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Breeding for drought tolerance: A major challenge for rice cultivation under water limiting conditions

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Abstract

Rice is a drought-susceptible crop because of its shallow root system, rapid stomatal closure and little epicuticular wax on the leaves. It is highly sensitive to drought stress at the reproductive stage. The reduction in grain yield under drought stress is mainly caused due to the sterility of spikelet at maturity. Deep and thick root systems have been correlated with better grain yield under drought stress in rice. Many QTLs have been identified under upland and rainfed lowland conditions for various root traits as well as grain yield under drought stress. The successful introgressions of these QTLs through Marker Assisted Breeding (MAB) followed by precise phenotyping have resulted in the development of several drought tolerant varieties. To be more effective, the breeding programme should aim at introgressing QTLs for root traits as well as grain yield under drought stress for development of drought tolerant high yielding rice variety.

Keywords: Rice, QTLs, grain yield, drought tolerance

Introduction

Rice, is the most important crop and staple food for more than half of the world's population (Todaka *et al*., 2012) [33]. It covers 2.54 million (M) ha of the total 3.3 M ha cropped area. More than 90 per cent of the world's rice is grown and consumed in Asia, where 60 per cent of the global population lives. Rapid growth in human population throughout the world is boosting demand for a corresponding increase in grain yield (Liang *et al*., 2010) [8] and there is need to increase production 50 per cent more by 2025 (Khush, 2001) [11]. To achieve this ambitious goal various rice varieties with greatly improved agronomic traits such as, high yield potential and stress tolerance should be developed. Worldwide, water for agriculture is becoming increasingly scarce, day by day, due to uncertain and uneven rainfall distribution patterns, shrinking groundwater resources, increasing level of salts in soil solution and diverting the fresh water resources to competing urban and industrial uses. In the coming future, water availability may be more affected due to ongoing changes in global climate.

The predominantly rice-growing areas in Asia are often threatened by severe abiotic stresses, of which the most common is drought. Drought is the major constraint to rice production in rainfed areas. Throughout the world, about 34 per cent (~54 million hectare) of the total land under rice cultivation is under rainfed conditions (Maclean *et al*., 2002 and Yoichi *et al*., 2011) [20, 44]. Asia occupies 32.1 per cent rainfed low land rice of the total rice area which currently averages production of 2.3 tonnes per hectare (Tuong and Bouman, 2003) [35]. Drought is the most devastating among abiotic stresses and it depresses yield by 15-50 per cent depending on the vigour and period of stress. Water-deficit may occur early in the growing season or any time from flowering to grain filling, and the intensity of the stress depends on the duration and frequency of water-deficit. Rice is highly sensitive to water stress at the reproductive stage (O'Toole 1982 and Venuprasad *et al*., 2007) [24, 2]. Drought stress suppresses leaf expansion, tillering, photosynthesis (Kramer and Boyer, 1995) [12] and reduces leaf area due to early senescence. Reduction of photosynthetic activity, accumulation of organic acids and osmolytes and changes in carbohydrate metabolism, are typical physiological and biochemical responses to drought stress (Tabaeizadeh, 1998) [32]. Water deficit also increases the formation of reactive oxygen species resulting in lipid peroxidation, protein denaturation and nucleic acid damage with severe consequences on overall metabolism. The requirement of drought tolerant rice varieties have long been felt to ensure crop production in rainfed areas. The global reduction in rice production due to drought stands at an average of 18 million tonnes annually. Therefore, drought mitigation, through development of drought tolerant varieties with higher yields under water-limiting environments will be a key to improve rice availability and ensure food security to 3 billion people in Asia.

