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Evaluation of Physiological and Biochemical Traits in Relation to Sodicity Tolerance in Selected Rice Genotypes under Different Sodicity Levels

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ABSTRACT

Background: Soil sodicity is becoming a serious problem which is increasing every year has a negative impact the physical and nutritional qualities of the soil and plant which has an immense adverse effect on crop growth. Sodicity tolerance includes the manifestation of biochemical and physiological variations. Understanding these physiological and biochemical mechanism in rice is one of the biological solution for increasing the yield of crops through increased tolerance mechanism.

Methods: A field experiment was conducted at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli, Tamil Nadu to evaluate the performance of different rice varieties *i.e.*, TRY 1, CO 43, TRY 2, CSR 27, TRY 3, white ponni (WP) with particular reference to Exchangeable Sodium Percentage (ESP) at various levels *viz*., ESP 8, 16, 24, 32, 40 and 48 and its impact on physiological and biochemical components. Plant samples were collected at flowering stage was analyzed for chlorophyll, sugars and proline content. Grain and straw yield of the crop was recorded.

Result: The Chlorophyll and non-reducing sugars showed decreasing trend with increasing ESP levels but proline, reducing sugar *and* total sugar showed an increasing trend with increasing sodicity levels. The variation in biochemical and physiological components had significantly affected the growth and yield of rice crop. Among different rice varieties TRY 3 was found to be superior at increasing sodicity levels.

Key words: Chlorophyll, Exchangeable sodium percentage, Non-reducing sugars, Proline, Reducing sugars.

INTRODUCTION

Soil sodicity is a common abiotic stress related to the space and time which may cause severe land degradation that notably affects the growth and development of agricultural crop production worldwide. In India a total of 6.73 million hectare was salt affected soils out of which 2.8 million hectare are sodic in nature. Tamil Nadu contributes about 0.36 million hectare in which a dominant portion of 0.35 million hectares are sodic and 0.01 million hectares falls under saline soil (Sharma *et al*., 2004).

Salt stress can inhibit crop growth and yield in three different ways, by reducing osmotic potential 1) enhancing ion toxicity 2) Alterations in ion absorption and 3) Disrupting ion balance (Murphy and Durako, 2003). These processes reduce physiological processes and eventually crop growth and yield (Sairam and Tyagi, 2004). Tripathi *et al.* (2018) reported that the biochemical components increased in salt tolerant rice varieties and decreased in susceptible varieties under salt stress. Therefore, an attempt was made to study the evaluation of selected salt tolerant rice genotypes for yield, physiological and biochemical traits under different sodicity levels.

MATERIALS AND METHODS

The field experiment was conducted during late samba season at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirappalli during 2022-2023. The experimental design used here was strip plot design with two replications with six different ESP levels *i.e.*, 8, 16, 24, 32, 40 and 48 with six different rice varieties. Totally six rice varieties were selected *i.e.*, TRY 1, CO 43, TRY 2, CSR 27, TRY 3 and WP. The plant samples were collected at the flowering stage and were subjected to analysis for

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Chlorophyll a, chlorophyll b, total chlorophyll, reducing sugars, non-reducing sugars, proline, soluble protein and lipid peroxidation content. The grain and straw yield were recorded at harvest.

Chlorophyll content

Standard procedure given by Arnon (1949) was followed for chlorophyll estimation. The absorbance was measured at 645, 663 and 652 nm and calibrated.

Reducing, non-reducing and total sugars

The reducing sugar was determined using DNSA (Dinitrosalicylic acid) method of Miller (1972) and the absorbance were read at 530 nm calculated using glucose as a standard. Total sugars were estimated using the phenol-sulfuric method (Dubois *et al*., 1956). By subtracting the total sugar minus reducing sugar non-reducing sugar content in the sample was determined.

Proline content

Proline content was estimated using the method given by Bates *et al.* (1973), using spectrophotometer the absorbance was read at 520 nm.

