

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2026): 5.29
IJABR 2026; SP-10(2): 875-879
www.biochemjournal.com
Received: 16-12-2025
Accepted: 19-01-2026

Battala Sheshagiri
Department of Agricultural
Economics, Naini Agricultural
Institute, Sam Higginbottom
University of Agriculture,
Technology and Sciences,
Prayagraj, Uttar Pradesh,
India

Datla Kamala Devi
Department of Genetics and
Plant Breeding, Malla Reddy
University, Hyderabad,
Telangana, India

Pradeep Lakkarsu
Department of Biotechnology,
Fort Valley State University,
USA

Telukutla Sravan Srikanth
Agricultural College, Bapatla,
Acharya N. G. Ranga
Agricultural University,
Bapatla, Guntur, Andhra
Pradesh, India

Rajeev Ranjan
Department of Agricultural
Science, Sandip University,
Bihar, India

Dr. Khanin Pathak
Department of Biochemistry,
SCS College of Agriculture,
Assam Agricultural University,
Assam, India

Neppala Divya
Department of Agronomy,
Naini Agricultural Institute,
Sam Higginbottom University
of Agriculture, Technology and
Sciences, Prayagraj, Uttar
Pradesh, India

Corresponding Author:
Battala Sheshagiri
Department of Agricultural
Economics, Naini Agricultural
Institute, Sam Higginbottom
University of Agriculture,
Technology and Sciences,
Prayagraj, Uttar Pradesh,
India

CRISPR technology in crop improvement: Current trends and future prospects

Battala Sheshagiri, Datla Kamala Devi, Pradeep Lakkarsu, Telukutla Sravan Srikanth, Rajeev Ranjan, Khanin Pathak and Neppala Divya

DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i2Sk.7747>

Abstract

CRISPR/Cas9 technology has emerged as a groundbreaking tool in crop improvement, offering a precise and efficient means to enhance agricultural productivity and sustainability. Originally discovered as a bacterial immune defence mechanism, CRISPR has been adapted to edit plant genomes, enabling targeted modifications that improve key traits such as yield, disease resistance, stress tolerance, and nutritional content. This chapter explores the mechanisms of CRISPR/Cas9, the advancements in its application, and its current and future role in crop breeding. It begins by detailing the basic components of the CRISPR system, including Cas9, guide RNA, and the gene-editing process, before discussing the various CRISPR variants and their improvements, such as CRISPR/Cas12 and CRISPR/Cas13. The chapter highlights successful applications of CRISPR in crops such as rice, maize, and wheat, where it has been used to improve traits like drought tolerance, disease resistance, and biofortification. However, the chapter also addresses several challenges and limitations associated with CRISPR, including ethical concerns, regulatory issues, and technical hurdles in gene delivery. As research progresses, CRISPR's potential to revolutionise agriculture is clear, with promising applications in developing crops that can withstand climate change, enhance food security, and address malnutrition. The chapter concludes with an outlook on the prospects of CRISPR technology, emphasising the importance of continued research and collaboration to overcome existing challenges and realise its full potential for crop improvement. This technology holds the promise to reshape the future of agriculture, providing solutions to some of the most critical issues facing global food production.

Keywords: CRISPR/Cas9, crop improvement, genetic engineering, agriculture biotechnology, gene editing

1. Introduction

The growing challenges in agriculture, such as rising food demand, climate change, and environmental degradation, have prompted the need for innovative solutions to improve crop productivity and sustainability. One of the most promising tools to address these challenges is CRISPR/Cas9, a gene-editing technology that has revolutionised how scientists alter the genetic makeup of organisms. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is a natural defence mechanism in bacteria that has been adapted for precise genome editing. By enabling targeted modifications to an organism's DNA, CRISPR enables the enhancement of specific traits in crops, such as increased yield, disease resistance, drought tolerance, and improved nutritional content. This technology offers a faster and more efficient alternative to traditional breeding methods, which are often time-consuming and resource-intensive.