Root traits associated with drought tolerance

Roots are essential organs for exploiting soil resources, such as water and mineral nutrients. The deeper, thicker and more branched root system with a high root to shoot ratio can enhance the tolerance of rice to water deficits (Gowda *et al*., 2011) [7, 8]. The increase in length and thickness of root in rice is correlated with drought tolerance and grain yield (Jeong *et al*., 2010) [9]. The prevalence of branched roots, the rate of root growth and the direction of root growth relative to limiting resources are important root traits that can be used for breeding purpose. The tropical *japonica* types have fewer tillers and deeper root systems than *indica* and *aus* types (Lafitte *et al*., 2006) [15]. Variability in the root thickness, root depth, and root mass among the rice cultivars was observed under drought stress (Gowda *et al*., 2011) [7, 8]. *Indica* types, grown mostly in lowland, have thinner and shallow roots, while *aus* types are often grown in upland conditions and exhibit intermediate diameter with length similar to *japonica* (which include upland Asian and temperate cultivars). Several rice cultivars were screened for root traits under stress and some promising cultivars such as Salumpikit, Azucena, Dular, Black Gora were identified for use in breeding programme (Henry *et al*., 2011) [7, 8]. Two deep rooted drought tolerant rice cultivars from Assam *viz*., ARC10372 and Banglami were also reported by Verma *et al*. (2017) [41]. In addition to cultivated forms, root systems of wild rice germplasm have also been characterized and *O. longistaminata* and *O. rufipogon* were identified as potential sources of novel genes for drought tolerance (Liu *et al*., 2004) [17]. Among the root morphological traits, maximum root length, root dry weight, root volume, root to shoot weight and length ratios are associated with drought tolerance in upland rice (O’Toole and Soemartono, 1981; Yoshida and Hasegawa, 1982; Babu *et al*., 2001 and Kanbar *et al*., 2009) [43, 1, 10].

As compared to above-ground organs, roots have undergone very little direct selection during cereal domestication, so most modern cultivars have insufficient root systems for optimum uptake of water and nutrients for maximum grain yield. Therefore, QTLs for various root traits were identified and used in Marker Assisted Breeding (MAB) in order to improve root system of shallow rooted high yielding mega rice varieties under drought.

Major QTLs associated with root traits under drought stress

A number of studies have reported QTLs associated with various root traits such as root length (Price *et al*., 2002; MacMillan *et al*., 2006 and Courtois *et al*., 2009) [25, 21, 4], root biomass (Courtois *et al*., 2003) [5], and root number (Zheng *et al*., 2000, 2003 and Courtois *et al*., 2009) [47, 5, 4]. In rice, root length, diameter, dry weight and total absorbing surface area were positively correlated with grain yield (Liu *et al*., 2014) [17]. A major root QTL (*DRO1)* was identified in the Near Isogenic Lines (NIL) derived from a cross between IR64 and Kinandang Patong (Uga *et al*., 2013) [23]. Four QTLs (*QTL2*, *QTL7*, *QTL9* and *QTL11*) were identified in the Recombinant Inbred Lines (RILs) derived from the cross between ‘Bala’ and ‘Azucena’ for various root traits such as root penetration, deep root weight, root thickness and maximum root length (Steel *et al*., 2013). The introgression of QTLs for increased root size enables plant to take up more water and nutrients, and thereby increase photosynthesis and carbohydrate accumulation resulting in mobilization of assimilates towards grain yield. Apart from these secondary traits, it was also reported that the marker assisted breeding using QTLs associated with grain yield under drought has much been effective in rice for improvement to drought stress. Many QTLs for high grain yield under drought have been identified (Kumar *et al*., 2014 and Verma *et al*., 2017) [41, 13] and breeding lines have been developed for upland and rainfed lowland conditions (Verulkar *et al*., 2010) [40] by using this approach. The breeding programmes have to combine favourable root traits with grain yield under stress as the selection criteria in order to develop drought tolerant rice variety.

