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Editorial

Genetic engineering in agriculture: Bridging plant science and molecular biology for sustainable solutions

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Abstract

Genetic engineering in agriculture has emerged as a groundbreaking approach to tackling some of the most pressing challenges of the modern era, including food security, environmental sustainability, and malnutrition. By integrating plant science with molecular biology, this innovative technology enables the development of crops that are more resilient to environmental stressors, enriched with essential nutrients, and less dependent on chemical inputs like pesticides and fertilizers. Examples such as drought-resistant maize, pest-resistant Bt cotton, and biofortified Golden Rice highlight the potential of genetically modified organisms (GMOs) to address global issues like hunger and nutrient deficiencies. Additionally, genetic engineering can promote sustainable farming by conserving water, reducing greenhouse gas emissions, and optimizing land use. However, the adoption of this technology is not without ethical and environmental concerns, including biodiversity impacts, corporate monopolization, and public skepticism about GMOs. Addressing these challenges through transparent research, robust regulatory oversight, and equitable access to innovations is critical. By responsibly harnessing the potential of genetic engineering, agriculture can be transformed into a more sustainable and equitable system capable of feeding a growing global population while preserving natural resources and promoting environmental health.

Agriculture, the foundation of human civilization, has witnessed significant transformations over the centuries (Thrall *et al.*, 2010). These advancements, particularly in modern times, have been driven by the need to address issues like food security, environmental sustainability, and the pressures posed by a rapidly growing global population (Bahar *et al.*, 2020; Wani *et al.*, 2023). Among the most transformative breakthroughs in recent decades is genetic engineering, which integrates molecular biology with plant science to create innovative agricultural solutions. By enabling precise modifications to plant genomes, genetic engineering offers the potential to solve some of the most pressing challenges in food production and sustainability (Yuan *et al.*, 2024; Aziz and Masmoudi, 2025). In this editorial, it is examined how genetic engineering bridges plant science and molecular biology to create sustainable solutions for agriculture, exploring its impact on crop productivity, resilience, and food security.

Plant science studies plant biology, growth, development, and interactions with the environment to improve crop yields, nutritional value, and resilience to diseases and environmental stresses (Kim *et al.*, 2021; Guzmán *et al.*, 2022). Molecular biology focuses on understanding molecular mechanisms within cells, including gene expression, protein synthesis, and DNA replication, to gain insights into how organisms function at the genetic level (Yang *et al.*, 2024). Genetic engineering in agriculture merges these two fields by using molecular biology tools to alter the genetic makeup of plants, introducing new traits that are beneficial for farming (Dong and Ronald, 2019). Unlike traditional breeding techniques, which rely on cross-breeding plants with desirable traits, genetic engineering enables more precise and targeted changes to an organism's genome. Through this process, specific genes can be inserted, deleted, or modified to enhance certain characteristics, such as pest resistance, drought tolerance, or improved nutritional content (Gao, 2021; Ahmad, 2023; Dutta, 2024a, 2024b).

The world's population is expected to reach 9.7 billion by 2050, putting immense pressure on global food production systems. According to the Food and Agriculture Organization (FAO), agricultural production must increase by 70% to meet this demand (Daszkiewicz, 2022). This challenge is compounded by environmental factors such as climate change, water scarcity, and soil degradation, which are threatening the viability of traditional farming practices (da Gama, 2023). In this context, genetic engineering offers a powerful solution to increase crop productivity and ensure food security. Traditional methods of improving crops are often slow, labor-intensive, and limited by natural genetic variation. Genetic engineering, however, allows scientists to introduce traits that enhance crop performance, making it a crucial tool for addressing global food security challenges (Anjanappa and Gruissem, 2021; Patil *et al.*, 2025). By integrating molecular biology into plant science, genetic engineering offers a faster, more efficient means of developing crops that can thrive in increasingly difficult environmental conditions while providing higher yields and improved nutritional value (Aziz *et al.*, 2022; Wang and Demirer, 2023).

One of the most significant advantages of genetic engineering is its ability to enhance crop resilience to environmental stressors, such as drought, extreme temperatures, and soil salinity. In many regions

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of the world, water scarcity and changing weather patterns pose a direct threat to crop production. Traditional crops are often ill-suited to cope with these conditions, leading to poor yields and food shortages (Shelake *et al.*, 2022; Muhammad *et al.*, 2024). Genetic engineering allows the introduction of genes from drought-resistant plants to help crops endure water stress. For example, GM rice and maize varieties are designed to thrive in flood-prone and arid areas, reducing water usage and promoting conservation (Valliyodan *et al.*, 2016; Villalobos-López *et al.*, 2022). Genetic engineering has produced crops that tolerate extreme temperatures and saline soils, enabling growth in previously unsuitable areas and enhancing food security while reducing land conversion and deforestation (Gill *et al.*, 2014; Tarolli *et al.*, 2024).

