JOURNAL OF PLANT RESEARCH AND INNOVATIONS
Jan-Dec 2024, VOL. 2, ISSUE 1, pp- 23-25
https://doi.org/10.61577/jpri.2024.100004

RESEAPRO JOURNALS

MINI REVIEW

OPEN ACCESS

CRISPR-Cas9 applications in developing climate-resilient crops: Recent advances and future prospects in plant biotechnology

Priyanka Prusty[1], Lipsha Ray[2]

[1]Department of Biotechnology, MITS school of Biotechnology, Odisha, India
[2]Department of Biotechnology, MITS school of Biotechnology, Odisha, India

ABSTRACT

The increasing effects of climate change on farming underscore the pressing necessity for creating crops capable of enduring environmental challenges. CRISPR-Cas9, a highly accurate and effective genome-editing tool, has transformed crop biotechnology by allowing targeted genetic alterations that boost stress resilience and adaptability. This review presents an in-depth summary of the latest developments in employing CRISPR-Cas9 for creating climate-resilient crops, concentrating on applications that tackle drought, salinity, and extreme temperatures. We also investigate the technical, regulatory, and ethical hurdles linked to CRISPR-Cas9 while considering its future possibilities for promoting sustainable agriculture. Furthermore, the review showcases encouraging case studies where CRISPR-based alterations have enhanced stress resistance in vital crops and discusses how these advancements could be combined with traditional breeding approaches to expedite the development of climate-resilient varieties.

KEYWORDS

CRISPR-Cas9; Climate resilience; Crop improvement; Abiotic stress tolerance; Plant biotechnology; Gene editing; Sustainable agriculture

ARTICLE HISTORY

Received 10 June 2024;
Revised 18 July 2024;
Accepted 21 August 2024

Introduction

The challenges of climate change are progressively impacting agricultural systems worldwide, jeopardizing food security due to increasing temperatures, erratic rainfall, and rising extreme weather occurrences. Consequently, the developing crops capable of enduring abiotic stressors such as drought, salinity, and temperature variations have become essential [1]. Although traditional breeding approaches have seen some success, they tend to be slow, labor-intensive, and limited by a narrow genetic base. The CRISPR-Cas9 technology, celebrated for its accuracy and flexibility in genome editing, presents a promising opportunity for cultivating crops that are more resistant to these environmental pressures [2]. By facilitating targeted genetic alterations, CRISPR enables swifter advancements in crop characteristics that are vital for stress resistance. This review focuses on recent developments in CRISPR-Cas9 applications for the creation of climate-resilient crops, presenting successful examples that illustrate the technology's capacity for quick, precise, and focused enhancements in essential crops [3]. Moreover, the review discusses the technical, regulatory, and ethical issues linked to CRISPR, such as off-target effects and societal acceptance, and investigates future possibilities for combining CRISPR-Cas9 with other technologies, including genomic selection and synthetic biology, to amplify its effectiveness. Ultimately, CRISPR-Cas9 offers significant potential for promoting sustainable agricultural practices, providing a means to safeguard global food security amid an increasingly unpredictable climate [4].

Advances in CRISPR-Cas9 for Climate-Resilient Crops

Drought tolerance

Drought is a major factor that hinders crop productivity globally, especially in areas characterized by erratic rainfall and increasing temperatures. The CRISPR-Cas9 technology has become a significant tool for improving drought tolerance by modifying genes related to water absorption, retention, and stress responses [5]. For instance, alterations in the abscisic acid (ABA) pathway have resulted in enhanced drought resistance in crops like rice and maize. Studies indicate that editing ABA-responsive genes can boost a plant's capacity to manage water shortages through strategies such as decreased transpiration, optimized root structure, and heightened osmotic adjustment. These characteristics are crucial for sustaining crop yields during drought periods [6]. Furthermore, CRISPR-based techniques have enabled more accurate and rapid identification of essential genes, providing a more effective alternative to conventional breeding methods for creating drought-resistant varieties. The ongoing use of CRISPR-Cas9 in drought resistance research has the potential to greatly enhance agricultural sustainability in areas facing water shortages [7].