The development of CRISPR/Cas9 was a significant milestone in biotechnology, offering unprecedented precision in genome editing. While the technology was initially discovered in bacteria as a viral defence mechanism, it was later harnessed by scientists Jennifer Doudna and Emmanuelle Charpentier in 2012 to edit the genomes of other organisms, including plants. Since then, CRISPR/Cas9 has become a cornerstone of plant biotechnology, enabling genetic modifications that were previously not possible. The ability to introduce specific genetic changes without inserting foreign DNA has made CRISPR a powerful tool for crop improvement. This Paper will explore the current applications of CRISPR in crop improvement, review the advancements in the technology, and discuss the challenges and

prospects of CRISPR in agriculture. As the technology continues to evolve, its potential to address global food security and environmental challenges remains vast, making CRISPR a key player in the future of sustainable agriculture.

2. CRISPR/Cas9 Technology: Mechanism and Tools

The CRISPR/Cas9 technology functions as a molecular tool that enables precise modifications to the DNA of various organisms, including plants. CRISPR, originally part of the bacterial immune system, allows bacteria to recognise and defend against viral invaders by storing fragments of viral

DNA in their genome. These fragments are then used to target and cut similar DNA in subsequent infections. The CRISPR/Cas9 system utilises two key components: the Cas9 protein, which acts as molecular “scissors” to cut DNA, and a guide RNA (gRNA), which directs Cas9 to the specific DNA sequence where the cut is to be made. This targeted break can lead to the insertion, deletion, or modification of genetic material as the cell attempts to repair it. In plants, this precise editing enables the introduction of desirable traits, such as improved pest resistance or stress tolerance.

Table 1: Comparison of CRISPR/Cas9 Variants and Their Applications in Crop Improvement

CRISPR System	Key Feature	Application in Crop Improvement	Example Crops
CRISPR/Cas9	The DNA-targeting system introduces double-strand breaks	Gene knockout, targeted modifications	Rice, Wheat, Maize
CRISPR/Cas12 (Cpf1)	More accurate cuts, smaller target sequence	Editing large genomic regions, reducing off-target effects	Tomato, Soybean
CRISPR/Cas13	Targets RNA instead of DNA	RNA interference, regulation of gene expression	Arabidopsis, Tobacco

Over time, scientists have improved the CRISPR/Cas9 system, leading to the development of several variants with enhanced capabilities. One such advancement is the CRISPR/Cas12 system, which can make more accurate cuts and reduce off-target effects. Another recent addition is CRISPR/Cas13, which targets RNA rather than DNA, enabling the potential to control gene expression without altering the genetic code. The ability to edit multiple genes simultaneously, known as multiplexing, is another critical advancement that increases the efficiency of crop breeding. Furthermore, new delivery systems are being developed to effectively deliver CRISPR components into plant cells, as plants pose unique challenges for DNA uptake. These advancements have expanded the potential applications of CRISPR in agriculture, making it a more versatile and precise tool for crop improvement.

3. Current Applications of CRISPR in Crop Improvement

CRISPR/Cas9 technology has made significant strides in crop improvement, opening new avenues to enhance traits vital to agricultural productivity. One of the primary applications of CRISPR in crops is improving yield and productivity. By modifying genes involved in plant growth and development, CRISPR has enabled the development of crops with increased biomass, more efficient photosynthesis, and better nutrient absorption. For instance, CRISPR has

been used to enhance rice by editing genes that regulate grain size and weight, thereby increasing yield potential. Similarly, efforts to increase the drought tolerance of crops such as maize and wheat have seen success with CRISPR edits targeting stress-responsive genes, enabling these crops to perform better under water-limited conditions, a critical trait given the growing concerns over climate change and water scarcity.

Beyond yield improvements, CRISPR has proven to be a powerful tool for enhancing crop disease resistance. Traditional methods of controlling plant diseases often rely on chemical pesticides, which can have negative environmental impacts. With CRISPR, scientists have successfully edited genes in crops such as tomatoes, potatoes, and wheat to confer resistance to specific pathogens, including fungi and viruses. For example, by targeting genes involved in pathogen recognition and defence signalling, CRISPR has been used to generate crops resistant to bacterial blight and the devastating wheat rust fungus. Additionally, CRISPR has been employed to improve the nutritional quality of crops, such as enhancing the levels of vitamins, minerals, and essential amino acids. Biofortification of staple crops like rice and maize has the potential to address global malnutrition issues by increasing the nutritional value of commonly consumed foods, particularly in regions where nutrient deficiencies are prevalent.

