Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 10 Issue 9 November 2026

Review Article

From Genetic Resources to Resilient Rice: Rethinking the Way We Breed for the Future

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Received: September 30, 2026

Published: November 16, 2026

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Rice production faces numerous challenges, ranging from climate change and emerging diseases to salinity, drought, and high temperatures. For rice-growing countries that depend heavily on local production for food security, the demand for climate-resilient and locally adapted varieties is increasing day by day. Rice is cultivated across a diverse range of production environments, from relatively stable irrigated fields to drought- and salt-affected areas. Recent studies highlight the spatial and temporal variability of climatic factors and their association with crop yields in different rice-growing regions. Researchers and breeders are working to respond to these identified production constraints.

A promising way to tackle current production problems is the use of genetic resources. Local and elite cultivars, as well as donor rice materials, play an important role in this context, as they can serve as sources of valuable genes and traits for disease resistance and stress tolerance. However, their rational use in breeding programs requires extensive characterization and evaluation.

Disease resistance provides a clear example. In rice production, bacterial leaf blight and blast are two major diseases against which genetic resistance can be the most cost-effective and environmentally friendly solution. However, resistance to individual diseases is often not broad-spectrum. In addition, the transfer of resistance genes to elite cultivars can be complicated by the presence of unfavorable alleles. Molecular markers can help in this case, as they allow breeders to determine whether a particular genotype carries the target gene or genomic region associated with a desired trait. Thus, marker-assisted backcrossing and gene pyramiding can be used to transfer several resistance genes simultaneously. In addition, molecular tools can be used not only to study resistance but also to identify and select other important traits.

Genome-wide association studies and genomic selection are promising methods for studying complex traits. The former allows researchers to identify genomic regions associated with the studied trait, while the latter is a method for predicting breeding values based on genome-wide information. Both approaches have shown their effectiveness in rice genetics and breeding. In combination with genomic resources, these technologies can be used to explore new genetic diversity, thereby providing valuable material for subsequent breeding work. Genome editing is another approach with great potential for rice breeding. As a powerful tool, it allows certain genes to be modified for breeding purposes. The CRISPR system and associated technologies can be used to edit a wide range of genes, from those responsible for disease resistance to those that control crop yield and quality.

However, it is necessary to emphasize that the breeding process cannot be automated, despite the availability of innovative technologies for analyzing genetic information. Molecular markers and associated methods are only tools that should be used in breeding practice to solve specific problems. This is particularly relevant in low-resource settings, where technological capabilities may be limited. Therefore, the choice of methods should be

based on specific breeding objectives within the framework of a broader strategy. The future of rice breeding will not belong to one technology or one method. Instead, breeders will need to combine and use technologies that allow them to study genetic diversity and implement targeted breeding. For rice production globally, such approaches are extremely relevant and should be actively used in the current context of climate change.