Biological and Clinical Sciences Research Journal
eISSN: 2708-2261; pISSN: 2958-4728
www.bcsrj.com
DOI: https://doi.org/10.54112/bcsrj.v2024i1.1412
Biol. Clin. Sci. Res. J., Volume, ***2024****: 1412*
Original Research Article

EXPLORING THE APPLICATIONS OF CRISPR-CAS9 IN REVOLUTIONIZING AGRICULTURE FOR FOOD SECURITY AND SUSTAINABILITY

KARIM A[1], AHMED SF[2], ASAD Z[3], *SARWER T[4], *KANWAL A[5], SHAINA H[6], ISMAIL A[1], SHAUKAT S[7], MAJEED F[7], TIPU ALK[8]

[1]*Department of Plant Breeding and Genetics, University of Agriculture Faisalabad, Pakistan*
[2]*Department of Biotechnology & Microbiology, GCU Lahore, Pakistan*
[3]*Center for Agriculture and Bioscience International, Pakistan*
[4]*Department of Plant Pathology, University of Agriculture Faisalabad, Pakistan*
[5]*Institute of Microbiology, University of Agriculture Faisalabad, Pakistan*
[6]*Department of Entomology, University of Agriculture Faisalabad, Pakistan*
[7]*Department of Plant Breeding and Genetics, Lasbela University of Agriculture, Water and Marine Sciences, Uthal, Balochistan, Pakistan*
[8]*Economic Botany Section, Regional Agricultural Research Institute Bahawalpur, Pakistan*
***Corresponding author email address:** agricultureconsultant2@gmail.com, Aimenj5438@gmail.com*

(Received, 17th September 2024, Revised 9th December 2024, Published 18th December 2024)

Abstract *CRISPR-Cas9 is a revolutionary gene-editing tool with the potential to transform agriculture by enabling precise modifications to plant genomes. This technology allows for the enhancement of critical crop traits, such as disease resistance, drought tolerance, and improved nutritional value, without introducing foreign DNA. It offers a faster, more cost-effective alternative to traditional breeding methods, contributing to food security in the face of climate challenges. One key application of CRISPR-Cas9 is its ability to improve crop resistance to pests and diseases, reducing reliance on chemical pesticides and promoting sustainable farming. It also holds promise for enhancing the nutritional content of crops and addressing global malnutrition. However, challenges remain, including ethical concerns, regulatory issues, and the need to assess the long-term environmental impacts of gene-edited crops. Despite these obstacles, CRISPR-Cas9 has the potential to revolutionize agriculture, and future research will focus on refining its precision and overcoming societal barriers. As these challenges are addressed, CRISPR-Cas9 could play a central role in developing resilient, sustainable crops for a growing global population.*

Keywords*:* *CRISPR-Cas9; Gene-editing; Crop improvement; Food security; Sustainable agriculture*

Introduction

The increasing global population and the pressing need for sustainable agricultural practices have placed immense pressure on modern farming systems (Pretty and Bharucha, 2014). Estimates suggest that by 2050, food production must increase by approximately 70% to meet the demands of over 9 billion people (Falcon et al., 2022). Simultaneously, climate change, land degradation, and diminishing natural resources are intensifying the challenges faced by agriculture. Traditional breeding methods, although successful in improving crop yield and quality, are often time-consuming, labour-intensive, and constrained by the natural genetic pool of species (Tester and Langridge, 2010). As a result, there is an urgent need for innovative approaches that can address these challenges efficiently and effectively. CRISPR-Cas9, a revolutionary genome-editing tool, has brought a paradigm shift in agricultural research and development (Aljabali et al., 2024). Unlike conventional methods, which rely on random mutations or lengthy hybridization processes, CRISPR-Cas9 enables precise modifications to plant genomes, making it possible to introduce desired traits with unparalleled accuracy (Jinek et al., 2012). Its versatility and cost-effectiveness have garnered widespread attention, positioning it as a game-changer in the quest for sustainable agriculture. The ability to enhance crop resilience, improve nutritional quality, and expedite breeding programs underscores its transformative potential. The objective of this review is to explore CRISPR-Cas9's applications in agriculture, focusing on stress resistance, crop quality, ethical considerations, regulatory challenges, and future directions for global food security.

CRISPR-Cas9 Technology and Its Versatility

CRISPR-Cas9, an acronym for Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-associated protein 9, is a naturally occurring defense mechanism in bacteria against viral infections (Barrangou et al., 2007). Scientists have harnessed this system to develop a programmable gene-editing tool that can target specific DNA sequences and introduce precise modifications. Unlike earlier genome-editing techniques, such as zinc finger nucleases and TALENs, CRISPR-Cas9 is cost-effective, user-friendly, and highly versatile, making it accessible to a broad spectrum of researchers (Hsu et al., 2014). Its adaptability has made it a cornerstone in modern agricultural biotechnology, offering solutions to numerous challenges in crop production.

