Universal Journal of Agricultural Research 3(3): 81-88, 2015 http://www.hrpub.org
DOI: 10.13189/ujar.2015.030303

Mitigation of Salt Stress by Foliar Application of Proline in Rice

Abu Bakkar Siddique[1], Md. Rafiqul Islam[1], Md. Anamul Hoque[1], Md. Mahmudul Hasan[2], Muhammad Tanvir Rahman[1], Mohammad Mahir Uddin[3,*]

[1]Department of Soil Science, Bangladesh Agricultural University, Bangladesh
[2]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, Malaysia
[3]Department of Entomology, Bangladesh Agricultural University, Bangladesh

Abstract A pot experiment was conducted at Bangladesh Agricultural University to evaluating the effect of exogenous application of proline on the growth and yield of rice under salt stress condition. There were six treatments including T_1 (Control), T_2 (25 mM NaCl), T_3 (50 mM NaCl), T_4 (25 mM NaCl + Proline), T_5 (50 mM NaCl + Proline) and T_6 (Proline). A salt sensitive variety of rice (cv. BRRI dhan29) was used as a test crop. Salinity (NaCl) was induced at vegetative growth stage (35 days after transplanting) of rice. Proline of 25 mL $plant^{-1}$ was applied as foliar on the same day of NaCl treatment. All plants virtually died when they were treated with 50 mM NaCl (T_3). On the other hand, foliar application of proline resulted in a significant increase in plant growth parameters of rice. The grain and straw yields $plant^{-1}$ decreased with increased salinity levels. When the salt treated plants were supplied with exogenous proline, they produced significant amount of grain and straw yields. Sodium content and uptake by plants were decreased with foliar application of proline. It can be concluded that salt stress in rice reduce to a significant extent due to the exogenous application of proline.

Keywords Foliar Application, Proline, Rice, Salt Stress

1. Introduction

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population. So it is imperative to increase rice production in different rice growing ecosystems to feed the increasing world population [15]. It is also staple food for about 142 million people in Bangladesh. The total area and production of rice in Bangladesh are about 11.7 million hectares and 31.94 million metric tons, respectively [4]. Although agro-climatic condition in Bangladesh is favorable for rice cultivation, rice production is being hampered in some areas of the country due to adverse situation such as salinity problem in coastal area of the country. About 15% of the cultivable area of Bangladesh is affected by varying degrees of salinity. At present, salinity is the second most widespread soil problem in rice growing countries after drought and is considered as a serious constraint to increase rice production worldwide [8].

Recently, a number of excellent reviews have been published on the abiotic stress response and tolerance mechanisms and transgenic technology for developing crop plants tolerant to abiotic stresses [7, 21 ,22]. Among them, the accumulation of compatible solutes is one of the main adaptive mechanisms to salt stress in plants. Proline is the most common compatible solute that occurs in a wide variety of plants. Increased levels of proline accumulated in plants correlate with improved salt tolerance. Besides functioning as osmoprotectant, proline protects plants against salt or osmotic stresses by stabilizing many functional units such as complex II electron transport, membranes, proteins and enzymes such as RUBISCO, and by preventing photoinhibition. Salt stress induces the accumulation of reactive oxygen species (ROS) including superoxide radical and hydrogen peroxide in plant cells. The excess production of ROS is toxic to plants and causes oxidative damage to cellular constituents, leading to cell death. Plants possess enzymatic and non-enzymatic antioxidant defense systems to protect their cells against the damaging effects of ROS. It has been shown that proline scavenges free radicals and ROS. It is expected that up-regulation of the components of antioxidant defense system offered by proline protects plant against NaCl-induced oxidative damage. Proline improves salt tolerance in salt-sensitive rice by increasing proline accumulation and enhancing antioxidant defense system [10]. In context of Bangladesh, very little is known about the protective roles of proline in rice responses to salt stress . Rice is central to Bangladesh's economy and agriculture, accounting for nearly 18.71% GDP (2009-2010). Therefore, development of salt tolerant varieties has been considered as one of the strategies to increase rice production in saline prone coastal areas. Hence, the situation justifies the need of undertaking a research study on the reduction of salt stress by foliar application of proline in rice to investigate the protective effect of proline on the yield performance of rice and also examine the effect of proline on nutrient content and uptake by rice under salt stress

2. Materials and Methods

2.1. Location and Site

The experiment was conducted in the net house of the Department of Soil Science, BAU, Bangladesh. The location of the pot experiments were 24°43.47'North latitude and 90°26.22' East longitude. The experimental area has subtropical humid climate and is characterized by high temperature accompanied by moderately high rainfall during Kharif (March-October) season and low temperature with very low rainfall in Rabi (November-February) season.

2.2. Collection and Preparation of Soils

Soils were collected from a depth of 0-15 cm from the Soil Science farm of Bangladesh Agricultural University, Mymensingh. After collection, soils were made free from the plant roots and unnecessary materials and dried in room temperature. Then the soils were mixed up thoroughly and 500 g soil was taken for initial physical and chemical analysis. The physio-chemical properties of the soil are presented in Table 1.

