Salt-Tolerant Rice

Subjects: Agriculture, Dairy & Animal Science

Contributor: Hua Qin , Yuxiang Li , Rongfeng Huang

Soil salinization and a degraded ecological environment are challenging agricultural productivity and food security. Salt stress-inhibited growth and development of plants is the key limiting factor resulting in the reduction of rice yield, the contradiction of yield promotion and salt tolerance greatly affects salt-tolerant rice breeding. Here, we highlight current advances and challenges to breeding salt-tolerant rice, providing a basis for further studies and efforts aimed at breeding salt-tolerant rice varieties.

rice salt tolerance breeding

1. Introduction

Rice (Oryza sativa) is an important staple food crop worldwide. As the global population continues to rise, rice production also needs to increase. However, global rice production is threatened by climate change[1]. Rice is considered to be a salt-susceptible species[2], and its salt tolerance depends on growth stage, organ type, and genotype[3][4][5]. Generally, the seedling and reproductive stages are more susceptible to salinity than the vegetative stage, roots are more sensitive than other organs[3], and japonica rice is more sensitive than indica rice[4]. Salinity stress suppresses photosynthesis and growth, leading to biomass loss, as well as partial sterility, which ultimately results in reductions in rice yield[6][7]. Therefore, the breeding of salt-tolerant rice cultivars is considered to be one of the most economic options to assure food security.

2. Salt-Tolerant Rice Identification and Evaluation Methods

The development of an efficient and reliable evaluation system is a prerequisite for breeding salt-tolerant rice varieties. The current rice salt tolerance indicators are divided into two aspects: morphological parameters and physiological parameters[8][9]. The morphological parameters evaluation method is to conduct salt treatments at different growth stages of rice and then observe and record the salt damage symptoms of plants, leaves, tillers, and spikelet fertility[10][11]. The standard evaluation score of visual salt injury was proposed by The International Rice Research Institute (IRRI); this method scores the salt tolerance of rice from 1 to 9 based on the tiller number, leaf symptoms, and the growth status of the whole plant under salt stress; the lower score (1) indicates tolerant and higher score (9) denotes sensitive genotypes[12]. However, this method is greatly affected by human qualitativeness, and there are time differences in the rate of leaf death and plant death of different materials. Therefore, this identification and evaluation system cannot completely and accurately reflect the salt tolerance of rice varieties.

Salinity stress induces metabolite changes, and several physiological mechanisms are perceived to contribute to the overall ability of rice plants to cope with excess salts[13][14][15]. Studies have shown that the Na+/K+ ratio, proline content, hydrogen peroxide, peroxidase activity, and sugars, etc. are affected under salt stress[11][16]. Therefore, it can be used to screen salt-tolerant rice varieties by comparing the changes of physiological and biochemical indices in rice with or without salt treatment. However, physiological and biochemical parameter methods lack specific evaluation standards, and the measurement of these indices requires corresponding instruments or kits, which are relatively cumbersome to operate.

Rice salt tolerance is a complex genetic and physiological characteristic, and the extent of its sensitivity varies during different growth and developmental stages[3][4][5]. The salt tolerance during the whole life of rice is a comprehensive reflection of the salt tolerance in each growth and developmental stage, which is closer to production practice and has more practical significance. However, due to soil heterogeneity, climatic factors and other environmental factors may influence the physiological processes; it is difficult to screen salt-tolerant rice varieties at the field level. Hence, screening under laboratory conditions is considered to be advantageous over field screening. Since the salt types in saline-alkali fields are double salts, the salt tolerance identified in the laboratory does not always correlate with that in the field. Therefore, the most reliable way to evaluate the salt tolerance of rice is to compare the changes of morphological parameters and physiological parameters in various growth and developmental stages under salt treatment and normal condition, both in the laboratory and in the field.