Improving Crop Resilience and Productivity

One of the most significant applications of CRISPR-Cas9 in agriculture is enhancing crop resilience to biotic and abiotic stresses. Plants face numerous challenges, including pests, diseases, drought, and salinity, which severely impact agricultural productivity (Liliane and Charles, 2020). By editing specific genes, CRISPR-Cas9 enables the development of crops with enhanced resistance to fungal, bacterial, and viral pathogens. For instance, genetic modifications in rice have conferred resistance against the bacterial blight pathogen, Xanthomonas oryzae, while tomato plants resistant to powdery mildew have been created to reduce fungal infections. These innovations minimize reliance on chemical pesticides and promote environmentally sustainable practices (Lamichhane et al., 2016). Abiotic stress tolerance is another frontier in crop improvement through CRISPR-Cas9. Modifications to genes involved in water use efficiency and salt stress response have produced crops capable of thriving in arid and saline environments. This capability is particularly crucial in light of climate change and its impact on agricultural land availability. By fortifying crops against these challenges, CRISPR-Cas9 enhances food security and reduces vulnerability to extreme weather events (Arshad et al., 2024; Bhatti et al., 2023; Ndudzo et al., 2024).

Enhancing Nutritional Quality and Consumer Appeal

CRISPR-Cas9 has been instrumental in improving the nutritional quality of crops, addressing global issues of malnutrition and "hidden hunger" (Sen et al., 2024). Gene-editing techniques have been used to biofortify staple crops such as rice and wheat with higher levels of essential micronutrients like iron and zinc (figure 1). These enhancements aim to mitigate widespread deficiencies that affect billions, particularly in developing regions. The tool has also improved the quality of edible oils by altering fatty acid composition in oilseed crops. Healthier oil profiles with reduced levels of harmful saturated fats have been achieved, benefiting public health on a broader scale (Chen et al., 2019). Moreover, CRISPR-Cas9 applications extend to horticultural crops, where modifications have enhanced fruit shelf life, flavor, and texture. For example, editing the polygalacturonase gene in tomatoes has produced fruits with longer shelf lives (Nie et al., 2024), while adjustments in sugar metabolism pathways have improved the sweetness and aroma of strawberries (Fatima et al., 2023; Haider et al., 2023; IQBAL et al., 2021; Vondracek et al., 2024). These developments cater to consumer preferences while addressing food waste issues.

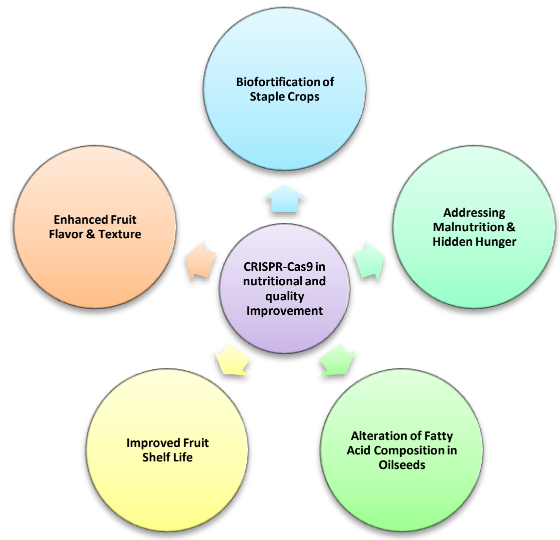

Figure 1: Role of CRISPR-Cas9 in Nutritional and quality improvement

Accelerating Breeding Programs

Traditional breeding programs rely on naturally occurring genetic variations, which can be slow and resource-intensive (Abbas et al., 2024; Gradziel, 2012). CRISPR-Cas9 accelerates this process by enabling targeted modifications to specific traits, such as high yield, pest resistance, and drought tolerance. For instance, gene-editing initiatives have developed maize and wheat varieties with higher productivity and adaptability to adverse conditions. Moreover, CRISPR-Cas9 facilitates the integration of multiple desirable traits into single-crop varieties. This capability, known as trait pyramiding, enables the simultaneous enhancement of disease resistance, stress tolerance, and nutritional content. Such advances are nearly impossible to achieve through conventional breeding alone, making CRISPR-Cas9 a transformative tool for modern agriculture (Javed et al., 2024; Junaid and Gokce, 2024; Liu et al., 2021; Mushtaq et al., 2024).