Table1. Physical and chemical properties of the soil under study

Constituents	Value
Physical characteristics	
% Sand	10.12
% Silt	73.95
% Clay	15.93
Textural class	Silt loam
Chemical characteristics	
pH (Soil: Water =1:2.5)	6.15
Organic matter (%)	1.90
Total N (%)	0.11
EC (dSm^{-1})	0.20
Available P (mg kg^{-1})	11.2
Available S (mg kg^{-1})	12.5
Exchangeable K (me 100^{-1}g soil)	0.082
Exchangeable Na (me 100^{-1}g soil)	0.383

2.3. Treatment and Crop Culture

The experiment was carried out in a Completely Randomized Design (CRD) with three replications. Salt sensitive rice cultivar (BRRI dhan29) was used as plant materials. Seedlings of rice were transplanted into pots. Plants were subjected to different concentrations of NaCl at vegetative growth stage (35 days after transplanting). Proline (25 mL $plant^{-1}$) was applied as foliar on the same day of NaCl treatment. There were six different treatment combinations consisting of T_1= Control, T_2 = 25 mM NaCl, T_3 = 50 mM NaCl, T_4 = 25 mM NaCl+ Proline, T_5 = 50 mM NaCl + Proline, and T_6 = Proline. Every pot received 100 mg N kg^{-1} soil, 25 mg P kg^{-1} soil, 40 mg K kg^{-1} soil and 25 mg S kg^{-1} soil from urea, TSP, MoP and gypsum, respectively. Except nitrogen, the full dose of other elements was applied at the final pot preparation. Nitrogen was applied in three equal splits at 7, 30 and 60 days after transplanting. Forty day old healthy seedlings were transplanted and 2 hills were placed in an equal distance and each hill consisted of the three seedlings. The irrigation, weeding and loosening of soils around the rice hills were done when felt necessary. Crops were harvested at maturity. Three hills were randomly selected from each plot at maturity to record the yield contributing characters like plant height (cm), panicle length (cm), number of tillers $hill^{-1}$, number of filled grains $panicle^{-1}$, number of unfilled grains $panicle^{-1}$ and 1000-grain weight (g). Grain and straw yields were recorded plot wise and the yields were expressed as t ha^{-1} on 14% moisture basis. Grain and straw samples were kept for chemical analysis.

2.4. Soil Analysis

Initial soil samples were analyzed for both physical and chemical characteristics. Mechanical analysis of soil was done by hydrometer method [5] and the textural class was determined by fitting the values for % sand, % silt and % clay to the Marshalls triangular co-ordinate following USDA system. Soil pH was measured with the help of a glass electrode pH meter, the soil-water ratio being maintained at 1:2.5 [13]. Organic carbon in soil was determined volumetrically by wet oxidation method of Walkley and Black [25]. The organic matter content was calculated by multiplying the percent organic carbon by 1.73 (van Bemmelen factor). Cation exchange capacity of the soil was determined by sodium saturation method as outlined by Rhoades [20]. Total N content in soil was estimated following the micro-Kjeldahl method [6]. Available phosphorus was extracted from the soil with 0.5 M $NaHCO_3$ solution, pH 8.5 [17]. Available S content of soil was determined by extracting the soil with $CaCl_2$ (0.15%) solution as described by Tabatabai *et al.,* [24]. Exchangeable potassium was determined on 1N NH_4OAc (pH 7.0) extract of the soil by using flame photometer [16]. Exchangeable sodium was determined on 1N NH_4OAc (pH 7.0) extract of the soil by using flame photometer [16]. Electrical conductivity (EC) of soil was determined using EC meter (Soil water ratio being 1:5).

2.5. Preparation and Analysis of Plant Samples

The grain and straw samples were dried in an oven at 65^0C for about 48 hours and then ground by a grinding machine to pass through a 20-mesh sieve. The ground plant materials (grain and straw) were stored in paper bags in a desiccator. Phosphorus, K, S, and Na were determined by nitric-perchloric acid digestion method [26]. The N contents of grain and straw were measured following the Kjeldahl method [6].Total chlorophyll content of the leaf tissues collected from rice leaves was measured following the method outlined by Porra *et al.,* [18].

2.6. Statistical Analysis

The analysis of variance for different crop characters and various nutrient concentrations was done following the MSTATC computer program. The mean comparison of the treatments was made by the Duncan's Multiple Range Test (DMRT).