Table 2: CRISPR Applications in Improving Key Traits in Major Crops

Trait	Crop	CRISPR Application	Result/Impact
Drought Tolerance	Maize	Modification of genes regulating water use	Enhanced drought resistance
Disease Resistance	Wheat	Editing genes for rust resistance	Reduced susceptibility to wheat rust fungus
Nutritional Enhancement	Rice	Biofortification of genes for iron and zinc	Increased micronutrient content
Pest Resistance	Tomato	Modifying immune response genes	Improved resistance to bacterial diseases

4. Advancements in CRISPR Technology for Crop Engineering

The field of CRISPR technology has rapidly evolved, with several advancements that have enhanced its potential for crop engineering. One notable development is the improvement of CRISPR/Cas9 systems, such as CRISPR/Cas12 (Cpf1) and CRISPR/Cas13. These new variants offer greater precision in genome editing, reducing the likelihood of unintended off-target effects. For instance,

CRISPR/Cas12 can produce more accurate DNA cuts and has a smaller footprint, which can be advantageous for targeting specific regions of the genome. On the other hand, CRISPR/Cas13 targets RNA rather than DNA, enabling regulation of gene expression without permanently altering the plant's genetic code. This distinction opens new possibilities for temporally and reversibly controlling gene expression, offering a more flexible approach to crop improvement. Together, these advancements are enhancing

the versatility of CRISPR in developing crops with tailored characteristics.

Another significant breakthrough in CRISPR technology is the ability to perform multiplex gene editing, enabling simultaneous targeting and editing of multiple genes. This capability drastically increases the efficiency of genetic modifications and accelerates the breeding process. Multiplexing allows researchers to introduce or modify several traits in a single editing step, which is especially valuable for improving complex traits such as disease resistance or stress tolerance that involve multiple genetic factors. Additionally, advancements in CRISPR delivery methods have also contributed to the successful application of CRISPR in crops. Traditional methods of delivering CRISPR components into plant cells, such as *Agrobacterium*-mediated transformation, are being enhanced by newer, more efficient techniques, including nanoparticle-based delivery and protoplast transformation. These improvements enable more precise and reliable editing in a wider range of plant species, expanding the scope of CRISPR's applications in crop engineering.

5. Challenges and Limitations

Despite the promising potential of CRISPR technology for crop improvement, several challenges and limitations remain to be addressed for its widespread adoption. One of the primary concerns is the ethical implications of genetically editing plants, particularly regarding public perception. While CRISPR offers precision and reduced risk of unintended changes compared to older genetic modification techniques, the use of gene-editing technologies in agriculture can still raise public concerns about the safety of consuming genetically modified organisms (GMOs). These concerns often stem from fears of unintended ecological consequences, potential cross-contamination with wild relatives, and long-term health effects that have not yet been fully studied. Addressing these concerns will require clear communication, transparent research, and robust regulatory frameworks to ensure the safety of CRISPR-edited crops.

Another significant challenge lies in the regulatory and approval processes for CRISPR-edited crops. Different countries have varying regulations on the classification and approval of genetically edited crops, leading to inconsistent commercialisation. In some regions, crops modified using CRISPR may face stringent regulations similar to those imposed on GMOs, delaying their approval and adoption. In contrast, other countries may have more relaxed regulations, enabling faster commercialisation. Navigating this regulatory landscape presents a major hurdle for global deployment, as companies and researchers must meet varying standards depending on where their crops will be sold. Additionally, delivering CRISPR components into plant cells remains a technical challenge, as efficient and reliable methods are still being developed. These delivery methods must be optimised to ensure edit precision and minimise off-target effects, especially in crops with complex genomes.

