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Breeding high-yielding drought-tolerant rice

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Abstract

Drought stress is a severe limiting factor in rice production, resulting in enormous economic losses. It becomes a more serious problem in terms of global climate change. Current and projected global food demands make it important to prioritize increasing crop productivity in drought-prone, rainfed regions. Drought-tolerant rice cultivars are needed to achieve production targets from rain-fed areas, and genetic improvement of drought-tolerant rice should be a priority research topic in the future. Breeding of drought-tolerant rice cultivars is a thoughtful task, as the complex nature of drought-tolerant traits and multigene regulation are major bottlenecks in current research. Over the past two decades, significant progress has been made in understanding the mechanisms involved in adaptation and tolerance to drought stress in rice. This review highlighted recent advances in the physiological, biochemical, and molecular adaptations of rice to drought tolerance. A brief discussion of molecular genetics and breeding approaches for drought tolerance in rice focuses on future crop improvement programs to develop drought-tolerant rice cultivars.

Keywords: Hernia, buffalo bull, umbilical, herniorrhaphy

1. Introduction

Rice (*Oryza sativa* L.) is an important source of calories and some protein for more than half of the world's population (Kilimo *et al*., 2020) [16]. Rice is a highly beneficial food as it provides energy and essential nutrients such as thiamine, riboflavin, niacin, vitamin E, zinc, potassium, iron and fibre (Schenker, S 2018) [36]. India is the second largest rice producer and largest exporter in the world. Rice production, grown on 43.86 million hectares under different climate, soil and water conditions, increased from 53.6 million tons in 1980 to 120 million tons in 2020-21. did. West Bengal and Uttar Pradesh are major rice producing states. (https://www.irri.org/). Climate change threatens the sustainability of modern agriculture. Ever-changing climatic conditions around the world require a constant effort to understand and adapt to the ecological challenges for sustainable crop production. The challenge is even more acute for crops such as rice (*Oryza sativa* L.), a staple food for more than half of the world's population and grown in a wide variety of environmental conditions. Most rice products come from developing countries in Asia, Africa and Latin America. Although these regions account for the majority of the world's rice production, much of the rice in these regions is grown by smallholder farmers with minimal inputs and infrastructure. Lacking basic infrastructure such as irrigation systems, many areas are dependent on rainfall and are severely impacted by uneven rainfall, leading to droughts and floods. At least 30.9% of the world's total rice area is rain-irrigated and exposed to varying degrees of drought and flooding. Drought is one of the major abiotic stressors leading to reduced rice production in rain-fed rice fields. In Asia alone, a total of 23 million hectares of rice have been affected by varying degrees of drought. Apart from that, recent climate change trends indicate that water scarcity will increase in the coming years (R. Wassmann, *et al*., 2017) [53]. This could further increase the intensity and frequency of droughts. Even areas with secured irrigation systems face problems related to reduced irrigation water availability. This is a result of declining freshwater resources and increasing demand from the industrial sector and urban centres (Barker *et al*., 2018) [54]. This paper focuses on methods used to develop new drought-tolerant cultivars, released cultivars, and quantitative trait loci (QTL) identified for drought yield.

2. Morphological responses to drought stress

Drought tolerance is the ability of plants to produce maximum economic yield under dry conditions (Rollins *et al*., 2013) [30]. It is a complex trait that depends on the action and interaction of various morphological, biochemical, and physiological responses (Kumar *et al*.,

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2016) [17]. Drought escape is defined as 'the ability of a plant to complete its life cycle before the development of serious soil water deficits'. Drought avoidance is defined by Kumar *et al* (2016) [17] as 'the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture'. Drought tolerance is defined as 'the ability of plants to survive under low tissue water content' (Kumar *et al* (2016) [17] Drought adversely affects crop growth parameters and ultimately reduces yields. Such damage depends on the degree of stress, duration and stage of plant development. Adverse effects are reflected in changes in plant morphological, physiological, biochemical and molecular processes and responses to drought stress.