3. Results and Discussion

3.1. Effects of Proline on Yield and Yield Contributing Characters under Salt Stress

3.1.1. Yield Contributing Characters

The plant height, root growth, effective tillers plant^{-1}, panicle length, filled grains panicle^{-1}, unfilled grains panicle^{-1}, 1000-grain weight of BRRI dhan29 was significantly influenced by the foliar application of proline under different salt stress conditions (Table 2). Plant height decreased with increased salinity levels. All plants virtually died when they were treated with 50 mM NaCl (T_3). On the other hand, foliar application of proline resulted in a significant increase in plant height induced by salt stress. The tallest plant (88.3 cm) was recorded at T_6 treatment where only proline was applied which was followed by T_1 (Control) and the shortest one (67.0 cm) was recorded at T_5 treatment (50 mM NaCl + Proline). Reduced plant height under salinity condition might be due to the inhibition of photosynthesis under salt stress that caused less amount of nutrient uptake by the plant, resulting in shorter plant height. Similar result was also reported by Sen [23] in rice who reported that plant height decreased with increased salinity levels. The number of effective tillers plant^{-1} decreased with increased salinity levels. All plants died when they were treated with 50 mM NaCl (T_3). However, the salinity was mitigated to a significant extent with the application of 25 mM proline. The highest number of effective tillers plant^{-1} (11.00) was recorded at T_1 (Control) which was similar with T_6 (Proline) and no effective tiller was found when plants were exposed to 50 mM NaCl stress (T_3). It was observed that the application of proline in the treatment T_4 (25 mM NaCl + Proline) produced 9.67 number of effective tillers plant^{-1}, indicating a significant difference with T_3 (50 mM NaCl) where no proline was applied. Similar findings were also reported by many workers [2, 10]. Panicle length decreased with increased salinity levels and that increased with the application of proline. The highest panicle length (25.85 cm) was recorded at T_6 (Proline) which was statistically similar to T_1 (Control) and no panicle was observed at T_3 (25 mM NaCl). The application of proline in the treatment T_5 (50 mM NaCl + Proline) produced 21.55 cm of panicle length, indicating a remarkable difference with T_3 (25 mM NaCl) where no proline was applied. The application of both 25 mM NaCl and 50 mM NaCl reduced the panicle length but the reduction in panicle length was more pronounced in 50 mM NaCl. The results of present study are in agreement with that of Sen [23] who reported that panicle length decreased with increased salinity levels.

The number of filled grains panicle^{-1} decreased with increased salinity levels and that increased with the application of proline. All plants were found to be died when they were treated with 50 mM NaCl (T_3). The highest number of filled grains panicle^{-1} (178.83) was obtained from T_6 (Proline) followed by T_1 (Control). The results are well corroborated with Sen [23] who reported that the number of filled grains panicle^{-1} was decreased with the increase of soil salinity levels. The highest number of unfilled grains panicle^{-1} (43.50) was recorded in T_2 (25 mM NaCl) where no proline was applied. The application of proline in the treatment T_4 (25 mM NaCl + Proline) and T_5 (50 mM NaCl + Proline) decreased the number of unfilled grains panicle^{-1} as compared to T_2 (25 mM NaCl). Increased unfilled grains panicle^{-1} under salt stress condition might be due to lower leaf number which was unable to supply available assimilates to grains and resulted more unfilled grains panicle^{-1} than NaCl treated plants. Islam [12] and Hossain [10] also observed that the number of unfilled grains panicle^{-1} of rice increased with the increase of salinity levels. It was observed that 1000-grain weight decreased with increased salinity levels. The highest 1000-grain weight (19.00 g) was recorded at T_1 (Control) followed by T_6 (Proline) and the 1000-grain weight in T_3 (25 mM NaCl) was not detected. The 1000-grain weight found in the T_4 (25 mM NaCl+Proline) was statistically similar to T_2 (25 mM NaCl). Reduction of 1000-grain weight under salinity condition might be due to lower amount of assimilate translocation from leaf to grain. The results are also in agreement with Abdullah *et al*., [1], Sen [23], and Ali *et al.,* [2] who observed that 1000-grain weight decreased with increased salinity levels.

Table2. Effect of proline on yield contributing characters of BRRI dhan29 under salt stress condition

Treatments	Plant height (cm)	Effective tillers plant^{-1} (number)	Panicle length (cm)	Filled grains panicle^{-1} (number)	Unfilled grains panicle^{-1} (number)	1000- grain weight (g)
T_1 (Control)	86.6ab	11.00a	25.53ab	164.4b	26.78b	19.00a
T_2 (25 mM NaCl)	81.3c	8.33b	23.77c	126.4c	43.50a	16.67b
T_3 (50 mM NaCl)	ND	ND	ND	ND	ND	ND
T_4 (25 mM NaCl + Proline)	84.0bc	9.67b	24.55bc	141.8c	33.00ab	17.33b
T_5 (50 mM NaCl + Proline)	67.0d	4.33c	21.55d	92.2d	23.67b	14.67c
T_6 (Proline)	88.3a	10.00a	25.85a	178.8a	28.67b	19.00a
SE (±)	10.69	1.42	3.17	20.68	4.90	2.36
CV (%)	2.31	19.62	3.78	9.63	18.88	16.34

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability by DMRT,CV= Coefficient of variance, SE= Standard error of means, and ND= Not detected

Table 3. Effect of proline on grain and straw yields of BRRI dhan29 under salt stress condition

Treatments	Grain yield plant-1 (g)	Straw yield plant-1 (g)
T1 (Control)	22.67a	27.85a
T2 (25 mM NaCl)	8.07c	10.37c
T3 (50 mM NaCl)	ND	ND
T4 (25 mM NaCl + Proline)	12.82b	14.37b
T5 (50 mM NaCl + Proline)	2.57d	3.73d
T6 (Proline)	21.58a	26.23a
SE(±)	2.99	3.15
CV (%)	9.02	15.61

In a column, the figures having common letter(s) do not differ significantly at 5% level of probability by DMRT, CV = Coefficient of variance, SE = Standard error of means, and ND = Not detected.

