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GENOTYPIC ENHANCEMENT OF RICE VARIETIES FOR SUPERIOR PERFORMANCE UNDER DIRECT SEEDING CONDITIONS

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Rice is staple food for over half of the population and forms the basis of food and financial stability in many developing and agricultural-dependent countries (FAOSTAT, 2021). Traditionally, growing rice involves transplanting seedlings into puddled fields, which is labor-intensive, water-demanding, and increasingly less sustainable due to climate change and growing labor shortages. Now a days Direct-seeded rice (DSR) is gaining prominence as a sustainable alternative to traditional puddled transplanted rice, offering significant savings in water, labor, and time. However, DSR adoption remains limited due to challenges such as poor seedling establishment, heavy weed infestation, lodging, and increased vulnerability to abiotic stresses like drought and temporary flooding. To address these issues, breeding programs are focusing on developing rice varieties with traits such as early seedling vigor, anaerobic germination tolerance, weed competitiveness, and lodging resistance. Advanced tools like marker-assisted selection, genomic selection, and gene editing are being utilized to incorporate key stress-resilient genes and quantitative trait loci (QTLs), including *SUB1*, *qDTY*, and *AG1*.

Desired Traits for Direct Seeding

DSR-adapted rice varieties include early seedling vigor, uniform germination, strong root development, weed competitiveness, lodging resistance, and tolerance to abiotic stresses such as drought, and low soil fertility. Traditional varieties bred for puddled transplanting often underperform in direct-seeded systems due to poor early establishment, vulnerability to weed competition, and susceptibility to stress during the critical early growth stages.

Hence, breeding efforts are now focused on developing varieties specifically tailored to the unique conditions of DSR ecosystems.

Rapid Germination and Seedling Vigor ensures rapid establishment and enhances the plant's ability to compete with weeds. This trait is influenced by seed size, coleoptile length, mesocotyl elongation, and seedling dry weight.

Lodging resistance is another critical requirement, as plants grown in non-puddled, aerobic soils often have weaker anchorage and are more prone to lodging due to shallow rooting and plant height. Traits such as stronger culm strength, shorter stature, and deeper rooting systems are therefore targeted in DSR breeding pipelines.

Weed competitiveness is a major challenge in direct seeding due to the absence of water cover that naturally suppresses weeds in transplanted systems. Breeding for traits like early canopy closure, rapid leaf area development, and allelopathy can reduce the need for herbicide inputs and support integrated weed management strategies.

Drought Tolerance ensures consistent performance under soil water deficits

Breeding strategies

- **Conventional breeding** Crosses between elite lines with desired traits are commonly used. Combine desirable traits from different varieties
- **Marker-Assisted Selection (MAS)** MAS helps pyramid multiple trait QTLs efficiently. Examples include lines combining AG, blast resistance, and drought tolerance (Islam et al., 2017; Laha et al., 2019).
- **Genomic Selection and GWAS** Genome-wide marker profiles enable breeding for complex traits. GS models are identifying multiple small-effect loci for early vigor and root traits (Sandhu et al., 2016). GS is speeding up selection processes.
- **Gene editing** Precise alteration of genes related to desirable traits. CRISPR/Cas9 holds potential for customizing root/development traits, e.g., editing DRO1 for root angle (Uga et al., 2013).

Future Directions

- Development of DSR-specific ideotypes
- Exploiting wild germplasm and landraces for novel traits
- High-throughput phenotyping and precision breeding
- Climate-resilient breeding for variable environments

Conclusion

Breeding rice for enhanced performance under direct seeding conditions requires a multi-disciplinary approach that combines conventional breeding, molecular genetics, stress physiology, and agronomy. By aligning breeding objectives with the agronomic realities of DSR, researchers can develop climate-smart, high-yielding, and resource efficient rice varieties that contribute to sustainable intensification and food security in rice-producing regions.

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