Yield traits associated with drought tolerance

Traits such as tiller number and plant height modify the expression of secondary and integrative traits by affecting transpirational demand. Plant type traits are highly heritable and are extensively used in traditional plant breeding. Plant height is an important developmental and yield related trait (Zhao *et al*., 2011) [45]. It was slightly lowered in aerobic conditions than the flooded conditions. The plant height in rice was associated with thick and deep root system (Tomar and Prasad, 1996) [28]. A significant positive correlation was observed for number of tillers with effective booting tillers, spikelet fertility and grain yield under drought stress. Higher number of tillers and effective booting tillers were observed in drought tolerant cultivars whereas, low tillering was observed in drought susceptible cultivars under drought stress (Verma *et al*., 2017) [41]. The most important cause of yield reduction under drought stress is the sterility of spikelets (Liu *et al*., 2006) [18] therefore higher spikelet fertility was observed in drought tolerant cultivars. A significant positive correlation of spikelet fertility was observed with number of tillers, effective booting tillers, plant height, panicle length, number of grains per panicle and grain yield per plant under drought stress (Verma *et al*., 2017) [41]. It showed that the various yield component traits associated with enhancement of grain yield in rice under drought stress. The QTLs for various yield component traits under drought stress were identified in rice (Suji *et al*., 2012; Muthu kumar *et al*., 2015 and Verma *et al*., 2017) [41, 22]. These traits can be used for indirect selection of grain yield under drought stress conditions. Moderate heritability of grain yield under drought stress was observed by Kumar *et al*. (2009) [14] therefore, large number of breeding programme have been started using grain yield as a selection criteria for development of high yielding drought tolerant rice variety and QTL mapping.

Major QTLs identified for grain yield under drought stress

A large number of QTLs for grain yield under reproductive-stage drought stress under both upland and lowland conditions have been identified. Among these, *qDTY12.1* was the first reported large-effect QTL with R^2 value of 33% in the F_3–derived lines from the upland rice cultivars Vandana and Way Rarem (Bernier *et al*., 2007) [2]. The two large-effect QTLs (*qDTY2.1* and *qDTY3.1*), were identified in a backcross inbred lines derived from a cross of high-yielding lowland rice variety ‘Swarna’ and upland rice variety ‘Apo’ with an R^2 of 16.3% and 30.7% respectively (Venuprasad *et al*., 2009) [14]. *QDTY6.1* was identified under aerobic and irrigated lowland conditions in the same population with an R^2 of 66% and 39% respectively (Venuprasad *et al*., 2012) [37]. A major QTL for grain yield *qDTY1.1*, was reported in F_3-derived populations developed from the cross between Nagina22/ Swarna, Nagina22/ IR64 and Nagina22/MTU1010 with an R^2 of 13.4%, 16.9%, and 12.6% respectively (Vikram *et al*.,

2011) [42]. Four large-effect QTLs, *qDTY2.2*, *qDTY4.1*, *qDTY9.1*, and *qDTY10.1*, were identified in the backcross inbred lines derived from the cross between Aday Sel and IR64 (Swamy *et al.*, 2013) [30]. Among the various QTLs reported for grain yield *qDTY1.1*, *qDTY2.2*, *qDTY2.3*, *qDTY3.1*, *qDTY3*.2, *qDTY6.1*, and *qDTY12.1* have shown an effect across multiple genetic backgrounds (Kumar *et al*., 2014) [13] Therefore, these are the most suitable QTLs to be used for development of drought tolerant rice variety in different genetic backgrounds.

MAB for drought tolerance

In MAB the different QTLs combinations were found effective in specific genetic background due to interaction of QTLs with genetic background as well as among the QTLs. In India several drought tolerant cultivars were released with very high degree of drought tolerance (Verulkar *et al*. 2010 and Gowda *et al*. 2011) [40, 8]. The introgression of *DRO1* QTL in a shallow-rooting variety (IR64) resulted in development of deep rooted plants with high yield performance under drought conditions (Uga *et al*., 2013 and Deshmukh *et al*., 2017) [36]. The introgression of multiple root QTLs increased root penetration, root thickness and nodal root apex stiffness (Clark *et al*., 2008). Similarly, a root QTL 9 was reported to increase the root length by 9.6 cm under both drought and well-watered conditions and a deep rooted variety “Birsa Vikas Dhan 111” was developed through MAB (Steele *et al*., 2006) [28].