3.1.2. Yield

The grain and straw yield of BRRI dhan29was significantly influenced by exogenous application of proline under salt stress condition (Table 3). Grain yield plant^{-1}decreased with increased salinity levels. However, the effect of 50 mM NaCl was more severe than that of 25 mM NaCl. The highest grain yield plant^{-1} (22.67g) was obtained with T_1 (Control) which was statistically similar to T_6 (Proline) and the grain yield was not observed in T_3 (50 mM NaCl). Grain yield plant^{-1}of 12.82 g was found in the T_4 (25 mM NaCl + Proline) which was significantly higher than that in T_2 (25 mM NaCl). All plants were died with 50 mM NaCl producing no grain yield. When the salinity treated plants were exposed to 25 mM proline, the plants survived and produced significant amount of grain yields. This justifies the positive effects of proline in mitigating soil salinity. Reduced grain yield under salinity condition might be due to the production of less effective tillers, lower panicle length, lower number of grains plant^{-1}, etc. Similar findings were also reported by Islam [12] and Hossain [10] in rice. They observed that grain yield decreased with increased salinity levels. Straw yield plant^{-1}decreased with increased salinity levels and that increased with the application of proline. The highest straw yield plant^{-1} (27.85 g) was obtained with T_1 (Control) which was statistically similar to T_6 (Proline) and the straw yield was not detected in T_3 (50 mM NaCl). The straw yield plant^{-1}of 14.37 g was found in the T_4 (25 mM NaCl + Proline) which was significantly higher than that (10.37 g) in T_2 (25 mM NaCl). Reduced straw yield under salinity condition might be due to inhibited photosynthesis under salinity stress that caused less amount of nutrient uptake by the plant. As a result, plant growth was slow which resulted in shorter plant height and fewer number of leaves plant^{-1}. That is why lower straw yield was obtained under salinity condition. Similar findings were reported by Hoque [9] who observed that proline application improved the growth and yield of salt-sensitive rice but not of salt-tolerant rice at 50 mM NaCl stress during aman season. The results are in agreement with Hossain [10] and Rashid [19] who observed that stem weight, leaf weight as well as TDM plant^{-1} of rice decreased with increased salinity levels. The results are also in agreement with Khan *et al.* [14] who observed higher straw yield of wheat with the foliar application of proline.

Table 4. Effect of proline on nutrient content in grain and straw of BRRI dhan29 under salt stress condition

Treat.	N content (%)		P content (%)		K content (%)		S content (%)		Na content (%)	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1	1.57d	0.95b	0.25a	0.13a	0.30a	0.77a	0.26b	0.22b	0.07c	0.34d
T_2	1.76c	0.93c	0.30a	0.11b	0.25ab	0.28c	0.31a	0.21b	0.29a	0.56a
T_3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T_4	1.82b	0.99b	0.27a	0.10c	0.22b	0.35b	0.23b	0.21b	0.10b	0.38c
T_5	2.38a	1.20a	0.27a	0.12b	0.21b	0.35b	0.31a	0.27a	0.12b	0.42b
T_6	1.59d	0.96b	0.23a	0.14a	0.28a	0.75a	0.26b	0.21b	0.06c	0.36d
SE(±)	0.25	0.14	0.04	0.02	0.03	0.11	0.04	0.03	0.02	0.06
CV (%)	5.72	7.66	16.41	10.11	11.53	19.35	8.70	11.32	19.97	18.45