Statistical analysis

The design used for field experiment is strip plot design. Various statistical analysis of the data like mean, maximum value, minimum value, ANOVA table at 95% confidence level *i.e*., 0.5% significant level was analyzed by using software SPSS. Post hoc test was done by LSD to test the significant level. The data results were interpreted on main plot (ESP levels), subplot (Varieties) and main plot*subplot.

RESULTS AND DISCUSSION

Grain yield

The different ESP level had significant effect on grain yield of rice crop. The grain yield decreases with increasing sodicity levels. The mean grain yield of different rice varieties at different sodicity levels *i.e*., ESP 8, ESP 16, ESP 24, ESP 32, ESP 40 and ESP 48 recorded 5434, 5204, 4477, 2343, 1659 and 947 kg ha^{-1}, respectively (Table 1). Among the rice varieties, the grain yield was found to be significantly different. The maximum grain yield was recorded in TRY 3 (4693 kg ha^{-1}) followed by CO 43 (3393 kg ha^{-1}), TRY 1 (3437 kg ha^{-1}), TRY 2 (3134 kg ha^{-1}), CSR 27 (3161 kg ha^{-1}) and the minimum yield recorded in susceptible variety WP (2246 kg ha^{-1}). At different ESP levels, different rice varieties exhibit the sodicity tolerance differently in view of grain yield. As compared to ESP 8, TRY 3 variety produced atleast 50% yield upto 32 ESP. However, in case of WP, 50% yield was recorded upto 16 ESP. Further, 50% yield was recorded upto 24 ESP in case of TRY 1, CO 43, TRY 2 and CSR 27. Due to sensitivity of WP variety, the yield has a substantially reduced at higher sodicity levers. Due to sensitivity of rice crop to salt stress, the grain production of rice crop in salt-affected soils is much declined (Gao *et al.,* 2007).

Straw yield

A significant difference was observed in straw yield at different ESP levels. The mean straw yield at different sodicity levels recorded highest at ESP 8 (8097 kg ha^{-1}) followed by ESP 16, ESP 24, ESP 32 and ESP 40 *viz*., 7751, 6902, 3801 and 2613 kg ha^{-1}, respectively (Table 1). The lowest straw yield was recorded at ESP 48 (2082 kg ha^{-1}). Coherently, the mean value of different rice varieties showed significant difference in straw yield *ie*., TRY 1, CO 43, TRY 2, CSR 27, TRY 3 and WP recorded straw yield of 5445, 5497, 4633, 4726, 7249 and 3696 kg ha^{-1}, respectively. Interaction between different rice varieties at various ESP levels was also significant. Comparing ESP 8 with ESP 32 a reasonable straw yield nearly 50% of is achieved in all tolerant rice varieties whereas in susceptible variety WP 50% yield was found only upto ESP 24. However, TRY 3 rice variety stands superior among the different rice varieties experimented at all ESP levels. The results are in consistent with Flowers and Yeo (1989).

Chlorophyll content

The data pertaining chlorophyll a, chlorophyll b and total chlorophyll at flowering stage of different rice varieties were presented in Table 2.

Table 1: Effect of different ESP levels on Grain and straw yield (kg ha^{-1}) in different rice varieties.

ESP	Grain yield							Straw yield						
levels	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean
8	5135	5725	4970	5255	6900	4620	5434	7754	8644	7132	7805	10362	6884	8097
16	5055	5275	4900	5100	6885	4010	5204	7786	7992	7350	7395	9548	6432	7751
24	4815	4480	4355	4705	6220	2285	4477	7295	6899	6446	7338	9280	4154	6902
32	2465	2325	2157	2020	4035	1055	2343	4492	3581	3441	3151	6194	1945	3801
40	1925	1860	1522	1043	2745	856	1659	3170	3103	1807	1548	4571	1478	2613
48	961	955	901	841	1370	652	947	2174	2765	1619	1118	3538	1280	2082
Mean	3393	3437	3134	3161	4693	2246		5445	5497	4633	4726	7249	3696	
	ESP levels		Variety		ESP×Variety			ESP levels		Variety		ESP×Variety		
SEm±	83.43		145.90		134.59			98.6		173		159		
CD	214.50*		375.11*		277.26*			224*		396*		354*		

*Significant at (P≤0.05%).