Recently, different combinations of grain yield QTLs were utilized in drought breeding programme. The combination of *qDTY12.1* with *qDTY2.3* and *qDTY3.2* results in significant yield advantage in Vandana and Way Rarem F_3 derived population under upland drought stress conditions (Swamy *et al.*, 2013) [30]. Similarly, in an IR64 background, plants with *qDTY2.2* and *qDTY4.1* showed a higher yield advantage under lowland drought stress. The QTL combinations (*qDTY3.1*,*qDTY2.2* and *qDTY3.1*,*qDTY12.1*) provided a higher yield advantage under reproductive stage drought stress in the background of elite Malaysian rice cultivar, MR219 (Shamsudin *et al*., 2016) [26]. The various combinations of QTLs were found effective in enhancement of grain yield in variable genetic backgrounds under drought stress. Therefore, the breeding strategies based on root traits and grain yield were utilized effectively through MAB for the development of drought tolerant rice variety across the rainfed rice growing areas of India and other countries. In future these two strategies for drought tolerance can be combined together. The plants will be selected for deep root along with high grain yield under drought stress in order to develop drought tolerance rice variety.

References

1. Babu RC, Shashidhar HE, Lilley JM, Thanh ND, Ray JD, Sadasivam S *et al*. Variation in root penetration ability, osmotic adjustment and dehydration tolerance among accessions of rice adapted to rainfed lowland and upland ecosystems. Plant Breed. 2001; 120:233-238.
2. Bernier J, Kumar A, Venuprasad R, Spaner D, Atlin GN. A large-effect QTL for grain yield under reproductive-stage drought stress in upland rice. Crop Sci. 2007; 47:507-516.
3. Clark LJ, Price AH, Steele KA, Whalley WR. Evidence from near-isogenic lines that root penetration increases with root diameter and bending stiffness in rice. Funct Plant Biol. 2008; 35:1163-1171.
4. Courtois B, Ahmadi N, Khowaja F, Price AH, Rami JF, Frouin J *et al*. Rice root genetic architecture: meta-analysis from a drought QTL database. Rice. 2009; 2:115-128.
5. Courtois B, Shen L, Petalcorin W, Carandang S, Mauleon R, Li Z. Locating QTLs controlling constitutive root traits in the rice population IAC165 × Co39. Euphytica. 2003; 134:335-345.
6. Deshmukh V, Kamoshita A, Norisada M, Uga Y. Near-isogenic lines of IR64 (*Oryza sativa* subsp. *indica* cv.) introgressed with Deeper Rooting 1 and Stele Transversal Area 1 improve rice yield formation over the background parent across three water management regimes. Plant Production Science, 2017.
7. Gowda VRP, Henry A, Yamauchi A, Shashidhar HE, Serraj R. Root biology and genetic improvement for drought avoidance in rice. Field Crop Res. 2011; 122:1-13.
8. Henry A, Gowda VRP, Torres RO, McNally KL, Serraj R. Variation in root system architecture and drought response in rice (*Oryza sativa*): phenotyping of the Oryza SNP panel in rainfed lowland fields. Field Crops Res. 2011; 120:205-214.
9. Jeong JS, Kim YS, Baek KH, Jung H, Ha SH, Do Choi Y *et al*. Root-specific expression of OsNAC10 improves drought tolerance and grain yield in rice under field drought conditions. Plant Physiol. 2010; 153:185-97.
10. Kanbar A, Toorchi M, Shashidhar HE. Relationship between root and yield morphological characters in rainfed low land rice (*Oryza sativa* L.). Cereal Res. Commun. 2009; 37:261-268.
11. Khush GS. Green revolution: The way forward. Nat. Rev. 2001; 2:815-822.
12. Kramer PJ, Boyer JS. Water relations of plant and soil. San Diego: Academic Press, 1995.
13. Kumar A, Dixit S, Ram T, Yadaw RB, Mishra KK, Mandal NP. Breeding high-yielding drought-tolerant rice: genetic variations and conventional and molecular approaches. J Exp. Bot. 2014; 65:6265-6278.
14. Kumar A, Verulkar SB, Dixit S, Chauhan B, Bernier J, Venuprasad R. Yield and yield-attributing traits of rice (*Oryza sativa* L.) under lowland drought and suitability of early vigor as a selection criterion. Field Crop Res. 2009; 114:99-107.
15. Lafitte R, Bennett J, Kathiresan A. Drought adaptation in rice. In: Drought Adaptation in Cereals, Ribaut, J.M.(ed.) Haworth Press, Inc., New York, 2006, 301-334.
16. Liang J, Lu Y, Xiao P, Sun M, Corke H, Bao J. Genetic diversity and population structure of a diverse set of rice germplasm for association mapping. Theor. Appl. Genet 2010; 121:475-87.
17. Liu L, Lafitte R, Guan D. Wild *Oryza* species as potential sources of drought-adaptive traits. Euphytica. 2004; 138:149-161.
18. Liu JK, Liao DQ, Oane R, Estenor L, Yang XE, Li ZC *et al*. Genetic variation in the sensitivity of anther dehiscence to drought stress in rice. Field Crop Res. 2006; 97:87-100.
19. Liu L, Zhang H, Ju C, Xiong Y, Bian J, Zhao B *et al*. Changes in Grain Yield and Root Morphology and Physiology of Mid-Season Rice in the Yangtze River Basin of China during the Last 60 Years. J Agric. Sci. 2014, 6.
20. Maclean JL, Dawe DC, Hardy B, Hettel GP. Rice Almanac: Sourcebook for the most important economic