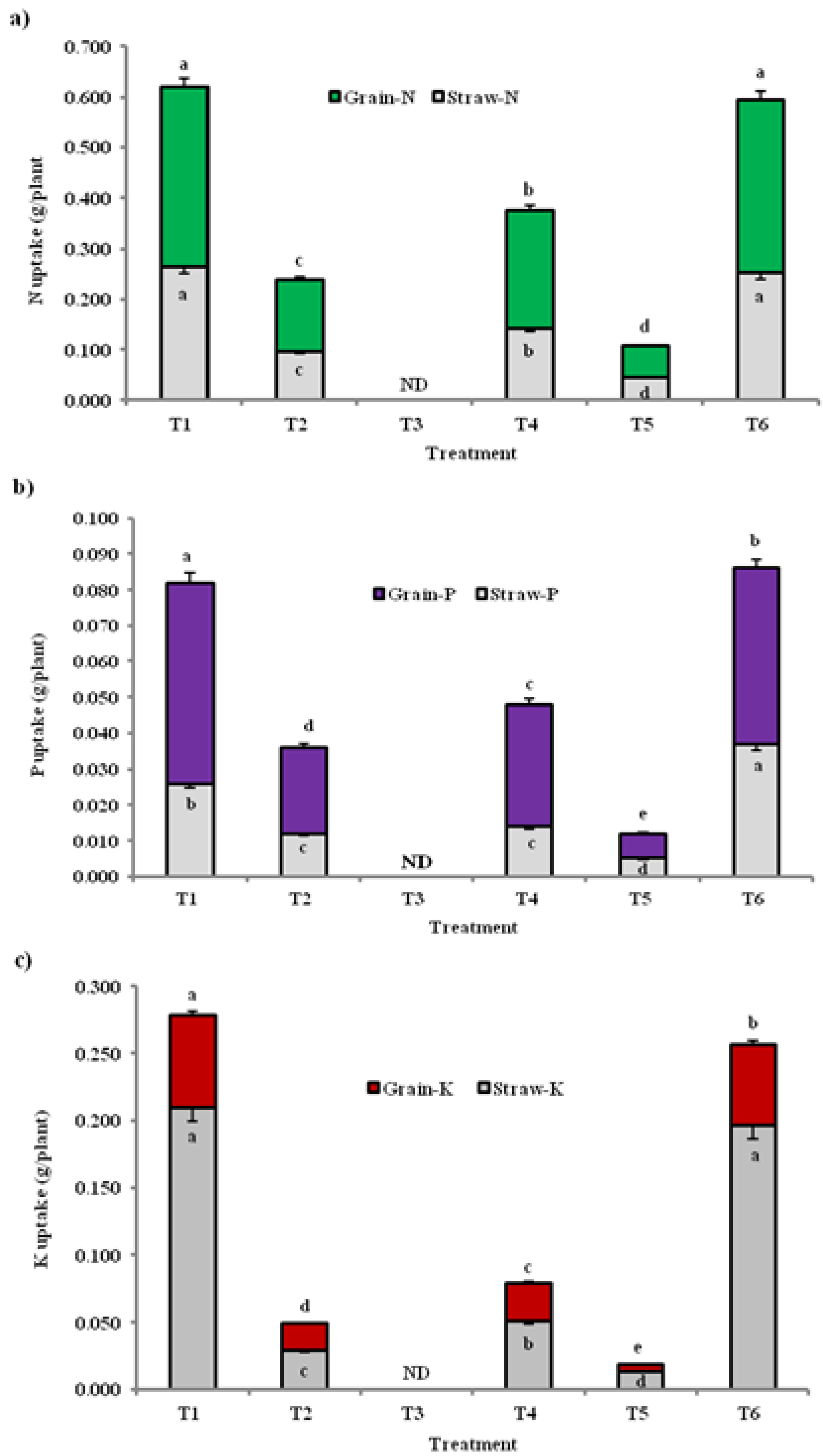
T_1= Control, T_2 = 25 mM NaCl, T_3 = 50 mM NaCl, T_4 = 25 mM NaCl+ Proline, T_5 = 50 mM NaCl + Proline, and T_6 = Proline. In a column, the figures having common letter(s) do not differ significantly at 5% level of probability by DMRT, CV = Coefficient of variance, SE = Standard error of means, and ND =Not detected

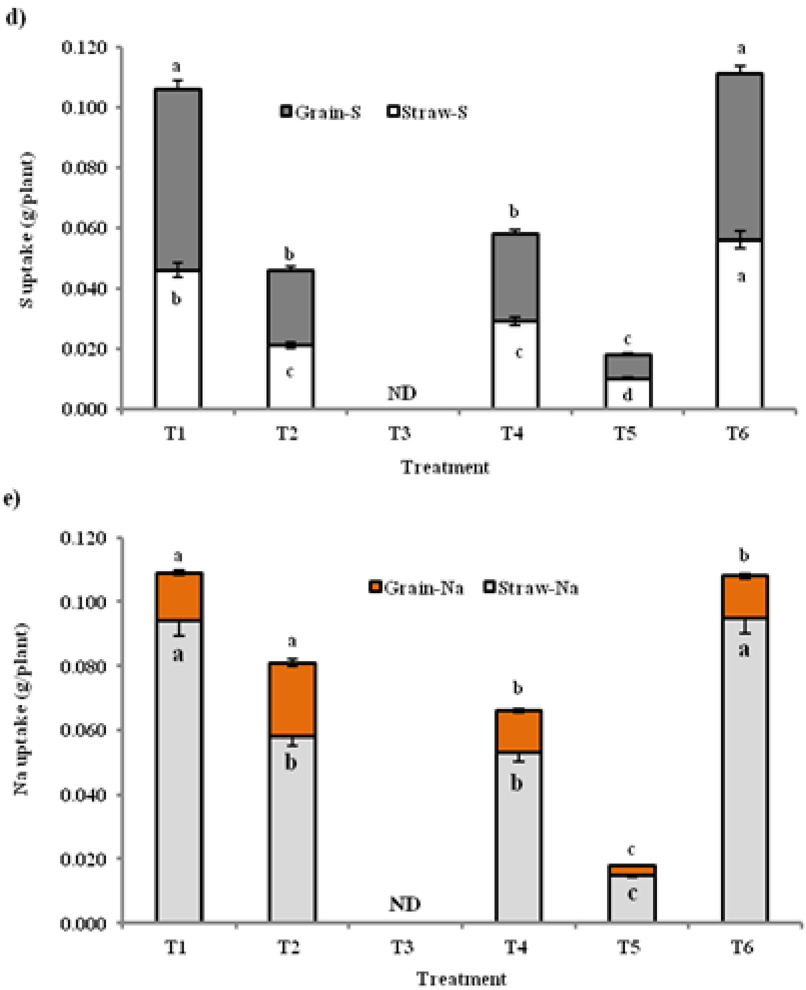
3.2. Effects of Proline on the Nutrient Content Under Salt Stress