3. Breeding of salt-tolerant rice varieties

Developing elite salt-tolerant rice varieties is considered to be the most economically viable and environmentally friendly method to effectively use saline-alkali land. As a food crop, yield is an important indicator to evaluate the merits of rice varieties. Salt-alkali tolerance in rice is defined as the ability to grow on land with a 0.3% saline-alkali concentration, with a yield of more than 4500 kg per hectare. Through years of hard work, breeders have sought out, collected, evaluated, and developed many salt-tolerant rice resources.

Ceylon (modern-day Sri Lanka) was the first country to carry out the screening and cultivation of salt-tolerant rice varieties, introducing the first salt-tolerant rice variety, *Pokkali*, in 1939[17]. Subsequently, India and the Philippines bred a series of salt-tolerant rice varieties, such as *Kala Rata 1-24*, *Nona Bokra*, *Bhura Rata*, *SR 26B*, *Chin.13*, and *349 Jhona*. Bangladesh bred *BRI*, *BR203-26-2*, *Sail*, and other salt-tolerant rice varieties. Thailand bred the salt-tolerant rice variety *FL530*. Japan bred the salt-tolerant rice varieties *Mantaro rice*, *Kanto 51*, *Hama Minoru*, *Chikushiqing*, and *Lansheng*. The United States bred the salt-tolerant rice variety *American Rice*. South Korea bred the salt-tolerant rice varieties *Dongjinbyeo*, *Ganchukbyeo*, *Gyehwabyeo*, *Ilpumbyeo*, *Seomjimbyeo*, and *Nonganbyeo*. Russia bred 16 the salt-tolerant rice varieties, including *VNIIR8207* and *Fontan*[18][19][20][21][22][23][24][25][26]. IRRI hosts more than 127,000 rice accessions collected worldwide, providing a rich source of genetic diversity. By evaluating the salt tolerance of these rice varieties, researchers identified approximately 103 varieties that were moderately to highly salt tolerant, including *Nona Bokra*, *Pamodar*, *Jhona349*, *IR4595-4-1-13*, *IR4630-22-2-5-1-3*, *IR9764-45-2-2*, and *IR9884-54-3*[27][28].

China began to study the salt tolerance of rice in the 1950s. In the 1980s, China launched a national collaborative research program on the salt-alkali resistance of rice and wheat. During the Seventh Five-Year Plan period (1986-1990), China began evaluating the salt tolerance of rice germplasm. This large-scale national cooperation resulted in some progress. The Liaoning Saline or Alkaline Land Utilization and Research Institute launched a salt-tolerant rice breeding program in the 1970s and cultivated a series of salt-tolerant *japonica* rice varieties, such as *Liaoyan No. 2*, *Liaoyan 241*, and *Liaoyan 16*. In 1984, the institute developed highly salt-tolerant *indica* rice varieties *81-210*. Since 1989, salt-tolerant varieties, such as *Salt-resistant No. 100*, *Yangeng 29*, *Yanfeng 47*, and *Yangeng 228*, have been cultivated[25]. The Jiangsu Institute of Agricultural Sciences in Coastal Areas began identifying and evaluating salt-tolerant rice germplasm resources in the 1980s. From more than 1300 germplasm resources, this group obtained 61 that were salt-tolerant[26], from which they developed many salt-tolerant materials, such as *Yancheng 156*, *Yandao No. 10*, and *Yandao No. 12*[26]. In addition, breeding institutes and breeders in China have used existing salt-tolerant germplasms or conventional breeding methods to obtain salt-tolerant rice varieties, such as *Changbai No. 6*, *Changbai No. 7*, *Changbai No. 9*, *Changbai No. 13*, *Jigeng No. 84*, and *Jinyuan 101*[25] [42].