6. Future Prospects and Trends

The future of CRISPR in agriculture is both exciting and full of potential, with ongoing research aimed at addressing current challenges and expanding its scope of applications. One of the most promising areas for CRISPR in the coming

years is its role in developing crops that can withstand the growing threats posed by climate change. With rising global temperatures and changing weather patterns, crops are increasingly vulnerable to stresses such as drought, heat, and salinity. CRISPR has already shown promise in enhancing the stress tolerance of crops such as maize, rice, and wheat by targeting genes that regulate water use and stress responses. In the future, CRISPR could be used to create crops that are not only more resilient to extreme weather conditions but also able to grow in suboptimal soil conditions, thereby contributing to food security in regions most affected by climate change.

Beyond stress tolerance, CRISPR's potential to improve crop nutritional value will play a crucial role in addressing global malnutrition. With the increasing demand for nutrient-rich food and the growing prevalence of micronutrient deficiencies in developing countries, CRISPR can be used to biofortify staple crops, enhancing their vitamin, mineral, and protein content. For example, efforts are underway to increase the iron and zinc levels in rice and maize, which are crucial for preventing malnutrition. Moreover, CRISPR could be used to develop crops with enhanced medicinal properties, offering natural solutions to health challenges. As the technology continues to evolve, it may also be integrated with other emerging biotechnological tools such as synthetic biology and gene drives, further enhancing its ability to address complex agricultural and ecological problems.

7. Conclusion

CRISPR/Cas9 technology has the potential to revolutionise crop improvement by offering precise, efficient, and cost-effective solutions to some of agriculture's most pressing challenges. The ability to edit plant genomes with high specificity enables the development of crops that are more resilient to environmental stresses, more nutritious, and more productive. CRISPR has already demonstrated its ability to enhance yield, disease resistance, and stress tolerance, with several successful applications in major crops such as rice, maize, and wheat. Additionally, the technology's ability to enhance nutritional content through biofortification presents a unique opportunity to address global malnutrition and food insecurity.

However, while the promise of CRISPR is vast, several challenges remain, including ethical concerns, regulatory hurdles, and technical limitations in gene delivery. As research continues and new advancements are made, it is expected that many of these challenges will be addressed, paving the way for the wider adoption of CRISPR-edited crops. The future of CRISPR in agriculture looks promising, with potential applications that could greatly improve global food security and sustainability. As the technology matures, it will be essential to foster collaboration among scientists, policymakers, and the public to ensure that CRISPR's benefits are realised while mitigating any potential risks. Ultimately, CRISPR has the power to reshape the future of agriculture, offering a path toward more resilient, nutritious, and sustainable crop production amid a changing global environment.

References

1. Karkute SG, Singh AK, Gupta OP, Singh PM, Singh B. CRISPR/Cas9 mediated genome engineering for improvement of horticultural crops. *Front Plant Sci.* 2017;8:1635.