Salt tolerance

Salinity affects around 20% of the world's irrigated farmland, posing a significant obstacle to crop productivity, especially in areas with low-quality irrigation water. The CRISPR-Cas9 technique has shown effectiveness in increasing salt tolerance by modifying genes related to ion balance, such as those that code for sodium-proton antiporters, essential for regulating sodium ion accumulation in plant cells. Alterations in these genes have led to enhanced salt tolerance in crops like tomatoes and wheat, allowing them to better control sodium levels and preserve cellular function in saline environments [8]. Furthermore, CRISPR-Cas9 has been utilized to improve other traits associated with salt stress, such as osmotic

***Correspondence:** Ms. Priyanka Prusty, Department of Biotechnology, MITS school of Biotechnology, Odisha, India, email: priyankaprusty110@gmail.com

pressure regulation and the development of mechanisms for salt secretion in leaves. This precise and quicker gene-editing method not only facilitates the creation of salt-tolerant plant varieties but also offers a potential solution for boosting crop yields in saline soils. By utilizing CRISPR-Cas9, agricultural practices in regions affected by salinity can become more robust, thereby enhancing food security in areas where salinity severely restricts crop production [9].

Temperature stress tolerance

High and low temperatures significantly disrupt the physiological processes of plants, influencing everything from seed germination to flowering and ultimately affecting crop yields. The CRISPR-Cas9 technology has proven effective in improving thermal resilience by modifying genes involved in temperature stress responses [10]. For instance, editing genes that control heat shock proteins in rice has resulted in enhanced heat tolerance, allowing the plant to endure extreme heat conditions more effectively. Likewise, CRISPR-based modifications have been investigated to increase cold tolerance in crops like maize, enabling them to resist low-temperature stress, which is vital in areas with shifting or unpredictable climate patterns [11]. In addition to enhancing heat and cold tolerance, CRISPR-Cas9 has been utilized to adjust genes that govern membrane stability and cellular protective mechanisms, further boosting plant resilience against temperature extremes. These advancements provide a more precise and faster means of developing crops capable of surviving in the face of increasing global temperatures and variable weather patterns, contributing to more reliable agricultural production in difficult climates [12].

Mechanisms of CRISPR-Cas9 in Stress Response Modulation

CRISPR-Cas9 serves as a potent tool for accurately altering stress-responsive genes, leading to a greater comprehension of how plants respond to abiotic stresses at a molecular level. This segment investigates the specific mechanisms through which CRISPR-Cas9 influences gene expression and signaling pathways crucial for stress resilience [13]. Research has shown that modifications made by CRISPR in genes that code for transcription factors, ion transporters, and components of signal transduction can directly affect how plants adapt to different stresses. For instance, editing transcription factors associated with the production and signaling of abscisic acid (ABA) has been demonstrated to improve drought resistance by regulating the gene expression pathways that manage responses to water stress [14]. Likewise, CRISPR has been employed to modify genes linked to salt and heat stress signaling, enhancing the overall robustness of the plant against various environmental pressures. A thorough understanding of these molecular processes not only enhances our insight into stress tolerance but also offers important information for developing crops with improved resilience to multiple stresses. By focusing on essential genes involved in these pathways, future applications of CRISPR could greatly increase agricultural yield despite the challenges posed by climate change [15].

Expanding CRISPR-Cas9 Applications in Crop Improvement

While CRISPR-Cas9 has primarily been used to enhance stress tolerance, its applications in crop improvement extend beyond abiotic stress resistance. Researchers are utilizing this gene-editing tool to improve disease resistance, enhance yield potential, and modify plant architecture for better adaptability to modern farming practices [16]. By precisely targeting genes associated with disease susceptibility, CRISPR has been successfully employed to develop fungal, bacterial, and viral-resistant crop varieties. For instance, in wheat and tomatoes, CRISPR modifications have reduced vulnerability to devastating pathogens, minimizing yield losses and reducing the reliance on chemical pesticides [17].