Sea Rice 86 (*SR86*) is a new cultivar domesticated from a wild strain of rice that was first found in 1986 in saline-alkaline soil submerged in sea water near the coastal region of the city of Zhanjiang in Southeast China[29]. *SR86* showed a significantly higher ability to cope with high salinity than a highly salt-resistant rice variety, *Yanfen 47*, measured by both germination and salt inhibition rates[29]. After more than 20 years of breeding and selection, *SR86* retains an extraordinary tolerance to salinity and is considered to be a strategic germplasm resource for the development of new rice varieties. *SR86* is being used to investigate the mechanism of salt tolerance and effective breeding strategies.

In recent years, our laboratory has also carried out a breeding program to develop salt-tolerant rice. We collected more than 750 rice accessions, including 500 rice accessions from all over the world and 250 salt-tolerant rice varieties from domestic coastal cities, such as Tianjin, Liaoning, Shandong, and Jiangsu. We investigated the salt tolerance of these varieties in Dongying, Shandong Province (37°31′29”N 118°33′57”E), a typical saline-alkali field in China. Briefly, thirty-day-old seedlings were transplanted to a normal field or saline field (0.35% NaCl, pH 8.2) at a spacing of 20 cm×15 cm, and all agronomic traits were performed at the maturity stage. Through comparing the agronomic traits of the normal field and saline field, we selected a series of varieties with excellent agronomic traits and salt tolerance (Table 1) (unpublished data). Using these varieties, we made more than 300 hybrid combinations, generated more than 100 salt-tolerant genetic populations, and identified more than 1000 high-yielding salt-tolerant recombinant inbred lines.

Table 1. Rice varieties with excellent agronomic traits and salt tolerance results**.**

Material code	Plant height (cm)		Panicle length (cm)		Tiller number		Yield (kg/hectare)	
	Control	Salt	Control	Salt	Control	Salt	Control	Salt

DYST1	94.6 ± 1.8	73.1 ± 3.5	21.6 ± 0.7	19.4 ± 1.0	8.0 ± 1.2	5.6 ± 0.5	6438.0	6271.5
DYST2	92.8 ± 3.2	71.8 ± 3.0	18.2 ± 1.8	16.9 ± 1.2	10.6 ± 1.5	9.6 ± 0.9	7159.5	5106.0
DYST3	91.3 ± 4.1	64.9 ± 4.2	19.2 ± 1.6	17.4 ± 1.5	13.0 ± 0.7	7.2 ± 1.1	8325.0	4662.0
DYST4	91.5 ± 3.9	78.8 ± 4.0	19.2 ± 1.1	18.4 ± 1.8	11.4 ± 1.8	8.0 ± 2.0	7270.5	6216.0
DYST5	99.7 ± 2.6	83.3 ± 1.8	22.8 ± 1.3	20.3 ± 1.6	11.8 ± 1.8	8.8 ± 2.2	8325.0	5217.0
DYST6	95.6 ± 1.0	74.6 ± 3.6	21.0 ± 0.6	18.9 ± 0.9	13.2 ± 0.8	11.0 ± 2.9	8103.0	5050.5
DYST7	91.6 ± 2.6	79.4 ± 5.4	21.8 ± 1.3	20.5 ± 0.7	11.8 ± 2.2	10.6 ± 1.7	6993.0	5050.5
DYST8	96.0 ± 3.1	81.5 ± 3.0	21.3 ± 0.7	20.3 ± 1.3	12.0 ± 1.4	10.8 ± 2.3	7992.0	5827.5
DYST9	95.6 ± 2.8	80.6 ± 3.0	21.3 ± 1.2	20.6 ± 1.1	11.6 ± 1.8	10.2 ± 2.9	8268.8	5142.0
DYST10	95.2 ± 1.8	83.0 ± 1.0	20.4 ± 1.6	19.7 ± 1.4	11.2 ± 2.4	10.2 ± 1.6	8880.0	5550.0

“Control” indicates that the variety was grown in a normal field. “Salt” indicates that the variety was grown in a field containing 0.35% NaCl and pH 8.2 throughout its life cycle. “DYST” means Dongying Salt Tolerance.

