

Advances in Biotechnology and Bioscience

ISBN: 978-93-49938-54-0 | Year: 2026 | pp: 55 - 59 |

Biotechnological Interventions for Enhancing Stress Tolerance in Paddy (*Oryza sativa* L.)

¹Albino Wins J

²Dharshinn M

³M. Murugan

¹P. Leema Rose

¹Department of Botany, Holy Cross College (Autonomous), Nagercoil -4,
Tamilnadu, India.

²Agricultural College and Research Institute, Tamil Nadu Agricultural University
(TNAU), Coimbatore, Tamilnadu, India.

³Department of Biomedical Engineering, Noorul Islam Centre for Higher
Education, Kumaracoil, Tamilnadu, India

Email: winsbt@gmail.com

Article DOI Link: <https://zenodo.org/uploads/18981670>

DOI: 10.5281/zenodo.18981670

Abstract

Rice (*Oryza sativa* L.) is one of the most important staple crops feeding more than half of the world's population. However, rice cultivation is severely affected by abiotic stresses such as drought, salinity, submergence, and temperature extremes, as well as biotic stresses caused by pathogens and pests. Conventional breeding approaches have contributed significantly to rice improvement, but the process is often slow and limited by the availability of genetic variability. Modern biotechnology provides powerful tools to enhance stress tolerance in rice through molecular breeding, genetic engineering, tissue culture, and genome editing techniques. Marker-assisted selection, transgenic approaches, and CRISPR-based gene editing have enabled the development of stress-resilient rice varieties with improved productivity and adaptability. Additionally, the use of plant growth-promoting microorganisms and biofertilizers contributes to sustainable rice cultivation by improving plant health and stress tolerance. This chapter discusses various biotechnological strategies used to improve stress tolerance in paddy and

highlights their significance in ensuring food security and sustainable agriculture under changing climatic conditions.

Keywords: Rice biotechnology, Stress tolerance, Genetic engineering, Marker-assisted selection

Introduction

Rice is cultivated across diverse agroclimatic regions and plays a crucial role in global food security. In many developing countries, rice serves as the primary source of calories and nutrition. However, rice production is increasingly threatened by environmental stresses, including drought, salinity, flooding, and extreme temperatures. Biotic stresses such as bacterial blight, blast disease, and insect pests also cause significant yield losses. Climate change has further intensified these challenges, making it necessary to develop stress-tolerant rice varieties.

Traditional plant breeding has been effective in improving yield and resistance to certain stresses, but the process is time-consuming and often limited by genetic barriers. Biotechnology offers innovative tools that enable precise manipulation of genes, rapid multiplication of elite varieties, and improved understanding of stress-response mechanisms. Advances in molecular biology, genomics, and bioinformatics have facilitated the identification of stress-responsive genes and their incorporation into cultivated varieties. As a result, biotechnological interventions have become essential components of modern rice improvement programs.

Abiotic Stress in Paddy and Its Impact

Abiotic stresses such as drought, salinity, submergence, and temperature extremes adversely affect rice growth, development, and yield. Drought stress reduces water availability, leading to decreased photosynthesis and impaired nutrient uptake. Salinity stress causes ionic imbalance and osmotic stress, which inhibit root growth and seedling establishment. Submergence, particularly in flood-prone regions, restricts oxygen availability and disrupts normal metabolic processes. Temperature extremes, both high and low, affect enzyme activity, pollen viability, and grain filling. These stresses collectively reduce crop productivity and threaten food security, emphasizing the need for developing stress-tolerant rice varieties through advanced techniques.

Molecular Breeding and Marker-Assisted Selection

Molecular breeding has revolutionized crop improvement by enabling the identification and transfer of specific genes associated with stress tolerance. Marker-assisted selection allows breeders to track desirable traits at the DNA level, thereby accelerating the breeding process and increasing selection accuracy. In rice, quantitative trait loci associated with drought tolerance, submergence tolerance, and salinity resistance have been successfully identified and introgressed into high-yielding varieties. The development of submergence-tolerant rice varieties

containing the SUB1 gene is a notable example demonstrating the effectiveness of molecular breeding in enhancing stress tolerance.

Genetic Engineering for Stress Tolerance

Genetic engineering enables the direct introduction of stress-responsive genes into rice plants to improve tolerance to adverse conditions. Genes involved in osmoprotection, antioxidant defense, and stress signaling pathways have been transferred into rice to enhance tolerance to drought, salinity, and temperature stress. Transgenic rice varieties expressing genes such as DREB and HVA1 have shown improved stress tolerance under controlled and field conditions. This approach provides greater precision compared to conventional breeding and allows the incorporation of genes from diverse organisms, thereby expanding the genetic base of rice.

