Research Article

Response of Seventeen Advance Rice Lines to Salinity and Sodicity

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Abstract | Rice is considered one of the most salt sensitive cereals, however, a great genetic diversity exists within rice species for salinity tolerance. Therefore, a study was executed to identify salinity tolerance of seventeen advance rice lines based on of agronomic characters and Na and K contents. Advance lines of rice namely, SRI-22, SRI-23, SRI-24, SRI-25, SRI-26, SRI-27, SRI-28, SRI-29, SRI-30, SRI-31, SRI-32, SRI-33, SRI-34, SRI-35, SRI-36, SRI-37, and SRI-38 were transplanted in cemented block at electrical conductivity of soil extract (EC_e) 6 dS m^{-1} and sodium adsorption ratio (SAR) 25. Data about plant height, shoot fresh/dry weight, root fresh/dry weight, panicle length, No. grain/ panicle, No. of tillers/plant, grain yield and 1000 grain weight were recorded at maturity while Na and K contents were determined in leaves. Overall results revealed that SRI-23 and SRI-28 showed better performance than all other genotypes and produced comparatively better plant height, shoot fresh/dry weight, root fresh/dry weight, 1000 grain weight, grain yield, with low leave's Na and high K contents. On contrary, the performance of SRI-38 and SRI-24 was poor for these attributes. It was concluded that SRI-23 and SRI-28 were comparatively salt tolerant, while SRI-38 and SRI-24 were salt sensitive genotypes. These findings are significant and could be used to bring the salt-affected area under rice culture.

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Introduction

Among the abiotic environmental stressors, soil salinity is one of the major constraints to crop productivity and continue to increase at an alarming rate due to climate uncertainties. Approximately, 77 million ha of cultivable land have been degraded by salt stress in the world (Munns and Tester, 2008), with an annual loss of US$110,000 million (Joshi *et al*., 2015). Globally, Asia has the largest salt affected area of 24.31% (Gerona *et al*., 2019), posing a great threat to food security for increasing population. This situation attracts many researchers to work for the efficient and economical utilization of salt stress areas by improving salt-tolerant plant species. Rice (*Oryza sativa* L.) serve as the staple food of about

50% of the world's population (Lafitte *et al*., 2004) and is susceptible to salt stress with a yield loss of 10% and 50% at 3 and 7 dS m^{-1} respectively (Umali, 1993). According to Vinod *et al*. (2013), Asian rice (*Oryza sativa*) is more susceptible and a significant yield loss occurs as a consequence of high soil salinity whereas this yield loss may reach up to 50% in salt sensitive rice cultivars (Selamat and Ismail, 2008). However, a great genetic diversity exists within traditional rice species for salinity tolerance (Raja Babu *et al*., 2005) that provides a tremendous opportunity to plant breeders to induce salinity resistance in rice. The selection of different rice cultivars based on their agronomic performance in relation to salt stress is one of the principal tasks of plant scientists to exploit the genetic diversity for the development of salt tolerant rice varieties. Moreover, the selection of salt tolerant rice genotypes is a valuable and feasible approach due to its scalability and rapidity (Bhowmik *et al*., 2009) because cultivation of such tolerant genotypes will be an effective strategy to bring the salt-affected area under rice production (Shereen *et al*., 2005).