References

1. Lobell, D.B.; Gourdji, S.M. The influence of climate change on global crop productivity. Plant Physiol. 2012, 160, 1686–1697.
2. Chinnusamy, V.; Jagendorf, A.; Zhu, J.K. Understanding and improving salt tolerance in plants. Crop. Sci. 2005, 45, 437–448.
3. Nam, M.H.; Bang, E.; Kwon, T.Y.; Kim, Y.; Kim, E.H.; Cho, K.; Park, W.J.; Kim, B.G.; Yoon, I.S. Metabolite profiling of diverse rice germplasm and identification of conserved metabolic markers of rice roots in response to long-term mild salinity stress. Int. J. Mol. Sci. 2015, 16, 21959–21974.
4. Lee, K.S.; Choi, W.Y.; Ko, J.C.; Kim, T.S.; Gregorio, G.B. Salinity tolerance of japonica and indica rice (Oryza sativa L.) at the seedling stage. Planta 2003, 216, 1043–1046.
5. Kurotani, K.; Yamanaka, K.; Toda, Y.; Ogawa, D.; Tanaka, M.; Kozawa, H.; Nakamura, H.; Hakata, M.; Ichikawa, H.; Hattori, T.; et al. Stress tolerance profiling of a collection of extant salt-tolerant rice varieties and transgenic plants overexpressing abiotic stress tolerance genes. Plant Cell Physiol. 2015, 56, 1867–1876.
6. Radanielson, A.M.; Angeles, O.; Li, T.; Ismail, A.M.; Gaydon, D.S. Describing the physiological responses of different rice genotypes to salt stress using sigmoid and piecewise linear functions. Field Crop. Res. 2018, 220, 46–56.
7. Yu-Chang Tsai; Kuan-Chuan Chen; Tung-Shan Cheng; Chuan Lee; Shih-Hung Lin; Chih-Wei Tung; Chlorophyll fluorescence analysis in diverse rice varieties reveals the positive correlation between the seedlings salt tolerance and photosynthetic efficiency. *BMC Plant Biology* **2019**, *19*, 1-17, 10.1186/s12870-019-1983-8.
8. Jaiswal, S.; Gautam, R.K.; Singh, R.K.; Krishnamurthy, S.L.; Ali, S.; Sakthivel, K.; Iquebal, M.A.; Rai, A.; Kumar, D. Harmonizing technological advances in phenomics and genomics for enhanced salt tolerance in rice from a practical perspective. Rice 2019, 12, 89.
9. Krishnamurthy, S.L.; Sharma, P.C.; Sharma, S.K.; Batra, V.; Kumar, V.; Rao, L.V.S. Effect of salinity and use of stress indices of morphological and physiological traits at the seedling stage in rice. Indian J. Exp. Biol. 2016, 54, 843–850.
10. Ali, M.N.; Yeasmin, L.; Gantait, S.; Goswami, R.; Chakraborty, S. Screening of rice landraces for salinity tolerance at seedling stage through morphological and molecular markers. Physiol. Mol. Biol. Plants 2014, 20, 411–423.

