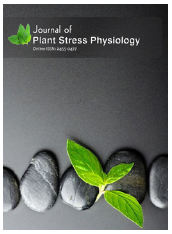
Journal of Plant Stress Physiology 2023, 9: 18-26
doi: 10.25081/jpsp.2023.v9.8595
https://updatepublishing.com/journal/index.php/jpsp

Research Article



ISSN: 2455-0477

Morphological responses of three contrasting Soybean (*Glycine max* (L.) Merrill) genotypes under different levels of salinity stress in the coastal region of Bangladesh

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ABSTRACT

Soil salinity, a global environmental issue, inhibits plant development and production. Soybean is an economically important legume crop whose yield and quality are highly affected by excessive levels of salt in the root zone. A factorial experiment was conducted in a net house from October 2019 to January 2020 to evaluate the performance of three distinct soybean genotypes under varying levels of salinity stress. The experiment followed a completely randomized design (CRD) with three replications. Three soybean cultivars, namely BINA Soybean 1, BINA Soybean 2, and BINA Soybean 4. were used in this experiment. The soil salinity treatments were 0 mM NaCl, 50 mM NaCl, 100 mM NaCl, 150 mM NaCl, and 200 mM NaCl. The electrical conductivity (EC) of the soil sample was 0.91dS/m. Six seeds were sown 3 cm deep in each pot. A total of 45 pots were used in this experiment. The performance of each variety was evaluated based on its germination percentage, time of germination, no. of branches/plant, no. of leaves/plant, no. of flowers/plant, plant height (cm), no. of pods/plant, pod length (cm), seeds/pod, and root length (cm). Based on the results obtained from this research trial, it can be inferred that the BINA Soybean 2 variety along with 0 mM NaCl, 50 mM NaCl, and 100 mM NaCl treatments exhibited superior performance in all parameters compared to the other varieties. This study provides clear evidence that the soybean, particularly the BINA Soybean 2 variety, holds significant promise as a crop suitable for coastal regions. Furthermore, it suggests that the cultivation of soybeans in such areas could potentially enhance agricultural productivity, particularly in the presence of mild saline conditions. Nevertheless, it exhibits limited growth potential in environments with elevated salinity levels.

KEYWORDS: Salt stress, Germination, Plant height, Yield, Soybean genotypes

Received: August 07, 2023
Revised: September 25, 2023
Accepted: September 25, 2023
Published: October 10, 2023

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INTRODUCTION

The issue of salinity stresses poses a continuous and enduring threat to field crops and is widely acknowledged as a significant limitation on global agricultural productivity. It has contrary effects on the plant life cycle, including seed germination, seedling establishment and development, vegetative and reproductive growth, and crop survival (Zhu, 2016; Shu *et al.*, 2017; Islam *et al.*, 2019). Salt stress substantially condenses crop production throughout the arid and semi-arid regions of the world (Carpýcý *et al.*, 2009). Approximately 6% of the total land area and 20% of irrigated land are affected by salinity (Ghonaim *et al.*, 2021) comprising about 1125 million hectares in the world (Hossain, 2019). In Bangladesh, about 2.85 million hectares are of seaside land of which about one million hectares are salt-stressed (SRDI, 2010; Howlader *et al.*, 2018). Saline soils are vastly contained in Na^+ and Cl^- particles which makes water unavailable and negatively impacts crop growth. High salt concentrations adversely affect plant development and growth through various pathways, including water stress, nutritional disorders, ion toxicity, oxidative stress, alterations to metabolic processes, cell membrane disorganization, and reduced cell expansion and division (Hasegawa *et al.*, 2000; Munns, 2002; Zhu, 2002; Shu *et al.*, 2017).

