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Development of Salt-Tolerant Rice Varieties to Enhancing Productivity in Salt-Affected Environments †

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Abstract: Among abiotic stresses, salt stress is the most complicated problem posing a major challenge for maintaining world food supplies as well as food security as it covers 1125 m ha globally and 6.73 m ha in India. It is very essential to increase rice productivity in salt-affected soils for food security and sustainability in salt-affected environments. The pass port data of 9000 rice Germplasm has been established for 30 traits and a mini core of 1500 lines has been developed. Approximately 20,000 rice lines have been screened for salinity and sodicity for both seedling and reproductive stages. The highly tolerant rice lines are being used in breeding programme to enhance the genetic diversity. The six QTLs in chromosomes 1, 2, 8, 9, 10 has been identified for the Na/K ratio, spikelet fertility and grain yield for the reproductive stage salt tolerance. The *Saltol* QTL has been transferred to Indian mega rice varieties namely, Pusa44 and Sarjoo52, to improve the salinity tolerance at the seedling stage. Similarly, the *qSSISFHS8.1* (QTL for spikelet fertility) QTL is being transferred into mega rice varieties namely, PR114, Pusa44 and Sarjoo52, to improve the salinity tolerance at the reproductive stage. The marker assisted selection accelerates the breeding activities to develop the salt-tolerant varieties as well as transfer the QTLs to HVYs through marker assisted back cross breeding. The Central Soil Salinity Research Institute (CSSRI) has developed 13 salt-tolerant rice varieties, namely CSR10, CSR13, CSR23, CSR27, Basmati CSR30, CSR36, CSR43, CSR46, CSR49, CSR52, CSR56, CSR60 and CSR76, through conventional breeding approaches to increase the productivity of salt-affected soils for resource poor farmers. The popularity of these salt-tolerant rice varieties can be ascertained from the facts that large quantity of breeder seeds (1056 quintals) and truthfully labelled seeds (3126 quintals) has been produced and sold during last 22 years (2000–2021), more demand from the farmers and large area app. One point two million hectares is covered by these salt-tolerant rice varieties every year. Numerous salt-tolerant rice lines are being developed at CSSRI to cope with salt-affected soils and enable sustainable agriculture under salt-affected soils.

Keywords: rice; salinity; sodicity

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1. Introduction

Rice is one of the important staple food crops and is consumed by approximately 50% of the global population as their main source of energy. The world population is increasing and will reach 9.5 billion by year 2050 and world food production will need to increase by 70% [1]. Therefore, there is a need to increase the productivity of rice by overcoming the lower crop productivity caused by various biotic and abiotic stresses. Among the abiotic stresses, salinity and sodicty are the most important environmental factors hampering crop productivity as they cause ionic disequilibrium and disrupt the metabolic activities of the plants [2]. Salinity and sodicity stress is highly influenced by environmental fluctuations such as rising temperature and relative humidity [3]. Salt stress affects all the stages of in plants, but early seedling and reproductive stages are the most sensitive in rice [4,5]. Salinity stress reduces root length, shoot length at the seedling stage and tiller number, number of spikes, panicle length and spikelet fertility at the reproductive stage [6,7]. Sodicity also affects crop productivity. Many workers have reported the effect of sodic soils on growth and development in rice [8–10]. Collection of the rice germplasm from salt-affected soils and other locations and their evaluation is crucial in breeding programmes. After the green revolution, breeding programs were adapted to develop saline tolerant genotypes at IRRI [11]. Extensive research has been redirected towards the advancement of salt resistance at the seedling stage of rice, but little effort has been made to recognize QTLs related to the reproductive stage salinity [12–19]. QTL mapping is generally based solely on the phenotypic performance under stress; therefore, the utilization of comparative performance of various genotypes under stress and non-stress conditions will be useful in identifying and mapping the QTLs for the development of stress-resistant varieties [20]. Introgression of QTLs into high-yielding mega varieties is an essential step in molecular breeding programmes once the identification of QTLs and fine mapping is completed. Conventional breeding has been very successful in developing salt-tolerant varieties of rice. The dissemination of salt-tolerant rice varieties to farmer's fields of salt-affected locations is a crucial step to enhance the productivity of salt-affected soils.

2. Methods

Plant Materials

A total of 9000 rice Germplasms were collected and evaluated for 30 different qualitative and quantitative traits and a mini core of 1500 lines was developed from the 9000 rice Germplasm. Approximately 20,000 rice lines were screened for salinity and sodicity for both seedling and reproductive stages during 2020–2022 [7,21,22] to identify salt-tolerant lines. Different mapping populations, namely GWAS panel [18,23] Bi-parental mapping populations of CSR11/MI48 and CSR11/MI48 [17]; CSR10/PS5 [16], CSR27/MI48 [24]; and MAGIC population, were used to identify the QTLs governing salt tolerance. Different segregating populations were evaluated in salt stress conditions to select good performing recombinants. We developed and released the 13 salt-tolerant rice varieties for different zones of the country after evaluation of AICRP rice. Breeder seed and truthfully label seed of these salt-tolerant rice varieties were produced and sold to different seed producing agencies and farmers.