The widespread use of chemical pesticides has raised concerns about environmental pollution and health risks, while genetic engineering has led to the development of pest-resistant crops, reducing the need for chemical pesticides (Ahmad *et al.*, 2024; Kaur *et al.*, 2024). Bt (*Bacillus thuringiensis*) crops are genetically engineered to produce a protein toxic to specific insect pests but safe for humans, animals, and beneficial insects. For instance, Bt cotton protects against the cotton bollworm, reducing the need for chemical insecticides and minimizing environmental damage while improving crop health (Abu El-Ghiet *et al.*, 2023). In addition to pest resistance, genetic engineering can also be used to create crops that are resistant to diseases caused by fungi, viruses, and bacteria. The ability to reduce pesticide use through genetic modifications leads to a more sustainable agricultural system, which benefits both farmers and the environment (Dong and Ronald, 2019; van Esse *et al.*, 2020).

Malnutrition is a global issue, especially in developing countries with nutrient-deficient diets. Genetic engineering, through biofortification, can enhance the nutrient content of staple crops, showing promise in improving global health (Mmbando and Missanga, 2024; Naik *et al.*, 2024). Golden Rice is a genetically engineered crop designed to produce higher levels of provitamin A (beta-carotene), addressing vitamin A deficiency, a leading cause of blindness and health issues in developing countries. Its introduction could save millions of lives by improving vitamin A intake in regions with limited access to other nutrient sources (Tang *et al.*, 2009; Dubock, 2017). Other crops have also been genetically engineered to enhance essential amino acids, iron, and zinc content, addressing widespread nutrient deficiencies. This approach offers a powerful tool to combat malnutrition, especially in regions with limited agricultural productivity and restricted access to diverse food sources (Sandhu *et al.*, 2023; Naik *et al.*, 2024)

Genetic engineering in agriculture can promote sustainable farming by reducing the need for chemical fertilizers and pesticides, conserving water, and optimizing land use. Crops engineered to require fewer inputs are more environmentally friendly and cost-effective for farmers (Das *et al.*, 2023; Gamage *et al.*, 2024). For example, nitrogen-efficient crops are being developed to reduce the need for synthetic fertilizers, which contribute to pollution and greenhouse gas emissions. Similarly, pest- and disease-resistant genetically engineered crops can lower pesticide use, reducing the environmental impact of farming (Brunelle *et al.*, 2024). Crops with improved nutrient content and higher yields can reduce food waste by enabling farmers to grow more food on less land, conserving natural resources. Incorporating genetic engineering into agriculture promotes sustainability by increasing productivity while minimizing the negative impacts of conventional farming (Aziz *et al.*, 2022; Zuma *et al.*, 2023).

While genetic engineering in agriculture offers significant benefits, it also raises ethical and environmental concerns. Critics worry about unintended consequences, such as gene flow to wild relatives, the development of resistant pests, and the long-term impact on biodiversity (Idris *et al.*, 2023). Public perception of genetic engineering remains divided, with some people expressing concerns about the safety of GMOs and the potential for corporate control over agricultural systems. Transparency in research, strict regulatory oversight, and open dialogue between scientists, policymakers, and the public are crucial to addressing these concerns (Lucht, 2015; Dessie and Zegeye, 2024).

Ethical considerations regarding the patenting of genetically modified seeds and the monopolization of agricultural technology by large corporations must be addressed. The benefits of genetic engineering should be equitably distributed to ensure smallholder farmers and developing countries also have access to these innovations (Aziz *et al.*, 2022; Idris *et al.*, 2023).

Genetic engineering in agriculture offers a transformative solution to food security, environmental sustainability, and global malnutrition. By combining plant science and molecular biology, it enables the creation of crops that are more resilient, nutritious, and less reliant on harmful chemicals. While the benefits are significant, addressing ethical concerns and public perceptions is essential for responsible and equitable use, ensuring a sustainable, food-secure future.

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Ethical approval statement

None to declare.

Data availability

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Conflict of interest

The authors declare no competing interests.

Authors' contribution

Md. Mosharraf Hossen contributed to the conceptualization and writing of this editorial. The author has read and approved the final version of the published editorial.

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