3. Physiological responses to drought stress

During drought stress, various physiological processes are adversely affected and plants adapt to adverse conditions in response to drought. To improve yield under drought conditions, it is essential to optimize physiological parameters and processes prior to breeding programs (Dash *et al*., 2018; Barik *et al*., 2019; Gupta *et al*., 2020) [4, 1, 8]. Draught adversely affects rice physiology in number of ways, including net photosynthetic rate, transpiration rate, stomatal conductivity, water use efficiency, internal CO2 concentration, photosystem II (PSII) activity, and reduced relative water content affect and membrane stability index (Farooq *et al*., 2009; Dash *et al*., 2018[4]; Mishra *et al*., 2018; Zhu *et al*., 2020) [55, 4, 22, 52].

4. Molecular mechanism of drought tolerance

Environmental drought stimuli are captured by sensors on membranes that are not yet very precisely imaged, and the signals then travel down different signalling pathways to develop drought-responsive traits with appropriate gene function and drought tolerance (Dash *et al*., 2018; Oladosu *et al*., 2019) [4, 25]. Drought is a composite phenomenon (Zargar *et al*., 2011; Kumar *et al*., 2016) [51, 17]. Therefore, hybridization and selection strategies cannot provide accurate results regarding drought tolerance. Nevertheless, the method can be applied to obtain accurate results when used for DNA markers in molecular studies. These molecular markers could also be used for screening large quantities of drought-tolerant germplasm and using it for further crop improvement purposes. Many studies have been conducted to establish several qualitative trait loci (QTL) associated with different traits (Kumar *et al*., 2016; Barik *et al*., 2019; Upadhyaya and Panda, 2019) [17, 1, 43]. The main method used to identify genes involved in drought tolerance in rice is marker-based phenotyping. Despite progress, few traits are actually recognized as drought-tolerant (Zargar *et al*., 2011; Prakash *et al*., 2019) [51, 27]. In this way, molecular breeding can lead to an improved assortment of plant varieties and yields, producing safe, agronomically justifiable and productive crops.

5. Breeding for Drought Tolerance in Rice

Most of the research on drought tolerance in rice has been conducted in Asian countries, and several drought-tolerant cultivars have been published by the International Rice Research Institute (IRRI).

5.1 Effect of Drought on Rice Growth and Production

Drought is one of the most devastating abiotic stresses, with mild, moderate and severe droughts can result in yield losses of up to 10%, 50% and 100%, respectively (Mottaleb *et al*., 2018) [23]. Drought stress affects rice at morphological, physiological, biochemical and molecular levels. Effects on rice include reduced germination, plant height, plant biomass, number of shoots, chlorophyll content, leaf number and size (Pandey *et al*., 2018) [26]. Morphological, molecular, physiological and biochemical responses of rice to drought stress include reduction in tillering, grain filling rate, spikelet fertility, panicle number and size, and grain size and weight induces delayed flowering with reduced yield due to (Noelle, *et al*., 2018). Drought increases leaf rolling and desiccation and increases the accumulation of osmoprotectants such as proline, sugars, polyamines and antioxidants (Pandey *et al*., 2018) [26]. In many soils, it takes at least 2 weeks without precipitation before significant differences in drought susceptibility occur during the vegetative period, and at least 7 days without precipitation during the reproductive period, resulting in severe drought damage (www.irri.org/).).