Genome Editing and CRISPR Technology

Genome editing technologies, particularly CRISPR-Cas systems, have emerged as powerful tools for precise modification of plant genomes. In rice, genome editing has been used to alter genes associated with stress response, plant architecture, and yield. Unlike transgenic approaches, genome editing enables targeted gene modification without introducing foreign DNA, making it a promising technique for developing improved crop varieties. The application of CRISPR technology in rice has accelerated the identification of gene functions and facilitated the development of stress-resilient cultivars in a shorter time frame.

Plant Tissue Culture and Micropropagation

Plant tissue culture plays a significant role in rice biotechnology by enabling rapid multiplication of elite and stress-tolerant varieties. Techniques such as somatic embryogenesis and anther culture are widely used for producing haploids and doubled haploids, which accelerate breeding programs. Tissue culture also facilitates the development of transgenic plants and the conservation of valuable germplasm. The ability to regenerate plants under controlled conditions ensures uniformity and enhances the efficiency of genetic improvement programs.

Role of Microbial Biotechnology in Stress Management

Microbial biotechnology contributes to stress tolerance in rice through the use of plant growth-promoting rhizobacteria, mycorrhizal fungi, and biofertilizers. These beneficial microorganisms enhance nutrient uptake, improve soil fertility, and induce systemic resistance against pathogens. Certain microbial strains help plants withstand drought and salinity by producing phytohormones, osmoprotectants, and stress-related enzymes. The integration of microbial biotechnology with crop management practices supports sustainable rice cultivation and reduces dependence on chemical inputs.

Future Prospects of Rice Biotechnology

Advances in genomics, transcriptomics, proteomics, and metabolomics are providing deeper insights into the molecular mechanisms of stress tolerance in rice. The integration of these approaches with artificial intelligence and precision agriculture is expected to further enhance crop improvement strategies. The development of climate-resilient rice varieties will play a critical role in ensuring food security in the face of global climate change. Continued research and collaboration among scientists, breeders, and policymakers are essential to harness the full potential of biotechnology in rice cultivation.

Conclusion

Biotechnological interventions have significantly contributed to improving stress tolerance in rice, enabling the development of resilient varieties capable of withstanding adverse environmental conditions. Molecular breeding, genetic engineering, genome editing, tissue culture, and microbial biotechnology collectively provide effective solutions for enhancing productivity and sustainability in rice cultivation. As climate change continues to pose challenges to agriculture, the adoption of advanced biotechnological tools will be crucial for ensuring stable rice production and global food security. Future research focusing on integrated approaches and farmer-friendly technologies will further strengthen the role of biotechnology in paddy cultivation.

References

1. Ashraf, M., & Foolad, M. R. (2013). Crop breeding for salt tolerance in the era of molecular markers and marker-assisted selection. *Plant Breeding*, 132(1), 10–20.
2. Fita, A., Rodríguez-Burruezo, A., Boscaiu, M., Prohens, J., & Vicente, O. (2015). Breeding and domesticating crops adapted to drought and salinity. *Plant Science*, 237, 45–56.
3. Ismail, A. M., Singh, U. S., Singh, S., Dar, M. H., & Mackill, D. J. (2013). The contribution of submergence-tolerant rice varieties to food security. *Field Crops Research*, 152, 83–93.
4. Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S., & Venkataraman, G. (2018). CRISPR for crop improvement: An update review. *Frontiers in Plant Science*, 9, 985.
5. Kumar, V., Shriram, V., & Kavi Kishor, P. B. (2019). Engineering crops for drought tolerance. *Plant Cell Reports*, 38(4), 371–389.
6. Mishra, P., Panigrahi, K. C. S., & Mishra, S. (2020). Abiotic stress responses in rice: Molecular mechanisms and biotechnological interventions. *Plant Cell, Tissue and Organ Culture*, 140(3), 457–476.

7. Nutan, K. K., Rathore, R. S., Tripathi, A. K., & Mishra, A. (2020). Advances in rice biotechnology for stress tolerance. *Plant Biotechnology Reports*, 14(3), 231–245.
8. Pandey, P., Irulappan, V., Bagavathiannan, M. V., & Senthil-Kumar, M. (2017). Impact of combined abiotic and biotic stresses on plant growth. *Frontiers in Plant Science*, 8, 537.
9. Ricroch, A., Clairand, P., & Harwood, W. (2017). Use of CRISPR systems in plant genome editing. *Plant Biotechnology Journal*, 15(3), 237–250.
10. Singh, R. K., & Singh, U. S. (2016). Molecular breeding in rice: Progress and future prospects. *Journal of Genetics*, 95(3), 675–689.
11. Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, 327(5967), 818–822.
12. Zhang, H., Zhu, J., Gong, Z., & Zhu, J. K. (2014). Abiotic stress responses in plants. *Nature Reviews Genetics*, 15(6), 385–397.