Plants, in general, have established natural morpho-physiological protective mechanisms to conquer stress conditions (Ahmad *et al.*, 2016). Halophytes can cope with the effects of salt stress by developing salt exclusion, salt elimination, and salt succulence (Larcher, 2003). However non-halophyte plants do not grow well in saline soil (Islam *et al.*, 2019) due to the accumulation of reactive oxygen species (ROS) resulting in oxidative damage which disrupts cellular homeostasis and decreases photosynthetic efficiency (Khan *et al.*, 2014). Therefore, salinity tolerance research is crucial to increase the ability of plants to raise in saline soil. Germination is the first criterion for consideration in salt-tolerant research (Fernández-Torquemada & Sánchez-Lizaso, 2013). In this study, we investigated the performance of salt stress on germination, growth, and development of three cultivars of soybeans.

Soybean (*Glycine max* (L.) Merrill) as a key commercial crop, is an important and foremost edible oil crop, widely adopted and cultivated throughout the tropics and subtropics of the world. It has good nutritional quality for humans including proteins, lipids, and carbohydrates. Additionally, Soybean has a lot of saturated, monounsaturated, and polyunsaturated fatty acids and includes beneficial secondary metabolites such as isoflavones, phenolic components, and saponins (Sakthivelu *et al.*, 2008; USDA, 2018). Over time, the global demand for soybeans is continuously rising. Soybean is a moderately salt-sensitive crop with a salinity threshold of 5.0dS/m (Pavli *et al.*, 2021). These plants are generally very sensitive to salinity stress during the seedling stage and less so for reproduction. That's why high salinity stress has expressively declined soybean yield by inhibiting seed germination and post-germinative growth. Several key reasons are responsible for decreasing soybean production. High and uniform germination and emergence in the field are the key determinants of soybean yield, especially under salt stress conditions (Shu *et al.*, 2017). Hence, the main objective of the current investigation was to assess the morphological responses of three distinct soybean genotypes under different salinity levels. The current observations have the potential to provide a conceptual framework for the identification and selection of soybean cultivars that exhibit tolerance to salinity.

MATERIALS AND METHODS

Location and Period of the Experiment

The experiment was conducted during the period from October 2019 to January 2020 in a net house of the Department of Agriculture at Noakhali Science and Technology University, Bangladesh.

Soil Sampling

The soil sample used in the experiment was examined by the Soil Resource Development Institute (SRDI) located in Noakhali, Bangladesh (Table 1). The soil exhibited a sandy loam in texture and had a pH value of 6.7 which was measured by a portable pH meter (Hach sensION+ PH1 Basic Portable pH Meter). The electrical conductivity (EC) of the soil sample was 0.91dS/m (deci Siemens per meter) using an EC meter (Hach sensION+ EC7) in the laboratory of the Department of Agriculture. So, the soil was determined to possess a low salinity level.

Climate Condition

The climatic conditions in the locality were suggestive of the winter season, showing both low temperatures and limited precipitation. The average air temperature at the experimental site (Figure 1) was measured throughout the duration of the experiment using a digital thermometer (Digital Thermometer JR-1).

Planting Materials

Genetically diverse three genotypes of soybean *viz.* BINA Soybean 1, BINA Soybean 2, and BINA Soybean 4 were used in this experiment. These respective soybean cultivars were developed by the Bangladesh Institute of Nuclear Agriculture (BINA).

Experiment Design and Treatments

The factorial experiment involving two factors was conducted using a Completely Randomized Design (CRD) with three

Table 1: Physio-chemical properties of the soil sample

Measured soil parameters	Analytical values
Electrical conductivity (EC) in dS/m	0.91
pH	6.7
Nitrogen (%)	
N_2	0.021
Macronutrients (meq/100 gm)	
K^+	0.22
Ca^{2+}	24.02
Mg^{2+}	10.34
Micronutrients (ppm)	
P	12
Fe^{3+}	32.09
Mn^{2+}	30.02
Organic matter (%)	0.79