5.2 Genetic Basis of Rice Drought-Tolerance

Drought tolerance is a quantitative trait with complex phenotypes, often complicated by plant phenology (Sahebi, *et al*., 2018) [32]. In a study by Swamy *et al*., (2019) [56] the heritability of grain yields under drought reached up to 78% in the broadest sense. Many genes controlling drought resistance have been reported. These include OsALDH2-1, OsALDH2-2, OsWRKY45, dOsMSOD1, OsRCN1, OsbZIP79, OsbZIP79, OsbZIP79 and OsbZIP. Several quantitative trait loci associated with drought tolerance have been reported, and the number varies among authors depending on the type of trait and experimental conditions (Sahebi, *et al*., 2018) [32]. For example, in a study by Huang *et al* (2019) [57]. There were 14 QTLs for relative leaf water content, 9 for relative water gradient, 12 for drought sensitivity, 3 for tolerance and 1 for relative plant growth rate. Saba *et al*., (2017) [32] 2 QTL for total water intake, 2 for leaf dryness value, 1 for leaf dry weight, 2 for deep root surface, 3 for root length depth, and leaf dryness. We found one QTL for weight, one for tillers per plant. For grass height. Swami *et al* (2019) [58] reported the presence of qDTY12.1 in 85% of strains tested, followed by qDTY4.1 in 79% of strains and qDTY1.1 in 64% of strains. These QTLs are common in drought-tolerant donors. (Kumar *et al*. 2011) [59] reported qDTY1.1 as the major QTL for grain yield under lowland drought stress in the CT9993/IR62266 population on chromosome 1, explaining 32% of the genetic variance.

5.3 Breeding for Rice Drought Tolerance

Breeding for drought tolerance is very complex due to different types of environmental stresses such as: High insolation, high temperature, nutrient deficiencies, and toxicity can simultaneously affect plants (Sahebi, *et al*., 2018) [32]. Drought-tolerant genotypes can be directly selected based on grain yield under drought conditions (Kumar *et al*., 2014) [29]. However, several traits with strong positive relationships with yield have been highlighted and indirect selection has been proposed to improve grain yield under drought stress (Sakran *et al*., 2022) [33]. The selection of drought-tolerant genotypes can take into consideration the growth stage of the target rice (Wang *et al*., 2019) [47]. Screening under drought stress conditions allows selection of drought-tolerant plants within each lineage. When developing pure lines, it was recommended to perform single plant selection in the F3 generation (Kumar *et al*., 2014) [29]. While traditional breeding approaches emphasize phenotypic traits, direct selection is hampered by low heritability and genotypic selection by environmental and genetic interactions such as epistasis and polygenic effects, thus been only partially successful (Sahebi, *et al*., 2018) [32].

Modified conventional breeding approaches include integrative and serial phenotypic, genotyping, and selection strategies to screen many genotypes and improve the assessment of plant response to drought stress included (Sandhu *et al*., 2017) [34]. Genotype selection saves time and has been used as an important method to predict genotype performance (Singh, *et al.*, 2011) [60]. However, QTL x genotype background interactions remain a major issue in improving drought tolerance (Kumar *et al*., 2019) [18]. Sandhu and Kumar (2017) [34] recommended using best linear unbiased prediction (BLUP) to select parents for use in breeding programs based on breeding value. BLUP was recently identified as the most effective predictive method among commonly used approaches in plant selection (Wang *et al*., 2019) [47].