Challenges, Ethical Considerations, and Regulatory Hurdles

[Citation: Karim, A., Ahmed, S.F., Asad, Z., Sarwar, T., Khanwal, A., Shaina, H., Ismail, A., Shaukat, S., Majeed, F., Tipu, A.L.K. (2024). Exploring the Applications of CRISPR-Cas9 in Revolutionizing Agriculture for Food Security and Sustainability. *Biol. Clin. Sci. Res. J.*, **2024**: *1412*. doi: https://doi.org/10.54112/bcsrj.v2024i1.1412]

Despite its immense potential, the application of CRISPR-Cas9 in agriculture is not without challenges (Rasheed et al., 2021). Regulatory frameworks governing gene-edited crops vary globally, with many countries subjecting them to the same scrutiny as genetically modified organisms (GMOs), even when foreign DNA is not introduced. This regulatory uncertainty often delays the deployment of CRISPR-edited crops and limits their adoption. Public perception also poses a significant hurdle. Skepticism about the safety and ethical implications of genome editing can lead to resistance from consumers and advocacy groups (Yang and Hobbs, 2020). Transparent communication about the benefits and risks of CRISPR-Cas9, supported by rigorous scientific research, is essential to addressing these concerns. Ethical considerations, including the potential misuse of the technology and its implications for biodiversity, must be carefully managed through responsible practices and inclusive dialogue (Khan, 2019).

Conclusion

CRISPR-Cas9 represents a groundbreaking advancement in agricultural biotechnology, offering transformative solutions to some of the most pressing challenges in food production and sustainability. From enhancing crop resilience and nutritional quality to accelerating breeding programs and integrating multiple traits, this technology has the potential to revolutionize agriculture. However, realizing its full potential requires addressing regulatory, ethical, and societal concerns through informed dialogue and collaboration. As researchers continue to explore new frontiers with CRISPR-Cas9, the future of agriculture stands poised for a genetic revolution that promises a more resilient, nutritious, and sustainable food system for generations to come.

Reference

Abbas, A., Arshad, A., Rehman, A. U., Bukhari, M. S., and Zaman, S. (2024). Revolutionizing plant breeding programs with advancements in molecular marker-assisted selection. *Bulletin of Biological and Allied Sciences Research* **2024**, 57.

Aljabali, A. A., El-Tanani, M., and Tambuwala, M. M. (2024). Principles of CRISPR-Cas9 technology: advancements in genome editing and emerging trends in drug delivery. *Journal of Drug Delivery Science and Technology*, 105338.

Arshad, A., Iqbal, M. A., Farooq, S., and Abbas, A. (2024). Genetic evaluation for seed yield and its component traits in sunflower (*Helianthus annuus* l.) using line × tester approach. *Bulletin of Biological and Allied Sciences Research* **2024**, 63.

Barrangou, R., Fremaux, C., Deveau, H., Richards, M., Boyaval, P., Moineau, S., Romero, D. A., and Horvath, P. (2007). CRISPR provides acquired resistance against viruses in prokaryotes. *Science* **315**, 1709-1712.

Bhatti, M., Ahmad, S., Bilal, S., and Iqbal, M. (2023). Evaluation of different strains of entmopathogenic fungi as potential agents for the management of Tribolium castaneum. *Bulletin of Biological and Allied Sciences Research* **2023**, 52-52.

Chen, K., Wang, Y., Zhang, R., Zhang, H., and Gao, C. (2019). CRISPR/Cas genome editing and precision plant breeding in agriculture. *Annual review of plant biology* **70**, 667-697.

Falcon, W. P., Naylor, R. L., and Shankar, N. D. (2022). Rethinking global food demand for 2050. *Population and Development Review* **48**, 921-957.

Fatima, S., CHEEMA, K., Shafiq, M., Manzoor, M., Ali, Q., Haider, M., and Shahid, M. (2023). The genome-wide bioinformatics analysis of 1-aminocyclopropane-1-carboxylate synthase (acs), 1-aminocyclopropane-1-carboxylate oxidase (aco) and ethylene overproducer 1 (eto1) gene family of fragaria vesca (woodland strawberry). *Bulletin of Biological and Allied Sciences Research* **2023**, 38-38.

Gradziel, T. M. (2012). Traditional genetics and breeding. *Genetics, genomics and breeding of crop plants, CRC Press, Boca Raton*, 22-54.

Haider, M., Sami, A., Mazhar, H., Akram, J., NISA, B., Umar, M., and Meeran, M. (2023). Exploring morphological traits variation in Gomphrena globosa: A multivariate analysis. *Biological and Agricultural Sciences Research Journal* **2023**, 21-21.

Hsu, P. D., Lander, E. S., and Zhang, F. (2014). Development and applications of CRISPR-Cas9 for genome engineering. *Cell* **157**, 1262-1278.