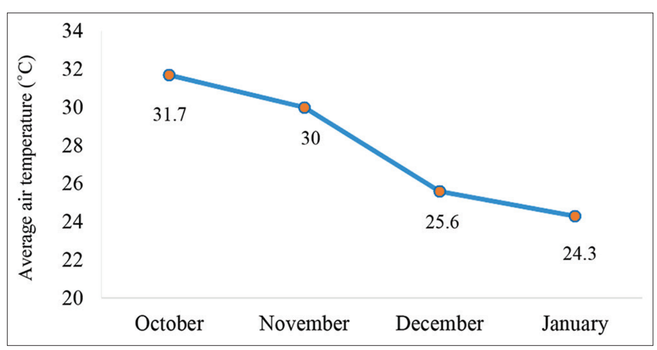

Figure 1: The mean air temperature at the experimental site. The maximum temperature was recorded in the month of October at 31.7 °C, while the minimum temperature was recorded in January at 24.3 °C

replications. The experiment consisted of three varieties *viz.* V_1= BINA Soybean 1, V_2= BINA Soybean 2, and V_3= BINA Soybean 4, along with five different salt concentrations (Table 2). Treatment combinations 15, the total number of pots 45, and the total number of seeds 270 were sown.

Pot Preparation and Fertilizers Application

In the pot experiment, soil that was not saline in nature was collected from the field and subsequently spread out on polythene sheets to go through the process of sun drying. The drying process lasted for a duration of one week. After that, the soil sample undergoes a process of crushing and screening, wherein a sieve is used to eliminate large particles and unnecessary substances. The soil was enriched with well-decomposed cow dung. The experiment utilized a total of 45 pots, each measuring 20 cm in width and 25 cm in height. Each pot contained 8 kg of soil that had been previously treated. A total of six seeds were planted at a depth of 3 cm in each individual pot. The soil was consistently kept moist to facilitate optimum germination, with water being applied as necessary. Afterward, the pots were placed inside the net house. Before starting the process of seeding, the soil was amended with fertilizers including Triple Super Phosphate (TSP), Muriate of Potash (MOP), and Gypsum. However, urea fertilizer was applied 25 days after seed germination (Table 3). All other agronomic practices were done when necessary.

Data Collection

The assessment of variety performance encompassed several parameters, including germination percentage, time of germination, no. of branches/plant, no. of leaves/plant, no. of flowers/plant, plant height (cm), no. of pods/plant, pod length (cm), seeds/pod, and root length (cm). The number of germinated seeds was recorded 10 days after sowing. The results were converted into a percentage. Germination percentage was determined by the following formula:

$$\text{Germination Percentage (GP} = \frac{\text{No. of germinated seeds}}{\text{Total no. of seed}} \times 100$$

Table 2: The treatments used in the experiment

Treatments	Salt concentration
T_0	0 mM NaCl (500 mL)
T_1	50 mM NaCl (1.46 g NaCl+500 mL Distilled water)
T_2	100 mM NaCl (2.925 g NaCl+500 mL Distilled water)
T_3	150 mM NaCl (4.38 g NaCl+500 mL Distilled water)
T_4	200 mM NaCl (5.85 g NaCl+500 mL Distilled water)

Table 3: Recommended fertilizer doses

Name of the fertilizers	Dose per pot	Total amount
Urea	20 gm	900 gm
TSP	45 gm	2.03 kg
MOP	35 gm	1.58 kg
Gypsum	10 gm	450 gm

The duration of germination was measured from the time of sowing until the last seed germinates. The total number of branches per plant, number of leaves per plant, and number of flowers per plant were recorded 70 days after sowing. Plant height (cm), number of pods per plant, pod length (cm), seeds per pod, and root length (cm) were recorded during harvesting. The soil temperature was recorded for each pot by using a digital thermometer.

Statistical Analysis

The data were statistically analyzed following the analysis of variance (ANOVA) and mean differences were adjudged by Tukey's HSD test at $p<0.05$ using MSTAT-C statistical software.

