IJIABS
INTERNATIONAL JOURNAL OF INNOVATIONS IN AGRICULTURE AND BIOLOGICAL SCIENCES

Multidisciplinary | Peer-Reviewed
Open Access | Research Journal
Volume 1 | Issue 1 | 2026

International Journal of Innovations in Agriculture and Biological Sciences

Agricultural Biotechnology and Crop Improvement: Developments, Applications and Future Prospects

Minakshi Golhani[1]

[1]*Research Scholar, Rani Durgavati Vishwavidyalaya, Jabalpur, India*

Received: 12.08.2026 | **Accepted:** 18.08.2026 | **Published:** 23.08.2026

Abstract

Agricultural biotechnology has become an essential approach for accelerating crop improvement and addressing emerging challenges to global food and nutritional security. This review examines major developments, applications and future prospects of biotechnology-based crop improvement. Key developments include molecular markers, marker-assisted selection, genomic selection, genetic engineering and CRISPR-based genome editing, including advanced tools such as base and prime editing. These technologies have expanded opportunities to improve yield, agronomic characteristics, resistance to biotic stresses and tolerance to drought, salinity and heat, as well as nutritional and quality traits. Recent advances further demonstrate the potential of integrating biotechnology with genomics, multi-omics, high-throughput phenotyping and artificial intelligence to develop precise and climate-resilient crop varieties. However, technical, biosafety, regulatory, ethical and accessibility challenges remain important considerations for responsible implementation. Overall, biotechnology offers substantial potential for sustainable and resilient crop improvement.

Keywords: *Agricultural biotechnology; Crop improvement; Genome editing; CRISPR-Cas; Climate-resilient crops*

1 Introduction

Agricultural biotechnology has emerged as an important component of modern crop improvement, providing advanced approaches for addressing the increasing demand for food, nutritional security and sustainable agricultural production. Conventional breeding has substantially contributed to the development of improved crop varieties; however, its effectiveness may be constrained by long breeding cycles, complex inheritance patterns and limited availability of desirable genetic variation [1]. Agricultural biotechnology complements conventional breeding by enabling the identification, selection, transfer and precise modification of genes associated with economically important traits. Molecular markers and marker-assisted selection (MAS) have improved the efficiency and accuracy of breeding by allowing breeders to select plants carrying desirable genes at an early stage [2].

The development of genetic engineering further enabled the introduction or modification of specific genes for traits such as insect resistance, herbicide tolerance and improved nutritional quality. More recently, genome-editing technologies, particularly CRISPR–Cas systems, have transformed crop improvement by allowing targeted modification of plant genomes [3]. Advanced approaches such as base editing and prime editing provide opportunities for increasingly precise genetic changes. These technologies are particularly relevant under changing climatic conditions, where crops with improved yield stability, disease resistance and tolerance to drought, salinity and heat are required. Therefore, agricultural biotechnology is increasingly shifting crop improvement from conventional selection towards more precise, rapid and trait-specific breeding strategies [4]. This review discusses major developments, important applications and future prospects of agricultural biotechnology in crop improvement.

2 Major Developments in Agricultural Biotechnology for Crop Improvement

Agricultural biotechnology has progressed from relatively conventional molecular breeding techniques towards highly precise genome-engineering approaches. These developments have increased the ability of breeders to identify desirable genetic variation, select superior genotypes and modify specific genes associated with important agricultural traits [5]. Major developments include:

- **Molecular markers and marker-assisted selection:** DNA markers linked with genes or quantitative trait loci (QTLs) enable early and accurate selection of desirable plants. MAS has been particularly useful for disease resistance, quality traits and the introgression of favourable genes into elite varieties.
- **Genomic selection and high-throughput genotyping:** Advances in sequencing and genotyping have enabled breeders to evaluate large numbers of genetic variants and predict breeding values, supporting faster selection for complex traits such as yield and stress tolerance.
- **Genetic engineering:** Transgenic approaches introduced specific genes into crops to develop traits such as insect and disease resistance, herbicide tolerance and improved nutritional characteristics.
- **CRISPR-based genome editing:** CRISPR–Cas systems have enabled targeted modification of crop genomes. Newer tools, including **base editing and prime editing**, allow increasingly precise changes without requiring conventional transgene-based approaches.