Chlorophyll a

The chlorophyll a content significantly decreases with increasing ESP levels. Among the mean of different ESP levels, ESP 8 recorded the highest chlorophyll a content of 1.62 mg g^{-1} followed by ESP 16, ESP 24, ESP 32, ESP 40 *i.e.*, 1.57, 1.50, 1.42, 1.31 mg g^{-1} and the lowest content at ESP 48 (1.21 mg g^{-1}). The chlorophyll a content differs significantly among the varieties. The chlorophyll a content recorded maximum in TRY 3 (1.83 mg g^{-1}) rice variety followed by TRY 1 (1.6 mg g^{-1}7), CO 43 (1.40 mg g^{-1}), TRY 2 (1.36 mg g^{-1}) and CSR 27 (1.83 mg g^{-1}). The least chlorophyll a content was observed in WP. The interaction between the different ESP levels and varieties were also found to be significantly different. The tolerant variety TRY 3 recorded reasonable chlorophyll a content upto ESP 40 followed by TRY 1, CO 43, TRY 2 and CSR 27 which also reflected in straw and grain yield. The straw and grain yield decreases with decrease in chlorophyll a content.

Chlorophyll b

Different ESP levels had significant effect on chlorophyll b content. The mean of chlorophyll b at different ESP levels *i.e.*, ESP 8, 16, 24, 32, 40 and 48 recorded 0.94, 0.84, 0.62, 0.50, 0.36 and 0.28 mg g^{-1}, respectively. In case of different rice varieties the mean value recorded 0.46, 0.70, 0.65, 0.54, 0.73 and 0.43 mg g^{-1} in TRY 1, CO 43, TRY 2, CSR 27, TRY 3 and WP, respectively. However, at higher sodicity levels the chlorophyll a content gradually decreases. The interaction between the sodicity levels and variety varied significantly. The highest chlorophyll b content was found in TRY 3 followed by CO 43, TRY 2, CSR 27, TRY 1 and the lowest in WP. Increased sodicity levels decreased the chlorophyll b content which also reflected in the yield. The grain and straw yield decreased with decreased chlorophyll b content.

Total chlorophyll

In case of total chlorophyll the data revealed that ESP 8 maintained the highest content of 2.56 mg g^{-1} followed by ESP 16 (2.41 mg g^{-1}), ESP 24 (2.12 mg g^{-1}), ESP 32 (1.92 mg g^{-1}), ESP 40 (1.68 mg g^{-1}) while ESP 48 recorded the lowest total chlorophyll content of 1.49 mg g^{-1}. Among the rice varieties the total chlorophyll recorded maximum in TRY 3 (2.55 mg g^{-1}) which is on par with TRY 1 (2.13 mg g^{-1}) followed by CO 43, TRY 2 and CSR 27. WP recorded lowest total chlorophyll content of 1.54. The interaction of ESP levels and variety was found to be significant. As the sodicity level increases the total chlorophyll content gradually decreases in TRY 3 upto ESP 48 which is found to be superior than TRY 1, CO 43, TRY 2 and CSR 27 which is also reflected in straw and grain yield. TRY 3 variety recorded highest straw and grain yield (Table 1). The chlorophyll content in tolerant varieties progressively decreased with increase in ESP levels upto 40%. In WP, a gradual decrease in total chlorophyll content was found only upto ESP 24 and drastically decreases from ESP 32 to 48.