Previously, physiological screening of rice genotypes has identified the highly salt tolerant line i.e., FL478 and Pokkali (Thomson *et al*., 2010). Aala and Gregorio (2019) evaluated the seedling performance of 688 traditional rice varieties in salt stress environment. On the basis of biomass production and K and Na uptake, 44 accessions outperformed and produced significantly higher biomass and Na: K ratios than the other genotypes. In a field experiment, Anshori *et al*. (2021) studied the agronomic characters of 56 rice lines. They reported that 24 lines have good agronomic characters like grain yield and number of productive tillers, and adaptive to salinity environment. Hakim *et al*. (2014) investigated the salinity tolerance of eight rice cultivars (BRRI dhan 29, MR33, MR52, MR211, MR232, MR219, IR20, and Pokkali) to four salinity levels (0, 4, 8 and 12 dS m^{-1}). They reported the IR20 and BRRI dhan 29 as salt susceptible while MR211 and MR232 as salt tolerant varieties. Murtaza *et al*. (2009) evaluated the growth and yield performance of seven rice cultivars i.e., Shaheen Basmati, PB-95, KS-282, SSRI-8, SSRI-13, IRRI-6 and IRRI-9 against different levels of salinity (0.9, 4, 8, 12 dS m^{-1}) and sodicity (1.5, 8, 16, 24, 32 and 48 SAR) in pots. Results revealed that maximum productive tillers and paddy yield were produced by SSRI-8. Razzaque *et al*. (2011) studied the mineral distribution in seven rice genotypes namely, NS15, Pokkali, PVSB19, PNR519, PVSB9, PNR381, and Iratom 24 which were subjected to salinity levels of (0, 3, 6, 9, 12 and 15 dS m^{-1}). Results showed that concentration of Na was significantly lowered in Pokkali, PVSB9, and PNR381 than salt sensitive genotype (NS15). Similarly, the maximum K contents were observed in PVSB9 which decreased with salinity stress. De Leon *et al*. (2015) studied the performance of 49 rice genotypes to electric conductivity of 12 dS m^{-1}. Results based on agronomic attributes and Na, and K contents revealed genotypes R609, Geumgangbyeo and TCCP266 as the novel and useful source of salinity tolerance for future rice breeding program.

Therefore, this experiment was executed to identify salinity tolerance of advance rice lines on the basis of good agronomic characters and Na and K contents, to recommend a suitable rice line for cultivation in salt stress conditions.

Materials and Methods

This study was executed at Soil Salinity Research Institute, Pindi Bhattian Pakistan (altitude 184 m, latitude 31.8950° N and longitude 73.2706° E) during 2018. The average weather conditions were minimum temperature (20.6±2.8°C), maximum temperature (42.7±2.5°C), minimum relative humidity (20.5±4.5%), maximum relative humidity (72.6 ± 3.5%), maximum sunshine hours, 14 h and 10 min, and minimum sunshine hours, 11 h and 11 min. A normal soil was collected and analyzed for EC_e (1.25 dS m^{-1}), pH_s (7.50), SAR (1.37) texture (sandy loam), organic matter (0.66%), available phosphorus (19.2 mg kg^{-1}), and available potash (120 mg kg^{-1}) following the method of U.S. Salinity Laboratory Staff (1969). Desired level of SAR (25) and EC_e (6 dS m^{-1}) was developed artificially with NaCl, Na_2SO_4, $CaCl_2$, $MgSO_4$ salts using quadratic equation (Ghafoor *et al*., 1988). After developing the desired levels of EC_e and SAR, soil was filled in cemented blocks (720 cm length×480 cm wide×90cm height). Twenty-five days old seedlings of 17 advance lines of rice namely, SRI-22, SRI-23, SRI-24, SRI-25, SRI-26, SRI-27, SRI-28, SRI-29, SRI-30, SRI-31, SRI-32, SRI-33, SRI-34, SRI-35, SRI-36, SRI-37, SRI-38 were transplanted during 1st week of July in cemented blocks keeping row to row and plant to plant distance of 22.5 cm. Experimental design was completely randomized design (CRD) having three replications. Fertilizers at the rates of N 110, P 90, and K 60 kg ha^{-1} in the form of urea, single superphosphate and sulphate of potash were used. All the agronomical practices and plant protection measures were conducted uniformly. At physical maturity, data about plant height, shoot fresh/dry weight, root fresh/dry weight, panicle length, No. grain $panicle^{-1}$, No. of tillers $plant^{-1}$, grain yield and 1000 grain weight were documented. Crop was harvested during 2nd week of November. Leaves Na and K contents were also determined using flame photometer (Digi flame code DV 710) by adopting standard protocol of U.S. Salinity Laboratory Staff (1969). The collected data were subjected to analysis of variance according to Steel *et al.* (1997) to calculate the least significant differences (LSD) among treatments means at 5% probability level using STATISTIX 8.1 package software. To assess the salinity tolerance of rice lines because of agronomical attributes and leaves ionic concentration, a scoring system was used from 1-17 for each parameter (Ahmed *et al*., 2012). The line with the best performance for a parameter was awarded 17 scores and the line with the poorest performance for a parameter was awarded 1. The rice line with maximum scores was ranked as a salt tolerant and the line with minimum scores was ranked as salt susceptive line.