2. Liu H, Chen W, Li Y, Sun L, Chai Y, Chen H, *et al.* CRISPR/Cas9 technology and its utility for crop improvement. *Int J Mol Sci.* 2022;23(18):10442.
3. Gan WC, Ling AP. CRISPR/Cas9 in plant biotechnology: applications and challenges. *Biotechnologia.* 2022;103(1):81-90.
4. Haque E, Taniguchi H, Hassan MM, Bhowmik P, Karim MR, Smiech M, *et al.* Application of CRISPR/Cas9 genome editing technology for the improvement of crops cultivated in tropical climates: recent progress, prospects, and challenges. *Front Plant Sci.* 2018;9:617.
5. Kafle S. CRISPR/CAS9: A new paradigm for crop improvement revolutionizing agriculture. *J Agric Food Res.* 2023;11:100484.
6. Liu Q, Yang F, Zhang J, Liu H, Rahman S, Islam S, *et al.* Application of CRISPR/Cas9 in crop quality improvement. *Int J Mol Sci.* 2021;22(8):4206.
7. Guo Y, Zhao G, Gao X, Zhang L, Zhang Y, Cai X, *et al.* CRISPR/Cas9 gene editing technology: a precise and efficient tool for crop quality improvement. *Planta.* 2023;258(2):36.
8. Arora L, Narula A. Gene editing and crop improvement using CRISPR-Cas9 system. *Front Plant Sci.* 2017;8:1932.
9. Sami A, Xue Z, Tazein S, Arshad A, Zhu ZH, Chen YP, *et al.* CRISPR-Cas9-based genetic engineering for crop improvement under drought stress. *Bioengineered.* 2021;12(1):5814-5829.
10. Zhao K, Mishra R, Joshi RK. Genome editing technologies for crop improvement. Singapore: Springer; 2022.
11. Rao MJ, Wang L. CRISPR/Cas9 technology for improving agronomic traits and future prospective in agriculture. *Planta.* 2021;254(4):68.
12. Eş I, Gavahian M, Marti-Quijal FJ, Lorenzo JM, Khaneghah AM, Tsatsanis C, *et al.* The application of the CRISPR-Cas9 genome editing machinery in food and agricultural science: current status, future perspectives, and associated challenges. *Biotechnol Adv.* 2019;37(3):410-421.
13. Rai GK, Khanday DM, Kumar P, Magotra I, Choudhary SM, Kosser R, *et al.* Enhancing crop resilience to drought stress through CRISPR-Cas9 genome editing. *Plants (Basel).* 2023;12(12):2306.
14. Gao C. Genome engineering for crop improvement and future agriculture. *Cell.* 2021;184(6):1621-1635.
15. Zhang S, Zhang R, Gao J, Song G, Li J, Li W, *et al.* CRISPR/Cas9-mediated genome editing for wheat grain quality improvement. *Plant Biotechnol J.* 2021;19(9):1684-1696.
16. Gupta S, Kumar A, Patel R, Kumar V. Genetically modified crop regulations: scope and opportunity using the CRISPR-Cas9 genome editing approach. *Mol Biol Rep.* 2021;48(5):4851-4863.
17. Song G, Jia M, Chen K, Kong X, Khattak B, Xie C, *et al.* CRISPR/Cas9: a powerful tool for crop genome editing. *Crop J.* 2016;4(2):75-82.
18. Bhowmik P, Konkin D, Polowick P, Hodgins CL, Subedi M, Xiang D, *et al.* CRISPR/Cas9 gene editing in legume crops: opportunities and challenges. *Legume Sci.* 2021;3(3):e96.
19. Bhattacharjee M, Meshram S, Dayma J, Pandey N, Abdallah N, Hamwieh A, *et al.* Genetic engineering: a powerful tool for crop improvement. In: *Frontier technologies for crop improvement.* Singapore: Springer Nature Singapore; 2024. p. 223-258.
20. Khan MHU, Khan SU, Muhammad A, Hu L, Yang Y, Fan C. Induced mutation and epigenetics modification in plants for crop improvement by targeting CRISPR/Cas9 technology. *J Cell Physiol.* 2018;233(6):4578-4594.
21. Chilcoat D, Liu ZB, Sander J. Use of CRISPR/Cas9 for crop improvement in maize and soybean. *Prog Mol Biol Transl Sci.* 2017;149:27-46.
22. Li C, Brant E, Budak H, Zhang B. CRISPR/Cas: a Nobel Prize award-winning precise genome editing technology for gene therapy and crop improvement. *J Zhejiang Univ Sci B.* 2021;22(4):253-284.
23. Ahmar S, Saeed S, Khan MHU, Ullah Khan S, Mora-Poblete F, Kamran M, *et al.* A revolution toward gene-editing technology and its application to crop improvement. *Int J Mol Sci.* 2020;21(16):5665.
24. Mishra R, Zhao K. Genome editing technologies and their applications in crop improvement. *Plant Biotechnol Rep.* 2018;12(2):57-68.
25. Wan L, Wang Z, Tang M, Hong D, Sun Y, Ren J, *et al.* CRISPR-Cas9 gene editing for fruit and vegetable crops: strategies and prospects. *Horticulturae.* 2021;7(7):193.
26. Aljabali AA, El-Tanani M, Tambuwala MM. Principles of CRISPR-Cas9 technology: advancements in genome editing and emerging trends in drug delivery. *J Drug Deliv Sci Technol.* 2024;92:105338.
27. Kumar M, Prusty MR, Pandey MK, Singh PK, Bohra A, Guo B, *et al.* Application of CRISPR/Cas9-mediated gene editing for abiotic stress management in crop plants. *Front Plant Sci.* 2023;14:1157678.
28. Afzal S, Sirohi P, Singh NK. A review of CRISPR associated genome engineering: application, advances and future prospects of genome targeting tool for crop improvement. *Biotechnol Lett.* 2020;42(9):1611-1632.
29. Das D, Singha DL, Paswan RR, Chowdhury N, Sharma M, Reddy PS, *et al.* Recent advancements in CRISPR/Cas technology for accelerated crop improvement. *Planta.* 2022;255(5):109.
30. Xu X, Yuan Y, Feng B, Deng W. CRISPR/Cas9-mediated gene-editing technology in fruit quality improvement. *Food Qual Saf.* 2020;4(4):159-166.
31. Yang N, Wang R, Zhao Y. Revolutionize genetic studies and crop improvement with high-throughput and genome-scale CRISPR/Cas9 gene editing technology. *Mol Plant.* 2017;10(9):1141-1143.
32. Miglani GS. Genome editing in crop improvement: present scenario and future prospects. *J Crop Improv.* 2017;31(4):453-559.
33. El-Mounadi K, Morales-Florian ML, Garcia-Ruiz H. Principles, applications, and biosafety of plant genome editing using CRISPR-Cas9. *Front Plant Sci.* 2020;11:56.
34. Erdoğan İ, Cevher-Keskin B, Bilir Ö, Hong Y, Tör M. Recent developments in CRISPR/Cas9 genome-editing technology related to plant disease resistance and abiotic stress tolerance. *Biology (Basel).* 2023;12(7):1037.
35. Faizal A, Nugroho S, Sembada AA, Theda Y, Komariyah T, Esyanti RR. Genome editing in future crop protection: utilizing CRISPR/Cas9 to improve