3. Results and Discussion

3.1. Collection and Evaluation of Rice Germplasms

We collected the 9000 rice Germplasms from the National Bureau of Plant Genetic Resources (NBPGR), New Delhi. We evaluated them for 30 qualitative and quantitative traits. We developed a mini core collection of 1500 rice Germplasms and evaluated them in salt stress conditions. We were able to identify 85 tolerant rice lines that are being used in breeding programmes to enhance the salt tolerance. We also evaluated 7500 rice lines from 2012–2021 for saline stress of EC ~ 10.00 dS/m at the seedling stage along with the sensitivity check IR29 and tolerance check FL478. We identified 241 tolerant rice lines. We are using these lines in our breeding programme to diversify the genetic base and enhance salinity tolerance.

3.2. Identification and Introgression QTLs for Salt Tolerance

We evaluated 391 MAGIC lines in saline stress of EC ~ 10.00 dS/m and sodic stress of pH of 9.7 at the seedling stage. We used GBS data of 391 MAGIC lines and identified QTLs for salinity and sodicity tolerance. One QTL was identified on chromosome 1 that had already been reported. Two novel QTLs tolerant to sodicity were mapped on chromosomes

6 and 11. An aluminium activated malate gene transporter, which is related to sodic stress, was localised on chromosome 6. Another gene, Os11g0565400 (Ring finger protein), was found on chromosome 11. These two genes could be used for the enhancement of sodicity tolerance in rice. We identified marker trait associations (MTA) for physiological traits at the reproductive stage. We identified 28 marker trait associations (MTA) on different chromosomes' physiological traits. In another study, we also identified two significant marker trait associations (MTA) on chromosome 1 for Na/K homeostasis. The biparental mapping population (CSR11/MI48) was used to identify the QTLs for sodicity tolerance at the reproductive stage. We phenotyped the CSR11/MI48 RIL population in normal (pH ~7.5) and sodic (pH ~9.5) stress across three seasons for grain yield and its contributing traits and genotyped using 50K SNP. We identified a major QTL qSSI6.2 on chromosome 6 for grain yield at sodic stress with a phenotypic variation of 32%. We introgressed Saltol QTL into two mega rice varieties, namely Pusa44 and Sarjoo52, through marker-assisted back crossbreeding. We used FL478 as donor parents and developed 10 near-isogenic lines (NILs) in the background of pusa44 and 8 near-isogenic lines (NILs) in the background of Sarjoo52. These NILs were tolerant up to a salinity of EC ~ 10.00 dS/m at the seedling stage. A major QTL qSSISFH8.1 for spikelet fertility was identified and fine mapped for salinity tolerance at the reproductive stage on chromosome 8 in CSR27. Introgressing of qSSISFH 8.1 into three mega rice varieties namely, Pusa44, PR114 and Sarjoo52 through marker-assisted back crossbreeding is underway. We developed BC_3F_2 populations in the Pusa44, PR114 and Sarjoo52 background. We also followed the stringent phenotyping to select the near isogenic lines (NILs).

3.3. Development of Salt-Tolerant Rice Varieties

Recently, we developed six salt-tolerant rice varieties namely, CSR46, CSR49, CSR52, CSR56, CSR60 and CSR76, through conventional breeding approaches to increase the productivity of salt-affected soils for resource poor farmers. Recently, we developed six salt-tolerant rice varieties. CSR46 is recommended for sodic soils of Uttar Pradesh. CSR46 is tolerant to a sodicity pH of 9.9 and salinity of EC ~ 8.00 dS/m. It is a medium duration rice variety with long slender grain. It has a yield potential of 7.0 t/ha in normal and 4.0 t/ha in salt stress situations. Rice variety CSR56 tolerates a sodicity pH of 9.9. It is a medium duration rice variety with long bold grain. It has a yield potential of 7.5 t/ha in normal and 4.1 t/ha in salt-stress situations. It is recommended for sodic soils of Uttar Pradesh and Haryana. CSR60 is tolerant to a sodicity pH of 9.9. It is medium duration rice variety with long slender grain. It has yield potentials of 7.5 t/ha in normal and 4.3 t/ha in salt stress situation. It is recommended for sodic soils of Uttar Pradesh and Pondicherry. CSR76 is tolerant to a sodicity pH of 9.9. It is medium duration rice variety with long slender grain. It has yield potentials of 7.5 t/ha in normal and 4.5 t/ha in salt stress situation. It is recommended for sodic soils of Uttar Pradesh. Many salt-tolerant rice varieties have been released for commercial cultivation in India. We have produced 1056 and 3126 quintals of breeder and truthfully labelled seeds of salt-tolerant rice varieties, respectively, during last 22 years (2000–2021). These salt-tolerant rice varieties covered an area of approximately 1.02 m ha every year.

4. Conclusions

These salt tolerant rice varieties cover about 1.6 m ha of salt-affected land and are estimated to earn USD 4732 million annually to the national exchequer. These salt tolerant varieties have been adopted by land reclamation corporations, benefiting 430,000 famers. With the introduction of these salt-tolerant varieties, about 0.6 million tons of gypsum has been saved, which would have cost USD 250,000. The salt-tolerant rice varieties facilitated the management of salt-affected soils and sustainable agriculture under salt-affected soils.

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