The results of chlorophyll a, b and total content clearly indicates that the tolerant varieties manage to maintain the

Table 2: Effect of different ESP levels in soil (mg g^{-1} FW) on chlorophyll a, b and total chlorophyll content at flowering stage of different rice varieties.

ESP levels	Chlorophyll a						
	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean
8	1.80	1.53	1.54	1.49	1.95	1.38	1.62
16	1.78	1.5	1.45	1.47	1.89	1.32	1.57
24	1.75	1.47	1.44	1.39	1.85	1.11	1.50
32	1.68	1.36	1.4	1.25	1.82	1.01	1.42
40	1.59	1.31	1.15	1.13	1.77	0.92	1.31
48	1.43	1.22	1.15	1.04	1.68	0.75	1.21
Mean	1.67	1.40	1.36	1.30	1.83	1.08	
	ESP levels		Variety		ESP×Variety		
SEm±	0.032		0.05		0.00		
CD	0.082*		0.14*		0.00*		

ESP levels	Chlorophyll b						
	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean
8	0.79	1.03	0.98	0.9	1.09	0.87	0.94
16	0.65	0.91	0.87	0.82	1.01	0.8	0.84
24	0.47	0.72	0.71	0.63	0.82	0.37	0.62
32	0.4	0.61	0.62	0.41	0.6	0.33	0.50
40	0.26	0.52	0.41	0.27	0.49	0.23	0.36
48	0.21	0.39	0.33	0.21	0.36	0.17	0.28
Mean	0.46	0.70	0.65	0.54	0.73	0.46	
		ESP levels		Variety		ESP×Variety	
	SEm±	0.045		0.095		0.032	
	CD	0.116*		0.244*		0.066*	

ESP levels	Total chlorophyll						
	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean
8	2.59	2.56	2.52	2.39	3.04	2.25	2.56
16	2.43	2.41	2.32	2.29	2.9	2.12	2.41
24	2.21	2.19	2.15	2.02	2.67	1.48	2.12
32	2.08	1.97	2.02	1.66	2.42	1.34	1.92
40	1.85	1.83	1.56	1.4	2.26	1.15	1.68
48	1.63	1.6	1.48	1.25	2.03	0.92	1.49
Mean	2.13	2.09	2.01	1.84	2.55	1.54	
		ESP levels		Variety		ESP×Variety	
	SEm±	0.032		0.141		0.032	
	CD	0.082*		0.363*		0.066*	

*Significant at (P≤0.05%).

chlorophyll content under different sodicity stresses when compared to that of susceptible ones. However, the chlorophyll content decreases with increase in ESP levels. This indicates that the chlorophyll content is more sensitive to higher sodicity levels. This decreased trend in chlorophyll content may be due to the excessive accumulation sodium carbonates and bicarbonates in the soil which may lead to the inhibitory effect in rice leaves. This variation in ion concentration has a greater impact on biosynthesis of chlorophyll fractions in the leaves which may sometimes causes leaf senescence and death. Santos and Vieira Conceicao (2004), pointed out that differences in the synthesis of aminolavulinic acid, a precursor of chlorophyll and differential activity of the enzyme chlorophyllase may be the contributing factors for the decrease in chlorophyll content in the leaves of different varieties of African marigold.

Reducing, non-reducing and total sugar content

The different ESP levels have a significant effect on reducing, non-reducing and total sugars of different rice varieties (Table 3).