RESULTS AND DISCUSSION

Soil Temperature

The soil temperature was recorded for each pot by using a digital thermometer during the experimental period. Then, it was converted into a month-wise average temperature (Figure 2). The optimum soil temperature for soybean germination is 25-28 °C (Tyagi & Tripathi, 1983; Bohner, 2003). In this experiment, in the month of December, the average soil temperature was found to be 25.2-26.9 °C which was suitable for soybean seed sprouting. That's why the maximum germination was observed in the month of December.

Germination Percentage

In terms of germination percentage, substantial variation was found among the varieties. At 10 DAS, the V_2 (BINA Soybean 2) variety exhibited the highest germination percentage (71.11%) compared to the V_1 (BINA Soybean 1) and V_3 (BINA Soybean 4) varieties (Figure 3a). In addition, Table 4 reveals that both T_0 and T_1 treatments showed greater than 75% germination at 10 DAS. Maximum germination (90.74%) was observed in the T_0 (0 mM NaCl) treatment, which was statistically similar to the T_1 (50 mM NaCl) treatment, while the T_4 (200 mM NaCl) treatment provided the lowest germination rate (27.78%). Substantial variation was obtained by combined effects of variety and different levels of salt concentration on germination percentage at 10 DAS (Table 5). All the combined treatments were statistically different. V_2 (BINA Soybean 2) along with

