resistance, along with improved nutritional content, could substantially contribute to food security and livelihoods for millions of smallholder farmers (Kavhiza et al., 2022). The establishment of enabling policy environments, including functional national biosafety regulatory frameworks, investment in research and development infrastructure, and integration with existing seed systems, will be essential for realizing the potential of genome-edited and transgenic crops in African agriculture (Tripathi et al., 2022). In South Asian contexts, where population density is high and land resources are constrained, the adoption of yield-enhancing and stress-tolerant varieties, coupled with improved agronomic practices, offers pathways toward more productive and resilient agricultural systems.

The future trajectory of genetically modified crops in contributing to global food security will be significantly influenced by ongoing technological innovations, regulatory development, and engagement with diverse stakeholders to address legitimate concerns while enabling adoption of beneficial technologies. The integration of CRISPR and advanced genome editing technologies with complementary innovations—including conventional breeding, marker-assisted selection, speed breeding platforms, and agronomic innovations—offers unprecedented capacity to develop crops suited to emerging challenges of climate change, population growth, and resource scarcity (Vats et al., 2024). Furthermore, the potential for combining genetic improvement with enhanced agronomic practices, improved soil health management through microbial interventions, and digital technologies for precision agriculture offers holistic pathways toward achieving sustainable intensification and food security in the coming decades (Razo-Belmén & Ozuna , 2023).

This comprehensive literature review synthesizes current knowledge regarding the role of genetically modified plants in addressing global food security challenges. The evidence demonstrates that GM crops offer substantial potential for enhancing agricultural productivity, improving crop quality, and enabling adaptation to environmental challenges while maintaining profitability for farmers. However, realizing this potential requires addressing regulatory barriers, building public confidence through transparent communication, ensuring equitable access for smallholder farmers, and integrating GM crop development within broader sustainable agriculture frameworks. Future advancement in this critical field will depend on continued interdisciplinary research, inclusive stakeholder engagement, and policy reforms that balance legitimate concerns regarding safety and sustainability with recognition of the substantial potential benefits of biotechnology for feeding a growing global population under increasingly challenging environmental conditions.

4. Conclusion

Genetically modified and genome-edited crops represent powerful tools for addressing the growing challenge of global food security. As the global population continues to expand and climate change intensifies pressures on agricultural systems, modern plant biotechnology provides practical solutions to increase crop productivity, enhance resistance to pests and environmental stresses, and improve the nutritional quality of staple foods.

Evidence from the literature demonstrates that genetically modified crops have already contributed to higher agricultural productivity and reduced crop losses, while newer genome-editing technologies—particularly CRISPR-based approaches—enable more precise and efficient development of improved crop varieties. These innovations allow scientists to enhance traits such as yield potential, nutrient-use efficiency, climate resilience, and micronutrient content, thereby strengthening the capacity of global food systems to meet future demands.

Realizing the full potential of GM and genome-edited crops requires supportive regulatory frameworks, transparent communication of scientific evidence, and equitable access to improved technologies for farmers, especially smallholder producers in developing regions. Addressing public concerns and strengthening institutional capacity will be essential for facilitating responsible adoption of these innovations.

Beyond productivity gains, agricultural biotechnology also offers important environmental and social benefits. By reducing pesticide use, improving nutrient efficiency, and enabling cultivation in marginal environments, genetically improved crops can contribute to more sustainable agricultural systems. At the same time, ensuring fair access to these technologies can enhance rural livelihoods and promote more inclusive agricultural development.

Overall, genetically modified and genome-edited crops should be viewed as essential components of integrated strategies for sustainable agriculture and global food security. When combined with conventional breeding, improved agronomic practices, and supportive policies, plant biotechnology can play a decisive role in ensuring a resilient, productive, and sustainable food system for a growing global population.

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