Reducing sugar

The reducing sugar was significantly influenced by different ESP levels and the content increased with increasing sodicity levels. ESP 48 recorded the highest reducing sugar content of 233 mg g^{-1} followed by ESP 40, ESP 32, ESP 24, ESP 16 *i.e.*, 224, 163, 144, 126 mg g^{-1}, respectively and the lowest at ESP 8 (114 mg g^{-1}). Among different rice varieties, reducing sugar recorded 198 mg g^{-1} in TRY 3 followed by TRY 1, CO 43, WP, TRY 2, CSR 27 *i.e.*, 179, 170, 162, 158 mg g^{-1}. The lowest content of reducing sugar was found in WP rice variety 136 mg g^{-1}. The interaction between the variety and sodicity levels was found to be significant. Higher reducing sugar was observed in TRY 3 rice variety at ESP 48 (282 mg g^{-1}) and lowest in WP (162 mg g^{-1}) at the ESP 48. The variation in reducing sugars also reflects in grain yield. The grain yield was higher in tolerant cultivars along with the increase in reducing sugars at higher ESP levels. The results clearly indicate that at increasing sodicity levels the reducing sugar content was increased and the magnitude of increase was higher in tolerant varieties. Comparable results were in accordance with Rajakumar (2013).

Non-reducing sugar

In non-reducing sugars, an opposite was trend observed. Increase in sodicity levels has decreased the non-reducing sugars. Different ESP levels have a significant effect on non-reducing sugars. At ESP 48 the non-reducing sugar recorded the minimum content of 53 mg g^{-1} while the maximum content was recorded at ESP 8 *i.e.*, 115 mg g^{-1} followed by ESP, 16, 24, 32 and 40 (105, 91, 78 and 65 mg g^{-1}). Among the rice varieties TRY 1, CO 43, TRY 2, CSR 27, TRY 3 and WP recorded the non-reducing sugar content of 120, 117, 110, 103, 124 and 116 mg g^{-1}, respectively. Significant difference was also observed in interaction between ESP levels and different rice varieties. The non-reducing sugar gradually

Table 3: Effect of different ESP levels on reducing sugar, non-reducing sugar and total sugar content (mg g^{-1}) in leaf of different rice varieties.

ESP	Reducing sugar							Non-Reducing sugar							Total sugar content						
levels	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean
8	118	114	108	105	126	113	114	120	117	110	103	124	116	115	238	230	218	208	250	229	229
16	132	125	116	114	143	128	126	111	106	99	96	117	103	105	243	231	214	210	260	231	231
24	155	148	135	132	169	128	144	98	93	87	83	108	81	91	253	240	222	215	276	209	236
32	182	164	156	147	195	133	163	86	75	72	68	97	68	78	268	239	228	214	292	200	240
40	238	230	226	222	273	154	224	75	67	61	60	82	46	65	313	297	287	282	354	200	289
48	251	240	234	230	282	162	233	61	56	52	49	71	31	53	312	296	286	279	353	193	286
Mean	179	170	162	158	198	136		92	86	80	76	100	74		271	256	243	235	298	210	
	ESP levels		Variety		ESP×Variety			ESP levels		Variety		ESP×Variety			ESP levels		Variety		ESP×Variety		
SEm±	2.26		1.24		2.04		SEm±	1.37		2.47		1.41		SEm±	5.51		3.10		2.45		
CD	6.53*		3.18*		4.21*		CD	3.52*		6.34*		2.90*		CD	14.2*		7.98*		5.05*		

*Significant at (P≤0.05%).

Table 4: Effect of different ESP levels on Proline ($\mu g\ g^{-1}$) content in straw of different rice varieties.

ESP	Proline						
levels	TRY-1	CO-43	TRY-2	CSR-27	TRY-3	WP	Mean
8	375	330	369	359	384	363	363
16	386	334	379	365	402	383	375
24	487	483	455	447	496	415	464
32	596	586	567	565	663	459	573
40	684	604	696	685	736	484	648
48	896	856	774	722	965	516	788
Mean	570	532	540	524	607	436	
	ESP levels	Variety	ESP×Variety				
SEm±	6.86	3.34	4.34				
CD	17.6*	8.59*	8.95*				

*Significant at ($P \leq 0.05\%$).

decreased upto ESP 32 and drastically decreased at ESP 40 and 48. In case of susceptible variety WP, the non-reducing sugar drastically decreased at ESP 24 itself. However, the tolerant varieties are able to maintain the non-reducing sugar content upto ESP 32. The reason for decrease in non-reducing sugars may be it acts as central metabolic pathways which are crucial for the formation of secondary metabolites that improve the therapeutic effects of plants (Rolland *et al*., 2002; Arsenault *et al*., 2010).