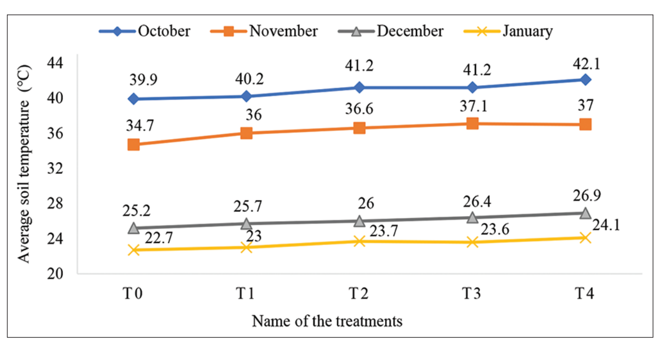

Figure 2: Average soil temperature during the pot experiment

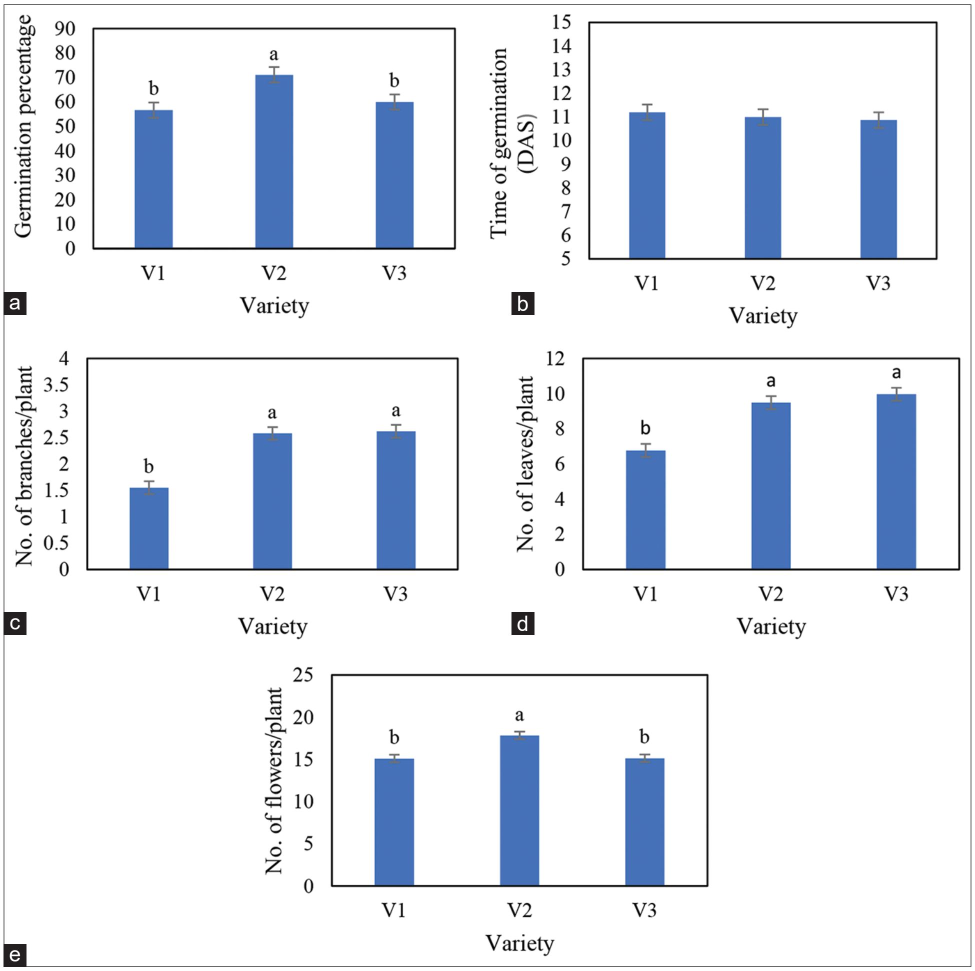

Figure 3: Genotypic performance effect on (a) germination percentage; (b) time of germination (DAS); (c) no. of branches/plant; (d) no. of leaves/plant; (e) no. of flowers/plant; V1: BINA Soybean 1; V2: BINA Soybean 2; V3: BINA Soybean 4. The values are the averages of three replicates ± SE (standard error). One-way ANOVA (analysis of variance) was used to find the mean, standard error mean, and p-value. Tukey's HSD of post-hoc test was used to find the significant differences between treatments. Different letters (a, b, c) show significant differences according to the homogenous subsets of Tukey's HSD test at 0.05 level of significance

Table 4: Effects of different levels of salt concentration on germination percentage, time of germination (DAS), number of branches per plant, number of leaves per plant, and number of flowers per plant

Salt concentration	Germination percentage	Time of germination (DAS)	Number of branches per plant	Number of leaves per plant	Number of flowers per plant
T_0	90.74a	8.11d	4.11a	15.44a	31.33a
T_1	79.63a	9.33cd	3.03b	12.63b	24.56b
T_2	62.96b	10.33c	2.37c	9.03c	17.04c
T_3	51.85b	12.78b	1.18d	4.63d	5.37d
T_4	27.78c	14.56a	0.56e	1.96e	1.82e
Level of significant	*	*	*	*	*
SE (±)	4.04	0.44	0.16	0.48	0.58
CV (%)	11.79	1.27	0.46	1.39	1.69

*=Significant at 5% level of probability, NS=Non-significant, CV=Co-efficient of variations, SE(±)=Standard Error. T_0=0 mM NaCl, T_1=50 mM NaCl, T_2=100 mM NaCl, T_3=150 mM NaCl, T_4=200 mM NaCl, Here, values in the column having a similar letter (s) are statistically identical (Tukey's HSD test at p<0.05)

T_0 (0 mM NaCl) provided the highest germination percentage (94.44%) which was statistically similar to the V_1T_0 and V_3T_0 treatment and minimum germination (16.67%) was recorded in V_1T_4 treatment. In addition, up to 70% germination was observed in the V_2T_2 (BINA Soybean 2×100 mM NaCl) treatment group. In contrast, less than 70% germination was observed for treatments V_1T_2 (BINA Soybean 1×100 mM NaCl) and V_3T_2 (BINA Soybean 4×100 mM NaCl). Among the three genotypes, BINA Soybean 2 performed better in the case of germination. Farhoudi and Tafti (2011) revealed that the germination rate and germination percentage of soybeans decreased as salinity levels increased during the growth