Results and Discussion

Effect of salinity and sodicity on growth parameters of rice lines

Data regarding the growth parameters (Table 1) showed a significant genotypic difference among 17 advance rice lines in saline-sodic conditions. Concerning the plant height, maximum value (161.23 cm) was divulged in SRI-23 followed by SRI-28. Whereas, minimum plant height (102.33 cm) was produced by SRI-25 at EC of 6 dS m^{-1} and SAR of 25. The maximum shoot fresh weight of 178.81 g was produced by SRI-28 followed by SRI-23. Only, SRI-26, SRI-27 and SRI-22 had statistically significantly *($P < 0.05$)* lower shoot fresh weight than all other advance lines. Similarly, maximum shoot dry weight (44.98 g) was recorded in SRI-28 and the minimum shoot dry weight (26.31 g) was noted in SRI-22. The maximum root fresh (27.42 g) and dry (9.02 g) weights were produced by SRI-23. While minimum root fresh (12.13 g) and dry (3.38 g) weights were produced by SRI-24.

Table 1: *Effect of salinity and sodicity on growth parameters of rice lines.*

Treatments	Plant height	Shoot fresh weight	Shoot dry weight	Root fresh weight	Root dry weight
SRI-22	137.67 D	96.55 C	26.31 B	13.11 C	3.43 B
SRI-23	161.23 A	171.28 AB	40.78 AB	27.42 A	9.02 A
SRI-24	147.80 B	171.17 AB	40.58 AB	12.13 C	3.38 B
SRI-25	102.33 J	174.04 A	42.31 AB	24.35 ABC	6.77 AB
SRI-26	121.77 E	101.51 BC	29.74 AB	24.30 ABC	3.84 B
SRI-27	121.07 E	100.89 BC	27.63 B	23.55 ABC	6.77 AB
SRI-28	148.71 B	178.81 A	44.98 A	25.54 AB	6.77 AB
SRI-29	113.67 F	171.17 AB	31.41 AB	22.74 ABC	6.68 AB
SRI-30	111.33 HI	171.15 AB	40.53 AB	21.23 ABC	6.64 AB
SRI-31	113.17 FG	169.88 AB	39.57 AB	21.02 ABC	6.43 AB
SRI-32	111.87 GH	153.66 ABC	39.09 AB	20.72 ABC	5.88 AB
SRI-33	110.27 I	146.92 ABC	37.80 AB	20.69 ABC	5.82 AB
SRI-34	147.53 B	140.57 ABC	35.99 AB	20.32 ABC	5.63 AB
SRI-35	113.67 F	139.67 ABC	34.44 AB	17.11 ABC	5.51 AB
SRI-36	142.00 C	128.91 ABC	33.83 AB	16.13 ABC	5.22 AB
SRI-37	141.33 C	128.90 ABC	33.68 AB	16.04 ABC	4.61 B
SRI-38	112.53 FGH	120.52 ABC	33.27 AB	14.18 BC	4.27 B
LSD	1.3518	72.238	16.923	12.294	4.0910

Table 2: *Effect of salinity and sodicity on yield and yield characteristics of rice lines.*