activity on earth. CABI Publishing, Wallingford, England. In association with the International Rice Research Institute, West Africa Rice Development Association, International Centre for Tropical Agriculture, and Food and Agriculture Organization of the United Nations, 2002.

21. MacMillan K, Emrich K, Piepho HP, Mullins CE, Price AH. Assessing the importance of genotype × environment interaction for root traits in rice using a mapping population ii: conventional QTL analysis. Theor. Appl. Genet. 2006; 113:953-964.
22. Muthukumar C, Deshmukh V, Vivek, Poornima R, Kavitha S, Gayathri V, Babu RC. Fine mapping of consistent quantitative trait loci for yield under drought stress using rice (*Oryza sativa*) recombinant inbred lines adapted to rainfed environment. Curr. Sci. 2015, 109.
23. O'Toole JC, Soemartono N. Evaluation of a simple technique for characterizing rice root systems in relation to drought resistance. Euphytica. 1981; 30:283-290.
24. O'Toole JC. Adaptation of rice to drought-prone environments. In: Drought Resistance in Crops, with Emphasison Rice. IRRI, Philippines, 1982, 195-213.
25. Price AH, Steele KA, Moore BJ, Jones RGW. Upland rice grown in soil filled chambers and exposed to contrasting water- deficit regimes: II. Mapping quantitative trait loci for root morphology and distribution. Field Crops Res. 2002; 76:25-43.
26. Shamsudin NA, Swamy BPM, Ratnam W, Cruz MTS, Sandhu N, Raman AK *et al*. Pyramiding of drought yield QTLs into a high quality Malaysian rice cultivar MRQ74 improves yield under reproductive stage drought. Rice. 2016; 9:21.
27. Srividhya A, Vemireddy LR, Sridhar S, Jayaprada M, Ramanarao PV, Hariprasad AS, *et al*. Molecular Mapping of QTLs for Yield and its Components under Two Water Supply Conditions in Rice (*Oryza sativa* L.). J Crop Sci. Biotech. 2011; 14:45-56.
28. Steele KA, Price AH, Witcombe JR, Shrestha R, Singh BN, Gibbons JM *et al*. QTLs associated with root traits increase yield in upland rice when transferred through marker-assisted selection. Theor. Appl. Genet. 2013; 126:101-108.
29. Steele KA, Price AH, Shashidhar HE, Witcombe JR. Marker- assisted selection to introgress rice QTLs controlling root traits into an Indian upland rice variety. Theor. Appl. Genet. 2006; 112:208-221.
30. Swamy BPM, Ahmed HU, Henry A. Genetic, physiological, and gene expression analyses reveal that multiple QTL enhance yield of rice mega-variety IR64 under drought. PLoS One, 2013, 8.
31. Suji KK, Biji KR, Poornima R, Prince KSJ, Amudha K, Kavitha S. *et al*. Mapping QTLs for plant phenology and production traits using indica rice (*Oryza sativa* L.) lines adapted to rainfed environment. Mol. Biotechnol. 2012; 52:151-160.
32. Tabaeizadeh Z. Drought-induced responses in plant cells. Int. Rev. Cytol. 1998; 182:193-247.
33. Todaka D, Nakashima K, Shinozaki K, Yamaguchi-Shinozaki K. Toward understanding transcriptional regulatory networks in abiotic stress responses and tolerance in rice. Rice, 2012, 5-6.