Nutrient content (N, P, K, S, and Na) in grain and straw of BRRI dhan29 was significantly influenced by the application of proline under salt stress condition (Table 4). The grain N content of 1.82% was found in T_4 (25 mM NaCl + Proline) which was significantly higher than that (1.76%) in T_2 (25mM NaCl). The grain N content in T_1 (Control) and T_6 (Proline) was statistically similar. Like grain N, the straw N content of 0.99% was found in T_4 (25 mM NaCl + Proline) which was significantly higher than that (0.93%) in T_2 (25 mM NaCl). The straw N content in T_1 (Control) and T_6 (Proline) was statistically similar. The highest P content 0.30% in grain was recorded in T_2 (25 mM NaCl) which was identical with T_1 (Control), T_6 (Proline), T_4 (25 mM NaCl + Proline) and T_5 (50 mM NaCl + Proline). The P content in grain was not detected in T_3 (50 mM NaCl). The highest P content (0.14%) in straw was found in T_6 (Proline). The P content of 0.12% in straw was found in T_5 (50 mM NaCl + Proline) which was higher than T_3 (50 mM NaCl). The P content in straw observed in T_2 (25 mM NaCl) and T_4 (25 mM NaCl + Proline) were statistically similar. The K content of grain in T_1 (Control) and T_6 (Proline) was statistically similar. The grain K content observed in T_2 (25 mM NaCl) and T_4 (25 mM NaCl + Proline) were statistically similar. In straw, the K content in T_1 (Control) and T_6 (Proline) was statistically similar. The K content of 0.35% found in T_5 (50 mM NaCl + Proline) was higher than that in T_3 (50 mM NaCl). The K content in straw obtained from T_2 (25 mM NaCl) was identical with T_4 (25 mM NaCl + Proline). The highest S content of 0.31% in grain was found in T_5 (50 mM NaCl + Proline) followed by T_2 (25 mM NaCl) with same rank and S content in grain was not detected in T_3 (50 mM NaCl). The S content of grain in T_1 (Control) and T_6 (Proline) were statistically similar. In straw, the highest S content (0.27%) in straw was obtained in T_5 (50 mM NaCl + Proline). The S content of 0.22% was found in T_1 (Control) which was statistically similar to T_6 (Proline) followed by T_2 (25 mM NaCl) and T_4 (25 mM NaCl + Proline). The Na content of 0.29% in grain recorded in T_2 (25 mM NaCl) was higher than that in T_4 (25 mM NaCl + Proline). There was no significant difference between T_1 (Control) and T_6 (Proline) treatment. Like grain, the Na content in straw found in T_2 (25 mM NaCl) was higher (0.56%) than that in T_4 (25 mM NaCl + Proline). The Na content in straw found in T_1 (Control) and T_6 (Proline) was statistically similar. It is noticeable that the Na content in both grain and straw decreased with the application of proline. Hussain *et al.* [11] observed that the values of K: Na, Ca: Na and (Ca + Mg): Na ratios in shoot and root are comparatively low under stress conditions.

3.3. Effects of Proline on the Nutrient Uptake Under Salt Stress

Nutrient (N, P, K, S, and Na) uptake by grain and straw of BRRI dhan29 was influenced due to foliar application of proline under different levels of salinity (Figure 1). The highest N uptake by grain (0.355 g plant^{-1}) was recorded in T_1 (Control) followed by T_6 (Proline) with same statistical rank and the N uptake by grain in T_3 (50 mM NaCl) was not detected. The N uptake by grain (0.233 g plant^{-1}) in T_4 (25 mM NaCl + Proline) was significantly higher than that in T_2 (25mM NaCl). The highest N uptake by straw (0.264 g plant^{-1}) was recorded in T_1 (Control) followed by T_6 (Proline) with same statistical rank and the N uptake by straw in T_3 (50 mM NaCl) was not detected. The N uptake by grain (0.142 g plant^{-1}) in T_4 (25 mM NaCl + Proline) was higher than that (0.096 g plant^{-}1) in T_2 (25mM NaCl) treatment. The highest total N uptake (0.619 g plant^{-1}) was obtained in T_1 (Control) followed by T_6 (Proline) with same statistical rank. The total N uptake (0.375 g plant^{-1}) in T_4 (25 mM NaCl + Proline) was higher than that (0.238 g plant^{-1}) in T_2 (25mM NaCl) treatment. The highest P uptake by grain (0.056 g plant^{-1}) was recorded in T_1 (Control) and the P uptake by grain in T_3 (50 mM NaCl) was not detected. P uptake by grain (0.034 g plant^{-1}) in T_4 (25 mM NaCl + Proline) was higher than that in T_2 (25mM NaCl) treatment. The highest P uptake by straw (0.037 g plant^{-1}) was obtained in T_6 (Proline) and the P uptake in T_3 (50 mM NaCl) was not detected. The highest total P uptake (0.086 g plant^{-1}) observed in T_6 (Proline) was identical with T_1 (Control) treatment. The total P uptake in T_3 (50 mM NaCl) was not detected. Total P uptake (0.048 g plant^{-1}) found in T_4 (25 mM NaCl + Proline) was higher than that in T_2 (25mM NaCl). The highest K uptake by grain (0.068 g plant^{-1}) was recorded in T_1 (Control) and the K uptake by grain in T_3 (50 mM NaCl) was not detected. The K uptake by grain (0.028 g plant^{-1}) was recorded in T_4 (25 mM NaCl + Proline) which was higher than T_2 (25mM NaCl) treatment. In case of straw, the highest K uptake (0.210 g plant^{-1}) was found in T_6 (Proline) followed by T_1 (Control) with same statistical rank and the K uptake by straw in T_3 (50 mM NaCl) was not obtained. The K uptake by straw (0.051 g plant^{-1}) recorded in T_4 (25 mM NaCl + Proline) was higher than that in T_2 (25mM NaCl). The highest total K uptake (0.278 g plant^{-1}) was recorded in T_1 (Control) followed by T_6 (Proline) with same statistical rank and the total K uptake in T_3 (50 mM NaCl) was not obtained. Total K uptake (0.079 g plant^{-1}) obtained in T_4 (25 mM NaCl + Proline) which was higher than T_2 (25mM NaCl) treatment. The highest S uptake by grain (0.060 g plant^{-1}) was recorded in T_1 (Control) which was statistically similar with T_6 (Proline).