Iqbal, U., Bashir, K., Khan, M., HASSAN, N., Jamil, S., Ullah, I., and Ullah, A. (2021). Cross-sectional study of covid-19 patients and their inflammatory markers in tertiary care hospitals of Peshawar, Pakistan. *Bulletin of Biological and Allied Sciences Research* **2021**, 31-31.

Javed, M. M., Sami, A., Haider, M. Z., Abbas, A., Ali, M. H., Naeem, S., Amjad, M., Ahmad, A., and Bostani, R. (2024). The contribution of transgenic rice to enhance grain yield. *Bulletin of Biological and Allied Sciences Research* **2024**, 65.

Jinek, M., Chylinski, K., Fonfara, I., Hauer, M., Doudna, J. A., and Charpentier, E. (2012). A programmable dual-RNA–guided DNA endonuclease in adaptive bacterial immunity. *science* **337**, 816-821.

[Citation: Karim, A., Ahmed, S.F., Asad, Z., Sarwar, T., Khanwal, A., Shaina, H., Ismail, A., Shaukat, S., Majeed, F., Tipu, A.L.K. (2024). Exploring the Applications of CRISPR-Cas9 in Revolutionizing Agriculture for Food Security and Sustainability. *Biol. Clin. Sci. Res. J.*, **2024***: 1412*. doi: https://doi.org/10.54112/bcsrj.v2024i1.1412]

Junaid, M. D., and Gokce, A. F. (2024). Global agricultural losses and their causes. *Bulletin of Biological and Allied Sciences Research* **2024**, 66.

Khan, S. H. (2019). Genome-editing technologies: concept, pros, and cons of various genome-editing techniques and bioethical concerns for clinical application. *Molecular Therapy-Nucleic Acids* **16**, 326-334.

Lamichhane, J. R., Dachbrodt-Saaydeh, S., Kudsk, P., and Messéan, A. (2016). Toward a reduced reliance on conventional pesticides in European agriculture. *Plant Disease* **100**, 10-24.

Liliane, T. N., and Charles, M. S. (2020). Factors affecting yield of crops. *Agronomy-climate change & food security*, 9.

Liu, Q., Yang, F., Zhang, J., Liu, H., Rahman, S., Islam, S., Ma, W., and She, M. (2021). Application of CRISPR/Cas9 in crop quality improvement. *International Journal of Molecular Sciences* **22**, 4206.

Mushtaq, F., Akram, M. H., Usman, M., Mohsin, M., and Nawaz, M. S. (2024). Global climate change and its influence on crop production. *Journal of Life and Social Sciences* **2024**, 27.

Ndudzo, A., Makuvise, A. S., Moyo, S., and Bobo, E. D. (2024). CRISPR-Cas9 genome editing in crop breeding for climate change resilience: Implications for smallholder farmers in Africa. *Journal of Agriculture and Food Research*, 101132.

Nie, H., Yang, X., Zheng, S., and Hou, L. (2024). Gene-Based Developments in Improving Quality of Tomato: Focus on Firmness, Shelf Life, and Pre-and Post-Harvest Stress Adaptations. *Horticulturae* **10**, 641.

Pretty, J., and Bharucha, Z. P. (2014). Sustainable intensification in agricultural systems. *Annals of botany* **114**, 1571-1596.

Rasheed, A., Gill, R. A., Hassan, M. U., Mahmood, A., Qari, S., Zaman, Q. U., Ilyas, M., Aamer, M., Batool, M., and Li, H. (2021). A critical review: recent advancements in the use of CRISPR/Cas9 technology to enhance crops and alleviate global food crises. *Current Issues in Molecular Biology* **43**, 1950-1976.

Sen, H., Kumar, A., and Janeja, H. S. (2024). Biofortification of Major Crops through Conventional and Modern Biotechnological Approaches to Fight Hidden Hunger: An Overview. *Journal of Advances in Biology & Biotechnology* **27**, 96-113.

Tester, M., and Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science* **327**, 818-822.

Vondracek, K., Altpeter, F., Liu, T., and Lee, S. (2024). Advances in genomics and genome editing for improving strawberry (Fragaria× ananassa). *Frontiers in Genetics* **15**, 1382445.

Yang, Y., and Hobbs, J. E. (2020). Supporters or opponents: will cultural values shape consumer acceptance of gene editing? *Journal of Food Products Marketing* **26**, 17-37.

Declaration

Acknowledgment

Not applicable

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

The study was approved by authors.

Funding Statement

Not applicable

Authors' Contribution

All authors contributed equally.

Conflict of interest

There is no conflict of interest among the authors of the manuscript.