In addition to disease resistance, CRISPR-Cas9 is being used to modify key agronomic traits such as flowering time, plant height, and grain size, helping crops adapt to diverse environments while maintaining high yields. Optimizing flowering time reduces yield losses from extreme weather, while modifying plant height improves resistance to lodging and enhances harvest efficiency [18]. CRISPR-based edits in rice have successfully improved flowering time, panicle structure, and tiller number, leading to better resource allocation and higher grain production. Additionally, gene-editing strategies are enhancing photosynthetic efficiency by improving chlorophyll synthesis and carbon fixation, boosting plant growth and productivity [19].

CRISPR-Cas9 is also improving nutrient uptake by modifying genes that regulate root architecture and transporter proteins, allowing crops to require fewer fertilizers while sustaining high yields. These advancements demonstrate CRISPR's potential in enhancing productivity and sustainability in modern agriculture. The versatility of CRISPR-Cas9 in addressing multiple agricultural challenges demonstrates its potential as a transformative tool for crop improvement [20]. By integrating this technology with traditional breeding and modern biotechnological approaches, researchers can accelerate the development of resilient, high-yielding, and resource-efficient crop varieties. These advancements contribute to global food security and sustainable agricultural practices, ensuring that farmers can cultivate productive crops despite the increasing pressures of climate change and evolving plant diseases [21].

Conclusion

CRISPR-Cas9 has made great progress in the development of crops that can withstand climate change, serving as a powerful and precise method to improve resistance to drought, salinity, and temperature extremes. By allowing targeted genetic modifications, CRISPR can speed up the creation of crops that thrive under difficult environmental conditions. Despite several challenges, including off-target effects and species-specific limitations, ongoing advancements in technology, such as enhanced editing accuracy and capabilities for targeting multiple genes, are expected to tackle these issues, solidifying CRISPR's role in sustainable crop improvement. This review emphasizes CRISPR-Cas9's transformative potential in enhancing food security and promoting sustainable agricultural methods, particularly as climate change increasingly affects the global food supply. As CRISPR technologies develop, it will be crucial to establish a supportive regulatory and ethical framework that fosters innovation while addressing public

https://doi.org/10.61577/jpri.2024.100004

RESEAPRO JOURNALS

concerns related to safety, fairness, and accessibility. By striking a balance between scientific advancement and responsible regulation, CRISPR-based approaches could create a more resilient and food-secure future.

Disclosure Statement

No potential conflict of interest was reported by the authors.