a)
N uptake (g/plant)
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
Grain-N
Straw-N
ND
T1
T2
T3
T4
T5
T6
Treatment
b)
P uptake (g/plant)
0.100
0.090
0.080
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
Grain-P
Straw-P
ND
T1
T2
T3
T4
T5
T6
Treatment
c)
K uptake (g/plant)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
Grain-K
Straw-K
ND
T1
T2
T3
T4
T5
T6
Treatment



T_1= Control, T_2 = 25 mM NaCl, T_3 = 50 mM NaCl, T_4 = 25 mM NaCl+ Proline, T_5 = 50 mM NaCl + Proline, and T_6 = Proline. Common letter(s) do not differ significantly at 5% level of probability by DMRT

Figure 1. Effect of proline on a) N, b) P, c) K, d) S, and e) Na uptake by BRRI dhan29 under salt stress condition

The S uptake by grain in T_3 (50 mM NaCl) was not found. The S uptake by grain (0.029 g plant^{-1}) was recorded in T_4 (25 mM NaCl + Proline) which was greater than T_2 (25 mM NaCl) treatment. The highest S uptake by straw (0.056 g plant^{-1}) was recorded in T_6 (Proline). The P uptake by straw in T_3 (50 mM NaCl) was not detected. The highest total S uptake (0.106 g plant^{-1}) was recorded inT_1 (Control) followed by T_6 (Proline) with same statistical rank and the total S uptake in T_3 (50 mM NaCl) was not found. Total S uptake (0.058 g plant^{-1}) observed in T_4 (25 mM NaCl + Proline) which was higher than that in T_2 (25 mM NaCl). The highest Na uptake by grain (0.023 g plant^{-1}) observed in T_2 (25 mM NaCl) which was higher than that found in T_4 (25 mM NaCl + Proline). The Na uptake by grain (0.015 g plant^{-1}) in T_1 (Control) was identical with T_6 (Proline). The highest Na uptake by straw (0.095 g plant^{-1}) was recorded in T_6 (Proline) followed by T_1 (Control) with same statistical rank. The Na uptake by straw was not detected in T_3 (50 mM NaCl) treatment. The highest total Na uptake of 0.109 g plant^{-1} was recorded in T_1 (Control) followed by T_6 (Proline) with same statistical rank. Application of proline reduced the total Na uptake by rice plant as noted in T_4 (25 mM NaCl + Proline) compared to T_2 (25 mM NaCl) treatment. Ali *et al.*, [3] exogenous application of proline counteracted the adverse effects of water stress on nutrient uptake because it promoted the uptake of K^+, Ca^{2+}, N and P in maize.

4. Conclusions

The overall results indicate that the growth and yield of BRRI dhan29 were affected significantly by different salt stresses. However, the foliar application of proline against salt stresses improved the growth and development of rice and resulted in increase the grain and straw yields to a significant extent. Therefore, it can be concluded that the salt stress can be mitigated by the exogenous application of proline in rice cultivation. Further, the experiment might be repeated in different locations with different rice varieties for making concrete recommendations.

REFERENCES

[1] Abdullah, Z., Khan, M. A. and Flowers, T. J. 2001. Causes of sterility in seed set of rice under salinity stress. J. Agron. Crop Sci. 187(1): 25-32.

[2] Ali, Y. and Awan, A.R. 2005. Influence of salinity at seedling stage and on yield and yield components of different rice lines. Intl. J. Biol. Biotechnol. 1(2): 175-179.

[3] Ali, Q., Ashraf, M., Shahbaz, M. and Humera, H. 2008. Ameliorating effect of proline on nutrient uptake in water stressed maize (*Zea mays* L.). *Pak. J. Bot*., 40(1): 211-219.

[4] BBS (Bangladesh Bureau of Statistics) 2011. Monthly Statistical Bulletin of Bangladesh. May 2011. Bangladesh Bureau of Statistics, Stat. Div., Ministry of Planning, Govt. People's Repub. Bangladesh, Dhaka. pp: 52-56.