- crop resistance against diseases, pests, and weeds. *Discover Agriculture*. 2024;2(1):104.
36. Khatodia S, Bhatotia K, Passricha N, Khurana SMP, Tuteja N. The CRISPR/Cas genome-editing tool: application in improvement of crops. *Front Plant Sci*. 2016;7:506.
37. Demirer GS, Silva TN, Jackson CT, Thomas JB, Ehrhardt DW, Rhee SY, *et al*. Nanotechnology to advance CRISPR-Cas genetic engineering of plants. *Nat Nanotechnol*. 2021;16(3):243-250.
38. Zhu H, Li C, Gao C. Applications of CRISPR-Cas in agriculture and plant biotechnology. *Nat Rev Mol Cell Biol*. 2020;21(11):661-677.
39. Marotkar S, Hirapure P, Paranjape S, Upadhye V. CRISPR/Cas9 technology for crop improvement: a new weapon for Indian agricultural threats. *Plant Cell Biotechnol Mol Biol*. 2020;21:1-9.
40. Hillary VE, Ceasar SA. Application of CRISPR/Cas9 genome editing system in cereal crops. *Open Biotechnol J*. 2019;13(1):1-10.
41. Negi C, Vasistha NK, Singh D, Vyas P, Dhaliwal HS. Application of CRISPR-mediated gene editing for crop improvement. *Mol Biotechnol*. 2022;64(11):1198-1217.
42. Abdallah NA, Prakash CS, McHughen AG. Genome editing for crop improvement: challenges and opportunities. *GM Crops Food*. 2015;6(4):183-205.
43. Bao A, Burritt DJ, Chen H, Zhou X, Cao D, Tran LSP. The CRISPR/Cas9 system and its applications in crop genome editing. *Crit Rev Biotechnol*. 2019;39(3):321-336.