Treatments	No. of tillers plant^{-1}	Panicle length	No. of grains panicle^{-1}	1000 grain weight (g)	Grain yield (t ha^{-1})
SRI-22	22.00 F	31.33 CD	112.00 GHI	24.66 D	2.70 EFG
SRI-23	31.00 A	35.53 A	141.67 A	32.66 A	3.60 A
SRI-24	12.33 J	24.53 I	97.33 J	24.00 D	2.46 FGH
SRI-25	27.33 BC	32.46 BC	128.3 BC	29.33 B	3.46 ABC
SRI-26	17.66 G	30.83 DE	112.33 GH	24.66 D	2.06 H
SRI-27	26.66 BC	30.93 DE	115.00 FGH	24.33 D	3.33 ABCD
SRI-28	30.66 A	34.53 A	131.67 B	30.66 AB	3.50 AB
SRI-29	23.00 EF	29.33 F	119.33 DEF	25.00 CD	2.61 EFGH
SRI-30	21.33 F	30.33 DEF	123.00 CDE	27.00 C	2.76 DEFG
SRI-31	16.33 GH	33.00 B	117.00 DEFG	26.00 CD	3.00 BCDEF
SRI-32	14.00 IJ	25.90 H	105.33 I	24.66 D	2.46 FGH
SRI-33	27.66 B	29.46 F	116.67 DEFG	25.66 CD	2.66 EFG
SRI-34	25.33 CD	29.66 EF	116.33 EFG	25.66 CD	2.70 EFG
SRI-35	25.33 CD	33.06 B	120.33 DEF	24.33 D	2.90 CDEF
SRI-36	24.33 DE	31.50 CD	120.67 DEF	25.66 CD	2.54 FGH
SRI-37	26.33 BCD	27.80 G	123.33 CD	25.33 CD	3.13 ABCDE
SRI-38	15.00 HI	27.50 G	108.33 HI	25.33 CD	2.30 GH
LSD	2.0521	1.3426	6.7502	2.2165	0.5758

Effect of salinity and sodicity on yield and yield characteristics of rice lines

Data for the yield and yield characteristics (Table 2) showed that there was a significant variation for these parameters of 17 advance rice lines under salinity (6 dSm^{-1}) and sodicity (SAR 25). SRI-23 showed maximum (31.00) number of tillers per plant^{-1} statistically similar to SRI-28. On the other hand, minimum number of tillers (12.33) were produced by SRI-24. With respect to panicle length, maximum length of 35.53 cm was produced by SRI-23, while the minimum panicle length (24.53 cm) was observed in SRI-24, whereas all the other genotypes were found between these two genotypes in respect of panicle length. Likewise, maximum 1000 grain weight (32.66 g) and No. of grains panicle^{-1} (141.67) were indicated by SRI-23 and minimum 1000 grain weight (24.0 g) and No. of grains panicle^{-1} (97.33) were recorded by SRI-24. Data about grain yield showed that genotype SRI-23 resulted in maximum grain yield of 3.60 t ha^{-1} that was statistically non-significant with SRI-25, SRI-27, SRI-28, and SRI-37. While the minimum grain yield of 2.06 was recorded by SRI-26.

Effect of salinity and sodicity on leaves ionic concentration of rice lines

Data about the ionic concentration in leaves revealed that maximum Na (1.40%) was accumulated by SRI-24 which was at par with SRI-27 and SRI-38 (Figure 1). At the same time, minimum Na contents were found in the leaves of SRI-23. Whereas, an opposite trend was noted for K uptake (Figure 2). The maximum K contents (2.33%) were observed in the leaves of SRI-23 and the minimum K contents (0.9%) were recorded by SRI-32, while, the values in all the other genotypes fell between these two genotypes.

The current study explored the response of 17 advance rice lines under the dual stress of salinity (6 ds m^{-1}) and sodicity (SAR 25) as well as identified the salt susceptible and tolerant lines based on their growth and yield attributes and salinity tolerance indices like Na and K uptake. A scoring system was also developed to select the salt susceptible and tolerant genotypes based on the performance of each genotype under salinity and sodicity (Ahmed *et al*., 2012). The scores of each genotype for agronomical and yield indices are shown in Table 3. Based on the current scoring system, maximum scores were awarded to SRI-23 followed by SRI-28 that were declared as salt tolerant, while on the contrary minimum scores were awarded to SRI-38 and SRI-24 which regarded as salt sensitive genotypes. The result of current study revealed a significant genotypic variation for salinity tolerance among 17 advance lines of rice and maximum value for plant height and shoot fresh/dry