References

1. Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y, et al. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. Plants. 2019;8(2):34. https://doi.org/10.3390/plants8020034
2. Abdelrahman M, Al-Sadi AM, Pour-Aboughadareh A, Burritt DJ, Tran LS. Genome editing using CRISPR/Cas9–targeted mutagenesis: An opportunity for yield improvements of crop plants grown under environmental stresses. Plant Physiol Biochem. 2018.131:31-36. https://doi.org/10.1016/j.plaphy.2018.03.012
3. Kouhen M, García-Caparrós P, Twyman RM, Abdelly C, Mahmoudi H, Schillberg S, et al. Improving environmental stress resilience in crops by genome editing: insights from extremophile plants. Crit Rev Biotechnol. 2023;43(4):559-574. https://doi.org/10.1080/07388551.2022.2042481
4. Muha-Ud-Din G, Ali F, Hameed A, Naqvi SA, Nizamani MM, Jabran M, et al. CRISPR/Cas9-based genome editing: A revolutionary approach for crop improvement and global food security. Physiol Mol Plant Pathol. 2024;129:102191. https://doi.org/10.1016/j.pmpp.2023.102191
5. 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. 2023;12(12):2306. https://doi.org/10.3390/plants12122306
6. Dejonghe W, Cutler SR. Abscisic acid as a gateway for the crops of tomorrow. InAdvances in Botanical Research. Academic Press. 2019;92:341-370. https://doi.org/10.1016/bs.abr.2019.09.015
7. Shelake RM, Kadam US, Kumar R, Pramanik D, Singh AK, Kim JY. Engineering drought and salinity tolerance traits in crops through CRISPR-mediated genome editing: Targets, tools, challenges, and perspectives. Plant Commun. 2022;3(6). https://doi.org/10.1016/j.xplc.2022.100417
8. Nazir R, Mandal S, Mitra S, Ghorai M, Das N, Jha NK, et al. Clustered regularly interspaced short palindromic repeats (CRISPR)/CRISPR-associated genome-editing toolkit to enhance salt stress tolerance in rice and wheat. Physiol Plant. 2022;174(2):e13642. https://doi.org/10.1111/ppl.13642
9. Chauhan PK, Upadhyay SK, Tripathi M, Singh R, Krishna D, Singh SK, et al. Understanding the salinity stress on plant and developing sustainable management strategies mediated salt-tolerant plant growth-promoting rhizobacteria and CRISPR/Cas9. Biotechnol Genet Eng Rev. 2023;39(2):311-347. https://doi.org/10.1080/02648725.2022.2131958
10. Chakraborty A, Choudhury S, Kar SR, Deb P, Wylie SJ. Gene editing for tolerance to temperature stress in plants: A review. Plant Gene. 2024;37:100439. https://doi.org/10.1016/j.plgene.2023.100439
11. 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 Apr 18;14:1157678. https://doi.org/10.3389/fpls.2023.1157678
12. Zafar SA, Zaidi SS, Gaba Y, Singla-Pareek SL, Dhankher OP, Li X, et al. Engineering abiotic stress tolerance via CRISPR/Cas-mediated genome editing. J Exp Bot. 2020;71(2):470-479. https://doi.org/10.1093/jxb/erz476
13. Razzaq MK, Aleem M, Mansoor S, Khan MA, Rauf S, Iqbal S, et al. Omics and CRISPR-Cas9 approaches for molecular insight, functional gene analysis, and stress tolerance development in crops. Int J Mol Sci. 2021;22(3):1292. https://doi.org/10.3390/ijms22031292
14. Hussain Q, Asim M, Zhang R, Khan R, Farooq S, Wu J. Transcription factors interact with ABA through gene expression and signaling pathways to mitigate drought and salinity stress. Biomolecules. 2021;11(8):1159. https://doi.org/10.3390/biom11081159
15. Kouhen M, García-Caparrós P, Twyman RM, Abdelly C, Mahmoudi H, Schillberg S, et al. Improving environmental stress resilience in crops by genome editing: insights from extremophile plants. Critical reviews in biotechnology. 2023;43(4):559-574. https://doi.org/10.1080/07388551.2022.2042481
16. 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. https://doi.org/10.3389/fpls.2023.1157678
17. Borrelli VM, Brambilla V, Rogowsky P, Marocco A, Lanubile A. The enhancement of plant disease resistance using CRISPR/Cas9 technology. Front Plant Sci. 2018;9:1245. https://doi.org/10.3389/fpls.2018.01245
18. Ahmad S, Wei X, Sheng Z, Hu P, Tang S. CRISPR/Cas9 for development of disease resistance in plants: recent progress, limitations and future prospects. Brief Funct Genomics. 2020;19(1):26-39. https://doi.org/10.1093/bfgp/elz041
19. Zheng S, Ye C, Lu J, Liufu J, Lin L, Dong Z, et al. Improving the rice photosynthetic efficiency and yield by editing OsHXK1 via CRISPR/Cas9 system. Int J Mol Sci. 2021;22(17):9554. https://doi.org/10.3390/ijms22179554
20. Ceasar SA, Maharajan T, Hillary VE, Krishna TA. Insights to improve the plant nutrient transport by CRISPR/Cas system. Biotechnol Adv. 2022;59:107963. https://doi.org/10.1016/j.biotechadv.2022.107963
21. He T, Li C. Harness the power of genomic selection and the potential of germplasm in crop breeding for global food security in the era with rapid climate change. Crop J. 2020;8(5):688-700. https://doi.org/10.1016/j.cj.2020.04.005

https://doi.org/10.61577/jpri.2024.100003