34. Tomar J, Prasad S. Relationship between inheritance and linkage for drought tolerance in upland rice (*Oryza sativa*) varieties. J. Agril. Sci. 1996; 66:459-465.
35. Tuong TP, Bouman BAM. Rice production in water scarce environments. In: Water productivity in agriculture: limits and opportunities for improvement. Kijne, J.W.; Barker, R. and Molden, D. (eds). CABI Publishing, Wallingford, UK, 2003, 53-67.
36. Uga Y, Sugimoto K, Ogawa S, Rane J, Ishitani M, Hara N *et al*. Control of root system architecture by DEEPER ROOTING 1 increases rice yield under drought conditions. Nat. Genet. 2013; 45:1097-1102.
37. Venuprasad R, Bool ME, Quiatchon L, Atlin GN. A QTL for rice grain yield in aerobic environments with large effects in three genetic backgrounds. Theor. Appl. Genet, 2012; 124:323-332.
38. Venuprasad R, Dalid CO, Del Valle M, Zhao D, Espiritu M, Sta Cruz MT *et al*. Identification and characterization of large-effect quantitative trait loci for grain yield under lowland drought stress in rice using bulk-segregant analysis. Theor. Appl. Genet. 2009; 120:177-190.
39. Venuprasad R, Lafitte HR, Atlin GN. Response to direct selection for grain yield under drought stress in rice. Crop Sci. 2007; 47:285-293.
40. Verulkar SB, Mandal NP, Dwivedi JL, Singh BN, Sinha PK *et al*. Breeding resilient and productive genotypes adapted to drought-prone rainfed ecosystem of India. Field Crops Res. 2010; 117:197-208.
41. Vermam RK, Chetia SK, Dey PC, Baruah AR, Modi MK. Mapping of QTLs for grain yield and its component traits under drought stress in elite rice variety of Assam. Int. J. Curr. Microbiol. App. Sci. 2017; 6:1443-1455.
42. Vikram P, Mallikarjuna Swamy BP, Dixit S, Ahmed HU, Sta Cruz MT, Singh AK *et al*. *qDTY1.1*, a major QTL for rice grain yield under reproductive-stage drought stress with a consistent effect in multiple elite genetic backgrounds. BMC Genet. 2011; 12:89.
43. Yoshida S, Hasegawa S. The rice root system: its development and function. In: Drought Resistance in Crops, with Emphasis on Rice. International Rice Research Institute, Manila, Philippines, 1982.
44. Yoichi F, Oda M, Horikawa N, Ogura C. Hydrologic Analysis of Rainfed Rice Areas Using a Simple Semi-distributed Water Balance Model. Water Resour. Manage. 2011; 25:2061-2080.
45. Zhao K, Tung CW, Eizenga GC, Wright MH, Ali ML, Price AH *et al*. Genome-wide association mapping reveals a rich genetic architecture of complex traits in *Oryza sativa*. Nat. Commun. 2011; 2:467.
46. Zheng BS, Yang L, Zhang WP, Mao CZ, Wu YR, Yi KK *et al*. Mapping QTLs and candidate genes for rice root traits under different water- supply conditions and comparative analysis across three populations. Theor. Appl. Genet. 2003; 107:1505-1515.
47. Zheng HG, Babu RC, Pathan MS, Ali L, Huang N, Courtois B *et al*. Quantitative trait loci for root-penetration ability and root thickness in rice: comparison of genetic backgrounds. Genome. 2000; 43:53-61.