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Table 3: *The ranking of rice lines based on of their growth, yield and leaf ionic composition.*

TR.	PH	SFW	SDW	RFW	RDW	NOT	PL	NOGP	TGW	GY	S Na	SK	Total
SRI-22	11	1	1	2	2	7	11	4	6	9	13	4	71
SRI-23	17	15	15	17	17	17	17	17	17	17	17	17	200
SRI-24	15	14	14	1	1	1	1	1	1	3	1	1	54
SRI-25	1	16	16	15	16	14	13	15	15	15	15	15	166
SRI-26	10	3	3	14	3	5	9	5	4	1	6	5	68
SRI-27	9	2	2	13	15	13	10	6	2	14	3	6	95
SRI-28	16	17	17	16	14	16	16	16	16	16	16	16	192
SRI-29	7	13	4	12	13	8	5	10	7	6	9	7	101
SRI-30	3	12	13	11	12	6	8	13	13	10	4	9	114
SRI-31	6	11	12	10	11	4	14	9	5	12	14	8	116
SRI-32	4	10	11	9	10	2	2	2	12	4	2	2	70
SRI-33	2	9	10	8	9	15	6	8	11	7	7	12	104
SRI-34	14	8	9	7	8	11	7	7	3	8	10	13	105
SRI-35	8	7	8	6	7	10	15	11	10	11	11	14	118
SRI-36	13	6	7	5	6	9	12	12	9	5	12	10	106
SRI-37	12	5	6	4	5	12	4	14	8	13	8	11	102
SRI-38	5	4	5	3	4	3	3	3	13	2	5	3	53

PH: plant height; SFW: shoot fresh weight; SDW: shoot dry weight; RFW: root fresh weight; RDW: root dry weight; NOT: No. of tillers; PL: panicle length; NOGP: No. grain/ panicle; TGW: thousand grain weight; GY: grain yield; LNa: leaves Na; LK: leaves K.

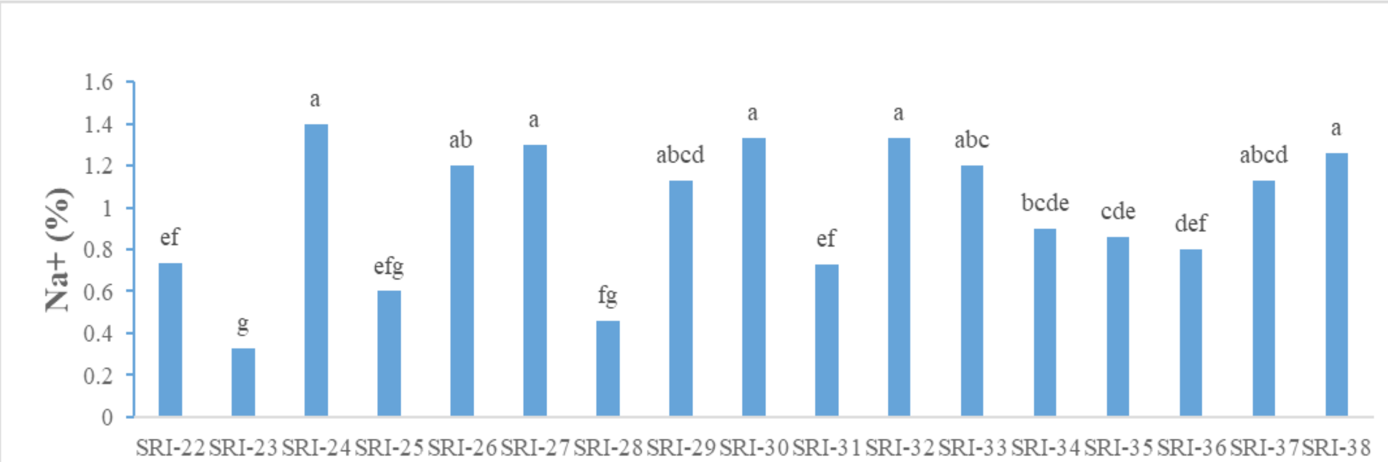

Figure 1: *Effect of salinity and sodicity on leaves Na⁺ (%) contents of rice lines.*