Table 5: Combined effects of variety and different levels of salt concentration on germination percentage, time of germination (DAS), number of branches per plant, number of leaves per plant, and number of flowers per plant

Treatment combination	Germination percentage	Time of germination (DAS)	Number of branches per plant	Number of leaves per plant	Number of flowers per plant
V_1T_0	88.87a	7.67e	3.11cd	12.67bc	32.33a
V_1T_1	77.78ab	9.67de	2.22def	10.44cd	23.56cd
V_1T_2	55.56cde	10.67bcd	1.33fgh	7.00e	15.00e
V_1T_3	44.44ef	12.67abc	0.67h	2.45f	3.22gh
V_1T_4	16.67g	15.33a	0.44h	1.23f	1.33h
V_2T_0	94.44a	8.67de	4.87a	19.11a	32.11a
V_2T_1	83.33ab	9.00de	3.22cd	14.11b	27.11bc
V_2T_2	72.22abcd	10.00cde	3.11cd	9.44de	20.22d
V_2T_3	61.11bcde	13.00ab	1.00gh	2.78f	7.56f
V_2T_4	44.44ef	13.67a	0.67h	2.00f	2.22gh
V_3T_0	88.87a	8.00de	4.33ab	14.56b	29.56ab
V_3T_1	77.78ab	9.33de	3.67bc	13.33bc	23.000d
V_3T_2	61.11bcde	10.33bcde	2.67cde	10.67cd	15.89e
V_3T_3	50.00de	12.67abc	1.89efg	8.67de	5.33fg
V_3T_4	22.22fg	14.67a	0.56h	2.67f	1.89gh
Level of significant	*	*	*	*	*
SE (±)	7.00	0.75	0.27	0.82	1.00
CV (%)	25.95	2.79	1.01	3.06	3.72

*=Significant at 5% level of probability, CV=Co-efficient of variations, SE(±)=Standard Error. V_1=BINA Soybean 1, V_2=BINA Soybean 2, V_3=BINA Soybean 4, T_0=0 mM NaCl, T_1=50 mM NaCl, T_2=100 mM NaCl, T_3=150 mM NaCl, T_4=200 mM NaCl, Here, values in the column having a similar letter (s) are statistically identical (Tukey's HSD test at $p<0.05$)

stages. Chowdhury *et al.* (2018) also reported a similar result in BARI Sunflower 2. Islam *et al.* (2019) suggested that up to 80 mM NaCl concentration was tolerable for soybeans but more than that the germination will be affected. Islam *et al.* (2021) claimed that more than 100 mM NaCl concentration affected the seed sprouting of okra and gradually decreased the emergence of seeds with the increase of salt concentration.

Time of Germination

Based on the data presented in Figure 3b, it has been observed that BINA Soybean 4 exhibited a rapid germination rate (10.87 DAS), which was found to be statistically equivalent to the other two varieties. Late germination (14.56 DAS) was observed in the presence of a 200 mM NaCl concentration, indicating salinity stress. Conversely, the absence of NaCl (0 mM) resulted in fast sprouting (8.11 DAS) (Table 4). Significant variation was observed at the time of germination when considering the combined effects of variety and different levels of salt concentration, as indicated in Table 5. The treatment combination V_1T_0 showed significantly fast germination (7.67 DAS) which was similar to the V_1T_1, V_2T_0, V_2T_1, V_3T_0, and V_3T_1 treatment combinations. Inversely, the treatment combinations V_1T_4, V_2T_4, and V_3T_4 showed a slower rate of germination. According to the study conducted by Farhoudi and Tafti (2011), it concluded that applying salinity stress resulted in a significant prolongation of the average germination period.