6. Marker-Assisted Breeding for Drought Tolerance

Natural genotypic variation in rice can be studied to identify novel genotypes with drought-tolerant traits and associated genes of interest. These new genotypes can be used in conventional breeding programs through marker-assisted selection to develop drought-tolerant rice cultivars. Breeding programs aim to produce high-yielding lines with improved quality parameters and introduce new varieties for agriculture. Breeding of drought-tolerant rice genotypes has been studied in the past (Singh *et al*., 2016; Vikram *et al.*, 2016; Dixit *et al*., 2017; Kumar *et al*., 2017; Barik *et al.* 2019) [38, 45, 5, 34, 1]. However, the success rate was much lower than expected due to the difficulty in finding matching donors with higher levels of resistance coupled with the environment-specific nature. Most of the marker-assisted breeding approaches to develop drought-tolerant rice cultivars have been carried out at the International Rice Research Institute over the past decade (Kumar *et al.*, 2016; Sandhu and Kumar, 2017) [17, 34]. Multiple QTLs for drought tolerance in rice have been incorporated into key cultivars using a marker-assisted breeding approach (Singh *et al*, 2016) [38]. They successfully integrated QTLs such as qDTY9.1, qDTY2.2, qDTY10.1, and qDTY4.1 into the high-yielding cultivar IR64 through a marker-assisted backcrossing approach (Singh *et al.*, 2016) [38]. Shamsuddin *et al*. (2016) [37] successfully developed an elite drought-tolerant Malaysian rice cultivar MR219 with pyramidal formation of three QTLs, qDTY2.2, qDTY3.1 and qDTY12.1. Dixit *et al.* (2017) [5] developed a rice cultivar TDK1 for high drought yield by incorporating three of his QTLs (qDTY3.1, qDTY6.1, and qDTY6.2). Drought has only attracted attention as a constraint, and there is still no validated means of successfully developing drought-tolerant rice cultivars. Most of the high-yielding varieties previously recommended for irrigated cultivation, such as Swarna, Sambamahsuri and IR36, have been used in drought breeding programs. When these cultivars are cultivated by farmers during periods of frequent drought in the rain-field ecosystem, significant losses in rice production are recorded because the above high-yielding cultivars are unable to succumb to frequent droughts (Hao *et al.*, 2018) [9]. Therefore, in the future, more attention should be paid to the improvement of special cultivars with high yields in drought conditions and adaptation to various adverse weather conditions.

7. Transgenic approaches for drought tolerance in rice

Many different types of genes are differentially expressed after rice is exposed to drought stress, with approximately 5000 genes upregulated and 6000 genes downregulated (Bin Rahman and Zhang, 2016; Joshi *et al.*, 2016) [3, 15]. A number of different genes/transcription factors identified by Kumar *et al*. (2016) [17] and Upadhyaya and Panda (2019) [43] show differential expression in rice and used for transgenic plants associated with drought stress. Most of the genes regulated under drought are both ABA-independent and ABA-independent regulatory systems (Du *et al*., 2018; Gupta *et al.*, 2020) [6, 8]. *OsJAZ1* regulate drought tolerance through ABA signaling in rice and modulates plant responses to growth and development under drought stress (Fu *et al*, 2017) [7]. Several genes are also associated with osmoregulatory and late embryogenesis (LEA) proteins that confer tolerance to water deficit in rice (Dash *et al*., 2018, Upadhyaya and Panda, 2019) [4, 43]. The increase in grain yield in rice under drought is of great importance and has been regulated by genes OsNAC*5* (Hu *et al*., 2006) [11], *OsLEA3-1* (Xiao *et al*., 2007) [49] and *OsbZIP71* (Liu *et al*., 2014) [21]. *OsCPK9* improves drought tolerance through improved stomatal closure and improved osmoregulation in transgenics (Wei *et al*, 2014) [48]. Several genes have been tested to confer drought tolerance to rice under laboratory or greenhouse conditions using transgenic approaches. However, these genes should be tested under field conditions before being used in molecular breeding programs.

8. Conclusion

Breeding drought-tolerant rice has always been a major challenge for plant breeders. Using grain yield as a selection criterion has proven to be a boon to this research area. In recent years, several varieties of rice have been launched in South and Southeast Asia. These cultivars exhibited higher grain yields during drought while maintaining yield potential equal to or greater than commercial controls in a variety of target environments. The breeding strategy pursued at IRRI has enabled the development of high-yielding cultivars that are resistant not only to drought, but also to biological stresses such as rice blast and leaf blight. drought. Several strong QTLs of drought grain yield that influence genetic background and environment have recently been reported. These QTLs have enabled the development of drought-tolerant versions of popular mega strains. QTLs were also combined with large QTLs to withstand other abiotic stresses such as flooding. Recent studies at IRRI have also allowed us to better understand the physiological and molecular mechanisms underlying these QTLs. As the development of drought-tolerant NILs for different target environments continues through QTL pyramiding, NILs will not only enable sustainable rice cultivation in drought-affected areas, but also enable rice cultivation in new areas.

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