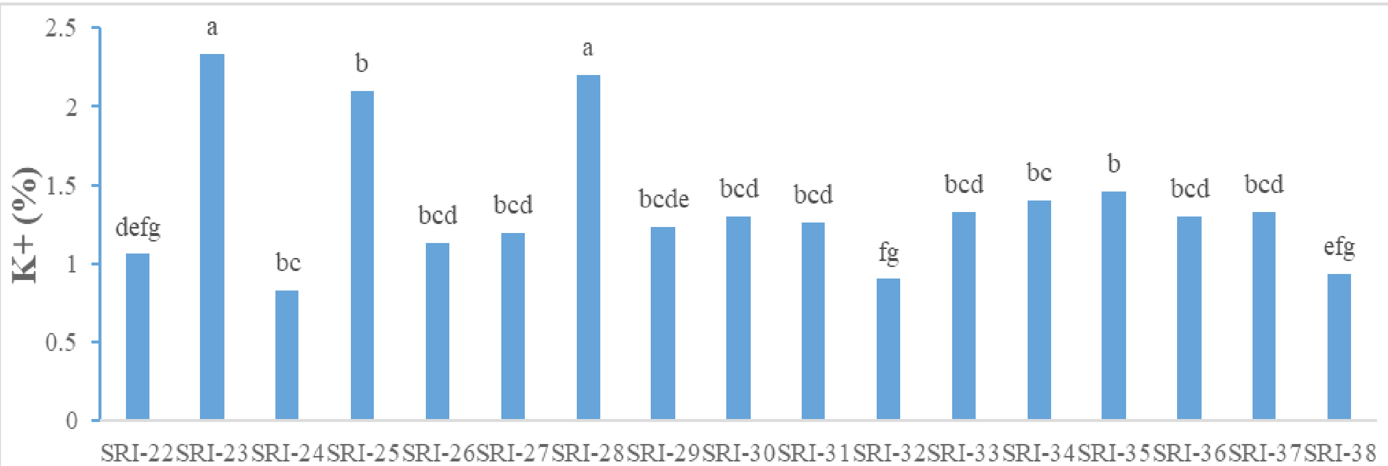

Figure 2: *Effect of salinity and sodicity on leaves K^+ (%) contents of rice lines.*

weights were divulged by SRI-23. At seedling stage of a crop, agronomical characteristics (shoot fresh/dry weights and plant height) are usually linked with salinity tolerance and could be employed as screening or selection tool for characterization of genotypes in relation to salt stress (Larcher, 1995). The primary effect of hyper salinized environment is osmotic imbalance that hinders the normal intake of water by roots resulting in poor development of tissue and plant height so as shoot fresh/dry weights are reduced consequently (Reddy *et al*., 2017). Additionally, excessive uptake of toxic ions in saline environment caused the nutritional imbalance and injured the plant cells, consequently reducing the plant growth (Hasan and Miyake, 2017). Similarly, Aala and Gregorio (2019) also screened the 688 traditional rice varieties for salinity tolerance. They observed a significant genetic diversity among genotypes in the terms of biomass yield, plant height, Na: K ratio and 44 genotypes were scored as salt tolerant.