[5] Bouyoucos, G.J. 1926. Hydrometer method improved for making particle size analysis of soils. Agron, J. 54: 4661-4665.

[6] Bremmer, J.M. and Mulvaney, C.S. 1982. Nitrogen: Total. In methods of Soil Analysis, Part 2 (Second Edition). Page, A.L., Miller, R.H. and Keeney, D.R. (eds.). Amer. Soc. Agron., Inc. and Soil Sci. Soc. Amer., Inc., Madison, Wisconsin. USA. pp. 595-622.

[7] Gao, J.P., Chao, D.Y. and Lin, H.X. 2007. Understanding abiotic stress tolerance mechanisms: recent studies on stress response in rice. J. Integr. Plant Biol.49: 742- 750.

[8] Gregorio, G.B., Senadhira, D., and Mendoza, R.D. 1997. Screening rice for salinity tolerance. IRRI Discussion Paper Serie no.22. Manila (Philippines): International Rice Research Institute. pp.1-30.

[9] Hoque, M.A. 2013. Mitigation of salt stress by enhancement of antioxidant defense systems with proline in rice. BAU Research proceedings, Vol.23, 2013, PP.17-18.

[10] Hossain, M.M. 2006. Effect of salinity level on growth and yield of advanced mutant rice in Boro season. M.S. Thesis, Dept. Crop Bot., Bangladesh Agril. Univ. Mymensingh.

[11] Hussain, N., Ali, A., Sarwar, G., Mujeeb, F., and Tahir, M. 2003. Mechanism of salt tolereance in rice. *Pedosphere.* 13(3): 233-238.

[12] Islam, M.M. 2004. Effect of salinity on growth and yield of advanced mutant rice in boro season. M.S. Thesis, Dept. Crop Bot., Bangladesh Agril. Univ. Mymensingh.

[13] Jackson, M.L. 1962. Soil Chemical Analysis. 1st ed. Constable and Co. Ltd. London.

[14] Khan, M.A., Shiraji, M.U., Mujtaba, S.M., Islam, E., Mumtaz, S., Shereen, A., Ansari, R.,U. and Yasin, A. 2009. Role of proline, K/ Na ratio and Chlorophyll content in salt tolerance of wheat (Triticum aestivum L.). Pak. J. Bot., 41(2): 633-638.

[15] Khush, G.S. 2005. What it will take to feed five billion rice consumers by 2030. Plant Mol. Biol. 59:1- 6.

[16] Kundsen, D., Peterson. G.A. and Prat, P.F. 1982. Lithium, Sodium and Potassium. In Methods of Soil Analysis. Part 2 (Second Edition). Page, A.L., Miller, R.H. and Keeney, D.R. (eds.). Amer. Soc. Agron., Inc. and Soil Sci. Soc. Amer., Inc., Madison, Wisconsin. USA. pp. 225-246.

[17] Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dept. Agr. Circ. p. 929.

[18] Porra, R.J., Thompson, W.A. and Kriedemann, P.E. 1989. Determination of accurate extinction coefficients and simultaneous equations for the assaying chlorophyll a and b with four different solvents: verification of the concentration of chlorophyll by atomic absorption spectrocoopy. Biochim. Biophys. Acta 975:384-394.

[19] Rashid, M.M. 2005. Effect of salinity at different growth stages of transplanted aman rice mutants. M.S. Thesis, Dept. Crop Rot., Bangladesh Agril. Univ., Mymensingh.

[20] Rhoades, J.D. 1982. Cation Exchange Capacity. In Methods of Soil Analysis. Part 2 (Second Edition). Page, A.L., Miller, R.H. and Keeney, D.R. (Eds.). Amer. Soc. Agron., Inc. and Soil Sci. Soc. Amer., Inc., Madison, Wisconsin. USA. pp. 149-157.

[21] Rodriguez, A. A., Stella, A. M. Storni, M. M. Zulpa, G. and Zaccaro, M. C. 2006. Effects of cyanobacterial extracellular products and gibberellic acid on salinity tolerance in Oryza sativa L. Saline Systems. 2 (7):1186-1148.

[22] Sahi, C., Singh, A., Kumar, K., Blumwald, E. and Grover, A. 2006. Salt stress response in rice: genetics, molecular biology, and comparative genomics. Funct. Integr. Genomics. 6 : 263-284.

[23] Sen, A.K. 2002. Salinity tolerance studies of some transplanted aman rice cultivars. M.S. Thesis, Dept. Crop Bot., Bangladesh Agril. Univ., Mymensingh.

[24] Tabatabai, M.A. 1982. Sulphur. In Methods of Soil Analysis. Part 2 (Second Edition). Page, A.L., Miller, R.H. and Keeney, D.R. (eds.). Amer. Soc. Agron., Inc. and Soil Sci. Soc. Amer., Inc., Madison, Wisconsin. USA. pp. 501-534.

[25] Walkley, A. and Black, D.R. 1975. An estimation of the digestion method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

[26] Yoshida, S., Ahn, J. S. and Forno, D. A. 1973. Occurrence, diagnosis and correction of zinc deficiency of lowland rice. Soil Sci. Plant Nutr. 19:83-93.