3 Applications of Agricultural Biotechnology in Crop Improvement

Agricultural biotechnology is applied to improve crop productivity, resilience, quality and nutritional value. Its major contribution is the ability to target specific genetic traits while reducing the time and resources required for conventional breeding [6]. Important applications include:

- **Yield and agronomic improvement:** Molecular breeding and genome editing can modify genes associated with plant architecture, growth, development and yield components, supporting the development of productive crop varieties. CRISPR-based approaches have also been explored for accelerated breeding and domestication.
- **Biotic stress resistance:** Biotechnology is used to develop resistance against insects, fungi, bacteria and viruses. Molecular markers facilitate the selection and pyramiding of resistance genes, while genome editing provides opportunities to modify susceptibility genes and enhance plant defence mechanisms.
- **Abiotic stress tolerance:** Drought, salinity, heat and other environmental stresses increasingly threaten crop productivity. Marker-assisted breeding and genome editing can help develop varieties with improved tolerance and greater yield stability under adverse conditions.
- **Nutritional and quality improvement:** Biotechnology can enhance nutritional components, improve food quality and support biofortification through targeted modification of genes controlling nutritional traits.

4 Future Prospects of Biotechnology-Based Crop Improvement

The future of biotechnology-based crop improvement is expected to depend increasingly on the integration of genome editing with genomics, high-throughput phenotyping and other data-driven breeding approaches. CRISPR–Cas technology is likely to remain central, while base editing, prime editing, multiplex genome editing and improved delivery systems may provide greater precision and flexibility for modifying complex traits. Integration of molecular markers, genomic selection and genome-wide information can further accelerate the identification and selection of superior genotypes. Future research is also expected to focus strongly on climate-resilient crops capable of maintaining productivity under drought, salinity, heat and other environmental stresses. Nutritional improvement and biofortification may simultaneously contribute to addressing micronutrient deficiencies. However, wider application will require attention to technical limitations, genome-editing efficiency, transformation and delivery challenges, biosafety, regulatory requirements and public acceptance. Equitable access to advanced biotechnology will also be important, particularly for crops and farming systems in developing regions. Overall, the integration of precision genome engineering with conventional breeding and genomic technologies offers considerable potential for developing productive, nutritionally improved and climate-resilient crops while supporting more sustainable agricultural systems [7].

5 Literature review

(Hossen et al., 2026) [8] Driven by rapid advancements in computer science and the need for efficient data processing, artificial intelligence (AI) is transforming the agricultural sector. As climate change and population growth threaten global food security, AI-driven models offer exceptional pattern-recognition capabilities to create novel solutions. This comprehensive review evaluates the evolution of AI in agricultural biotechnology, detailing its applications across crop improvement, genomic selection, precision agriculture, pest detection, and soil nutrient management. Additionally, the study contrasts commercial intellectual property growth with academic outputs and addresses critical ethical barriers like data sovereignty and the digital divide. Ultimately, the authors highlight future frontiers involving quantum computing to build sustainable, climate-resilient agricultural systems capable of overcoming modern food security challenges.

(Gidi, 2023)[9] To feed a projected global population of nine billion by 2050, agricultural biotechnology is critical for sustainable crop production improvements. Developing regions, particularly sub-Saharan Africa and South Asia, face severe agricultural limitations due to climate change, land scarcity, and a lack of modern technology, leading to widespread poverty and food insecurity. Advanced biotechnological techniques—such as genetic modification and plant transformation—play a vital role by introducing novel genes or suppressing existing traits. Traits like herbicide tolerance, insect resistance, abiotic stress tolerance, disease resistance, and enhanced grain quality contribute to community adoption. Consequently, harnessing crop improvement through agricultural biotechnology represents one of the most efficient strategies to combat global food insecurity and climate change disasters.

(Mallick et al., 2026) [10] Faced with unprecedented challenges like population growth, climate change, and declining crop yields, the global agricultural sector must transition from conventional breeding to holistic strategies integrating biotechnology, genomics, and data analysis. This book chapter examines how agricultural biotechnology accelerates genetic improvement, enhances climate resilience, and optimizes resource-use efficiency. It explores tools like tissue culture, molecular markers, RNA-based technologies, and CRISPR-Cas genome editing, emphasizing their synergy with whole-genome sequencing, multi-omics, and artificial intelligence models. Furthermore, the chapter addresses vital governance issues, including biosafety assessments, intellectual property rights, and regulatory frameworks. It argues that success depends on harmonizing scientific innovations with effective seed distribution systems to ensure long-term benefits for agriculture in developing countries.

(Adlak et al., 2019)[11] Plant breeding traditionally focuses on genetic crop improvement through hybridization and selection, yet conventional methods are time-consuming, taking six to twelve years to yield advanced varieties. Modern biotechnology significantly accelerates this process, increasing accuracy while reducing development time. Key techniques include plant tissue culture for somatic hybrids, transgenic approaches for genetically modified organisms, and DNA markers for targeted trait selection. Furthermore, the integration of nanotechnology and bioinformatics opens a new era of genomics-assisted molecular breeding. Next-generation sequencing and high-throughput genotyping further amplify the efficiency and output of agricultural biotechnological tools, enabling the rapid development of varieties with enhanced biotic and abiotic stress resistance.