It is most widely accepted that Na: K ratio is an important salinity resistant mechanism. According to Hniličková *et al*. (2019), salt resistant genotypes avoid the accumulation of toxic Na either by excluding Na from newly expanding leaves or reducing its uptake by roots. In the present study, a significant difference for leaves Na and K was observed among 17 rice genotypes, the minimum leaves Na was accumulated by SRI-23 due to which its performance was better than all other genotypes, on the other hand, maximum Na was accumulated by SRI-38 and its performance was poor than all other genotypes. At the same time, an inverse trend was noted for K because maximum leaves K was accumulated by SRI-23 and minimum K was observed in the leaves of SRI-38. It has been reported that excessive sodium is metabolically toxic to plants and affects the survival and growth of rice plants which decreased grain yield and productive tillers (Mel *et al*., 2018). In the salinized environment, high uptake of K and low Na is positively correlated to salinity tolerance. Preferential uptake of K over Na among the different genotypes is useful salinity tolerance criteria (Mel *et al*., 2018). K worked as a co-factor for more than 50 enzymes that may be susceptible to high Na (Munns and Tester, 2008). Current findings are in harmony with that of Rahman *et al*. (2016) who observed that rice genotype Akundo was protected from osmotic damage by accumulating less Na in its leaves. The plant root is an organ that has direct contact with growing medium and supply all the essential nutrients to growing regions of plant. However, salinity stress in rhizosphere adversely affected root growth (Chartzoulakis and Klapaki, 2000). Therefore, root growth is especially important criterion for salinity tolerance (Ahmed *et al*., 2012). Root growth of SRI-23 was better than all other genotypes while SRI-24 produced minimum root fresh and dry weight. Yield supporting attributes like number of filled grains, productive tiller and, 1000 grain weight are effective benchmarks to identify salt tolerant genotypes (Anshori *et al*., 2021). Seventeen rice genotypes used in current study also exhibited the variability of the responses to dual stress of salinity and sodicity in terms of yield and yield components. Maximum 1000 grain weight, tiller plant^{-1}, grain panicle^{-1} and grain yield were divulged in SRI-23 followed by SRI-28 while the minimum values for these attributes were observed in SRI-24 and SRI-38 suggesting that these attributes are genotypic-specific, and SRI-23 has considerable adaptation to salinity stress. Rice is reported as salt sensitive cereals (Munns and Tester, 2008) with a yield loss of 10% at 3 dS m^{-1} and 50% yield loss at 7 dS m^{-1} (Umali, 1993). Salinity tolerance is a complex phenomenon involving numerous factors e.g., minimum Na uptake by the root, compartmentalization of Na in vacuoles at cellular level (Munns and Tester, 2008), and exclusion of toxic ions from leaves (Adem *et al*., 2014). The present study also showed that low Na and high K were observed in SRI-23 and vice versa in SRI-24 and SRI-38. In rice, the salinity tolerance mechanism is genotypic-specific and depends upon the different capability of each genotype to exclude the Na from shoot (Platten *et al*., 2013). Exclusion of toxic Na, and higher uptake of K conserve the normal functioning of photosynthesis and tissue growth (Yamane *et al*., 2009). Similarly, Gerona *et al*. (2019) reported a considerable genetic variation among six rice varieties at the reproductive stage in salt affected soil. On the basis of Na exclusion and to conserve better K: Na ratio, they recommended the line IR670 as most salt tolerant genotypes. Earlier studies also suggest that response of rice in saline conditions is dependent on genotypes and growth stage (Kanawapee *et al*., 2013; Hakim *et al*., 2014). Current findings are in conformity with those of Thomson *et al*. (2010) who identified the putative salt tolerant cultivars like Pokkali and FL478 on the basses of physiological and genetic screening.

Conclusions and Recommendations

In current experiment, seventeen advance rice lines were screened to dual stress of salinity (6 dS m^{-1}) and sodicity (SAR 25). On the basis of agronomical characters and quantum of Na and K uptake; SRI-23 and SRI-28 showed better performance than all other genotypes. Therefore, it was concluded that SRI-23 and SRI-28 were comparatively salt tolerant, while SRI-38 and SRI-24 were salt sensitive genotypes. These findings are significant and could be used to bring the salt-affected area under rice cultivation.

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Novelty Statement

Out of seventeen advance rice lines, SRI-23 and SRI-28 outperformed and were found comparatively salt tolerant, while SRI-38 and SRI-24 were salt sensitive genotypes. These findings are significant and could be used to bring the salt-affected area under rice cultivation.

Author's Contribution

MKB, GS and MI conducted the study. KA, MS, MQN, AIS, GQ, MR and MFN did data collection and statistical analysis. MAA, AW, HR and ND provided the technical input.

Conflict of interest

The authors have declared no conflict of interest.

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