11. Chang, J.; Cheong, B.E.; Natera, S.; Roessner, U. Morphological and metabolic responses to salt stress of rice (Oryza sativa L.) cultivars which differ in salinity tolerance. Plant Physiol. Biochem. 2019, 144, 427–435.
12. Gregorio, G.B.; Dharmawansa, S.; Mendoza, R.D. Screening Rice for Salinity Tolerance; IRRI Discussion Paper Series NO.22; International Rice Research Institute: Manila, Philippines, 1997; pp. 2–23.
13. Van Zelm, E.; Zhang, Y.; Testerink, C. Salt tolerance mechanisms of plants. Annu. Rev. Plant Biol. 2020, 71, 1–31.
14. Ganie, S.A.; Molla, K.A.; Henry, R.J.; Bhat, K.V.; Mondal, T.K. Advances in understanding salt tolerance in rice. Theor. Appl. Genet. 2019, 132, 851–870.
15. Abdelbagi M. Ismail; Sigrid Heuer; Michael J. Thomson; Matthias Wissuwa; Genetic and genomic approaches to develop rice germplasm for problem soils. *Plant Molecular Biology* **2007**, *65*, 547-570, 10.1007/s11103-007-9215-2.
16. Shivani Saini; Navdeep Kaur; Pratap Kumar Pati; Reactive oxygen species dynamics in roots of salt sensitive and salt tolerant cultivars of rice. *Analytical Biochemistry* **2018**, *550*, 99-108, 10.1016/j.ab.2018.04.019.
17. Fernando, L.H.; The performance of salt resistant paddy, Pokkali in Ceylon. *Trop. Agric.* **1949**, *105*, 124–126.
18. Ghose, R.L.M.; Butany, W.T. Botanical improvement of varieties-general characters of Indian varieties and the application of genetics to rice improvement. Proc. Indian Acad. Sci. Sect. B 1959, 49, 287–302.
19. Yeo, A.R.; Flowers, T.J. Salinity resistance in rice (Oryza sativa L.) and a pyramiding approach to breeding varieties for saline soils. Aust. J. Plant Physiol. 1986, 13, 161–173.
20. Fageria, N.K. Salt tolerance of rice cultivars. Plant Soil 1985, 88, 237–243.
21. Akbar, M.; Yabuno, Y.; Nakao, S. Breeding for saline resistant varieties of rice. I. Variability for salt-tolerance among some rice varieties. Jpn. J. Breed. 1972, 22, 277–284.
22. Fageria, N.K.; Barbosa, M.P.; Gheyi, H.R. Tolerance of rice cultivars to salinty tolerance. Pesqui. Agropecu. Bras. 1981, 16, 677–681.
23. Bernstein, A.L.; Hayward, H.E. Physiology of salt tolerance. Annu. Rev. Plant Physiol. 1958, 9, 25–46.
24. Heenan, D.P.; Lewin, L.G.; Mccaffery, D.W. Salinity tolerance in rice varieties at different growth stages. Aust. J. Exp. Agric. 1988, 28, 343–349.

25. Sun, M.F.; Yan, G.H.; Wang, A.M.; Zhu, G.Y.; Tang, H.S.; He, C.X.; Ren, Z.L.; Liu, K.; Zhang, G.Y.; Shi, W.; et al. Research progress on the breeding of salt-tolerant rice varieties. Barley Cereals Sci. 2017, 34, 1–9.
26. Wang, C.L.; Zhang, Y.D.; Zhao, L.; Lu, K.; Zhu, Z.; Chen, T.; Zhao, Q.Y.; Yao, S.; Zhou, L.H.; Zhao, C.F.; et al. Research status, problems and suggestions on salt-alkali tolerant rice. China Rice 2019, 25, 1–6.
27. Platten, J.D.; Egdane, J.A.; Ismail, A.M. Salinity tolerance, Na+ exclusion and allele mining of HKT1;5 in Oryza sativa and O-glaberrima: Many sources, many genes, one mechanism? BMC Plant Biol. 2013, 13, 32.
28. Rahman, M.A.; Thomson, M.J.; Shah-E-Alam, M.; De Ocampo, M.; Egdane, J.; Ismail, A.M. Exploring novel genetic sources of salinity tolerance in rice through molecular and physiological characterization. Ann. Bot. Lond. 2016, 117, 1083–1097.
29. Risheng Chen; Yunfeng Cheng; Suying Han; Ben Van Handel; Ling Dong; Xinmin Li; Xiaoqing Xie; Whole genome sequencing and comparative transcriptome analysis of a novel seawater adapted, salt-resistant rice cultivar – sea rice 86. *BMC Genomics* **2017**, *18*, 1-11, 10.1186/s12864-017-4037-3.