Total sugar

The total sugars increased with increasing ESP levels. The different ESP levels had a significant effect on total sugars. The mean value was found to be highest at ESP 40 (286 mg g^{-1}) followed by ESP 48, 32, 24, 16 *ie*., 286, 240, 236, 231 mg g^{-1}, respectively and lowest at ESP 8 (229 mg g^{-1}). The different rice varieties were found to be significantly different. The mean of total sugars in different rice varieties *viz*., TRY 1, CO 43, TRY 2, CSR 27, TRY 3 and WP recorded 271, 256, 243, 235, 298 and 210 mg g^{-1}, respectively. Significant difference was observed in the interaction between ESP levels and varieties. The total sugar was found highest in tolerant varieties *ie*., TRY 3, TRY 1, CO 43, TRY 2 and CSR 27 and recorded lowest in WP. The findings are comparable with Sadia Javed *et al*. (2014) that the sugar content increases when the stress in plants increased.

Proline content

The data pertaining to proline content was presented in Table 4. The proline content at different ESP levels was found to be significantly different. The mean of proline content recorded highest at ESP 48 (788 $\mu g\ g^{-1}$) continued by ESP 40, 32, 24, 16 (648, 573, 464, 375 $\mu g\ g^{-1}$) and the lowest at ESP 8 *i.e*., 363 $\mu g\ g^{-1}$. Pessarakali (1999), observed that proline accumulation is influenced by the severity of increasing stress. In rice varieties, the proline content recorded highest in TRY 3 (607 $\mu g\ g^{-1}$) followed by TRY 1 (570 $\mu g\ g^{-1}$), TRY 2 (540 $\mu g\ g^{-1}$), CO 43 (532 $\mu g\ g^{-1}$), CSR 27 (524 $\mu g\ g^{-1}$) and lowest in WP (436 $\mu g\ g^{-1}$). The interaction between ESP level and variety were significant. Under low ESP levels the proline content was found to be very low and with increasing sodicity levels, the proline content considerably increases. The proline content helps to increase the tolerance mechanism of rice crop which reflects in the straw and grain yield. The result indicated that the proline accumulation will be higher under high sodicity levels in tolerant varieties may one of the reason for its survival under stressed conditions. Cultivars *i.e*., TRY(R) 2, TRY 1 and CO 43 showed increased proline concentration and these genotypes are tolerant to salt stress by performing a positive correlation between proline and grain production (Raja Babu and Ramesh, 2007). In terms of proline content, the tolerable varieties at all observational stages CSR 36 and NDR 2009 significantly outperformed when compared to all susceptible types (Tripathi *et al*., 2018).

CONCLUSION

The sodicity stress had a diversified impact on physiological and biochemical components like chlorophyll, sugars and proline contents. As the magnitude of the sodicity levels increases the reducing sugar, total sugar and proline content also increases. However, an opposite trend was observed in chlorophyll and non-reducing sugars *ie*., these contents decreased with increasing sodicity levels. At higher sodicity levels the tolerant varieties, TRY 3 followed by TRY 1, CO 43, TRY 2 and CSR 27 recorded a higher reducing sugar, total sugar and proline content. While comparing the susceptible variety WP, all tolerant varieties showed an increased chlorophyll content, sugars and proline contents. The increase in proline content increases the salt tolerance capacity in rice and as a result 50% of yield in TRY 3 was recorded at ESP 32 proving that improved biochemical mechanism has an ability to improve yield parameters under sodic stress. Hence, understanding the physiological and biochemical mechanisms further supports our speculation for matching the nutrient and crop management practices to get a potential yield even under the stressed condition.

Conflict of interest: None.

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