(S. Singh et al., 2025) [12] Biotechnology has ushered in a new era for plant improvement, overcoming the limitations of traditional breeding. Beyond conventional genetic engineering, modern innovations like RNA interference (RNAi), microRNAs, and microproteins provide precise control over gene expression and complex traits such as stress tolerance and nutrient uptake. Furthermore, advanced genome-editing tools like base editing and prime editing allow targeted DNA modifications without double-strand breaks. When integrated with omics technologies and high-throughput phenotyping, these tools accelerate the development of elite cultivars suited for specific environments. Understanding these innovations, alongside necessary ethical and regulatory frameworks, is vital for ensuring responsible deployment and securing the productivity, climate resilience, and sustainability of global food systems.

6 Conclusion

Agricultural biotechnology has substantially transformed crop improvement by complementing conventional breeding with precise, efficient and increasingly rapid approaches for manipulating and selecting desirable traits. The developments from molecular markers and marker-assisted selection to genomic selection, genetic engineering and CRISPR-based genome editing have expanded the possibilities for developing improved crop varieties. The reviewed literature demonstrates that these technologies can contribute to enhanced yield and agronomic performance, resistance to insects and diseases, tolerance to drought, salinity and heat, and improvement of nutritional and quality characteristics. Future progress will increasingly depend on integrating genome editing with genomics, multi-omics, high-throughput phenotyping and artificial intelligence to accelerate the development of climate-resilient and resource-efficient crops. Nevertheless, technical limitations, biosafety concerns, regulatory requirements, ethical considerations and unequal access must be addressed. Responsible integration of biotechnology with conventional breeding and effective seed systems can therefore contribute significantly to sustainable agricultural production and long-term global food security.

References

[1] V. K. Meshram, R. K. Misra, and P. K. Tiwari, “A Review on Physicochemical Characteristics of Coal Ash and Soil,” *Int. J. Innov. Sci. Eng. Manag.*, vol. 4, no. 2, pp. 155–160, 2025, doi: 10.69968/ijisem.2025v4i2155-160.

[2] L. N. PATIL, A. A. PATIL, S. A. PATIL, S. D. SANCHETI, and V. K. AGRAWAL, “Advancements in Crop Yield Improvement through Genetic Engineering,” *Curr. Agric. Res. J.*, vol. 12, no. 3, 2024.

[3] M. R. Lundgren, A. P. Cavanagh, and P. Macnaghten, “Agricultural biotechnology: Potential, challenges, and debate,” *Plants People Planet*, pp. 1215–1219, 2025, doi: 10.1002/ppp3.70019.

[4] M. Riaz *et al.*, “Evolution of agricultural biotechnology is the paradigm shift in crop resilience and development: a review,” *Front. Plant Sci.*, pp. 1–17, 2025, doi: 10.3389/fpls.2025.1585826.

[5] R. Pathirana and F. Carimi, “Plant Biotechnology—An Indispensable Tool for Crop Improvement,” *Plants*, vol. 12, 2024.

[6] M. Singh, R. P. Singh, A. Patra, H. Singh, and R. M. Ram, “Application and Recent Trends of Biotechnology in Sustainable Agriculture: A Brief Review,” *J. Adv. Biol. Biotechnol.*, vol. 28, no. 1, pp. 846–858, 2025.

[7] M. A. Hossain and H. Roslan, *Emerging genomic technologies for agricultural biotechnology: Current trends and future prospects*. 2023. doi: 10.3389/978-2-8325-3439-7.

[8] Z. Hossen *et al.*, “Artificial intelligence-driven advancements in agricultural biotechnology,” *J. Genet. Eng. Biotechnol.*, vol. 24, no. 3, p. 100749, 2026, doi: 10.1016/j.jgeb.2026.100749.

[9] M. Gidi, “Agricultural Biotechnology and Crop Improvement: A Review,” *Int. J. Genet. Genomics*, vol. 11, no. 3, pp. 81–85, 2023, doi: 10.11648/j.ijgg.20231103.13.

[10] H. K. Mallick, M. Imtiyaz, D. A. K. Dolai, D. P. Ghosh, D. A. Ray, and D. S. Dewanjee, “AGRICULTURAL BIOTECHNOLOGY AND CROP IMPROVEMENT PLATFORMS,” *Adv. Biotechnol. Res. Tech. Appl.*, vol. 6, pp. 58–72, 2026.

[11] T. Adlak *et al.*, “Biotechnology: An Advanced Tool for Crop Improvement,” *Curr. J. Appl. Sci. Technol.*, vol. 33, no. 1, pp. 1–11, 2019, doi: 10.9734/CJAST/2019/v33i130081.

[12] S. Singh, P. Bhattacharyya, K. Aditya, and J. Jorben, “Gene revolution: Unravelling biotechnology for crop improvement,” *Physiol. Mol. Plant Pathol.*, vol. 139, p. 102793, 2025, doi: https://doi.org/10.1016/j.pmpp.2025.102793.