Number of Branches per Plant

The quantification of the number of branches per plant was done and the findings revealed inequalities among the different varieties (Figure 3c). The varieties BINA Soybean 2 and BINA Soybean 4 showed the highest number of branches per plant, with recorded values of 2.58 and 2.62, respectively. These two varieties were found to be statistically similar. However, the number of branches per plant gradually declined with the increase in the concentration of salt. In 0 mM NaCl showed maximum branching in the plant instead of other treatments (Table 4). The combination treatment V_2T_0 showed a maximum number of branches per plant (4.87) whereas the minimum number of branches per plant was found in V_1T_4, V_1T_3, V_2T_4, and V_3T_4 treatments (Table 5). El-Sabagh *et al.* (2015) observed that the control condition resulted in the highest average number of branches per plant. Furthermore, the researchers found that an application of salinity stress caused a significant decrease in the number of branches per plant compared to the control condition. Islam *et al.* (2012) reported a similar finding, observing a decrease in the number of branches in lentil plants exposed to salinity. The inhibition of new branch formation may be assigned to the presence of salinity.

Number of Leaves per Plant

Considering the number of leaves per plant, significant variations were noticed among all treatments and genotypes. Variety V_2 and V_3 showed maximum leaves per plant whereas variety V_1 showed minimum (Figure 3d). High salt concentrations decline the leaves number in plants. The highest number of leaves per plant (15.44) was found in 0 mM NaCl treatment (Table 4). In combination treatments, V_2T_0 (BINA Soybean 2×0 mM NaCl) showed maximum leaves per plant (19.11), and the minimum leaves were found in V_1T_3, V_1T_4, V_2T_3, V_2T_4, and V_3T_4 treatment respectively (Table 5). According to Mishra *et al.* (1995), the presence of a low concentration of NaCl did not have a significant impact on the leaf count. However, a higher concentration of soluble salt in water was found to have a notable influence on the number of leaves. Islam *et al.* (2012) and El-Sabagh *et al.* (2015) also observed that control treatment provided the most leaves per plant.

Number of Flowers per Plant

The superiority of the V_2 (BINA Soybean 2) variety in the number of flowers per plant (17.84) was more evident compared with other varieties (Figure 3e). The treatment with 0 mM NaCl resulted in the highest number of flowers per plant, while the number of flowers exhibited a decreasing trend as salt stress levels increased (Table 4). Combining the effects of variety and various levels of salt concentration on the number of flowers per plant produced substantial variation. V_1 (BINA Soybean 1) along with T_0 (0 mM NaCl) provided the highest number of flowers (32.33) which was statistically similar to the V_2T_0 (32.11) treatment and the minimum flower number was recorded in V_1T_4 (1.33) treatment (Table 5). Previous studies have demonstrated that the presence of high salinity levels has a substantial negative impact on the abundance of inflorescences and flowering (Ventura *et al.*, 2014; Tayyab *et al.*, 2016).

Plant Height

The data presented in Figure 4a clearly indicates that the various cultivars had significant effects on plant height. The highest plant height (20.64 cm) was obtained from V_1 (BINA Soybean 1). The results also showed that salt stress reduced the plant height. The maximum plant height (32.63 cm) was found in 0 mM NaCl salt concentration and the minimum plant height (2.52 cm) was found in 200 mM NaCl salt concentration (Table 6). The combined effects of variety and different levels of salt concentration in terms of plant height exposed significant variation (Table 7). The highest plant height was found in V_1T_0 (BINA Soybean 1×0 mM NaCl) treatment which was statistically similar to the V_1T_1, V_2T_0, and V_3T_0 treatments, and the lowest plant height was found in the V_3T_4 treatments which was statistically similar to the V_3T_3, V_2T_3, V_2T_4 and V_1T_4 treatment combinations. Begum *et al.* (2022) reported that salt stress reduced the plant height, biomass, and relative water content. Amirjani (2010) observed that increasing salinity levels of 50, 100, and 200 mM NaCl resulted in a reduction of plant height of 30, 47, and 76%.

Number of Pods per Plant

Statistically significant differences existed among the varieties for the average number of pods per plant (Figure 4b). From the results, the maximum number of pods per plant (13.38)

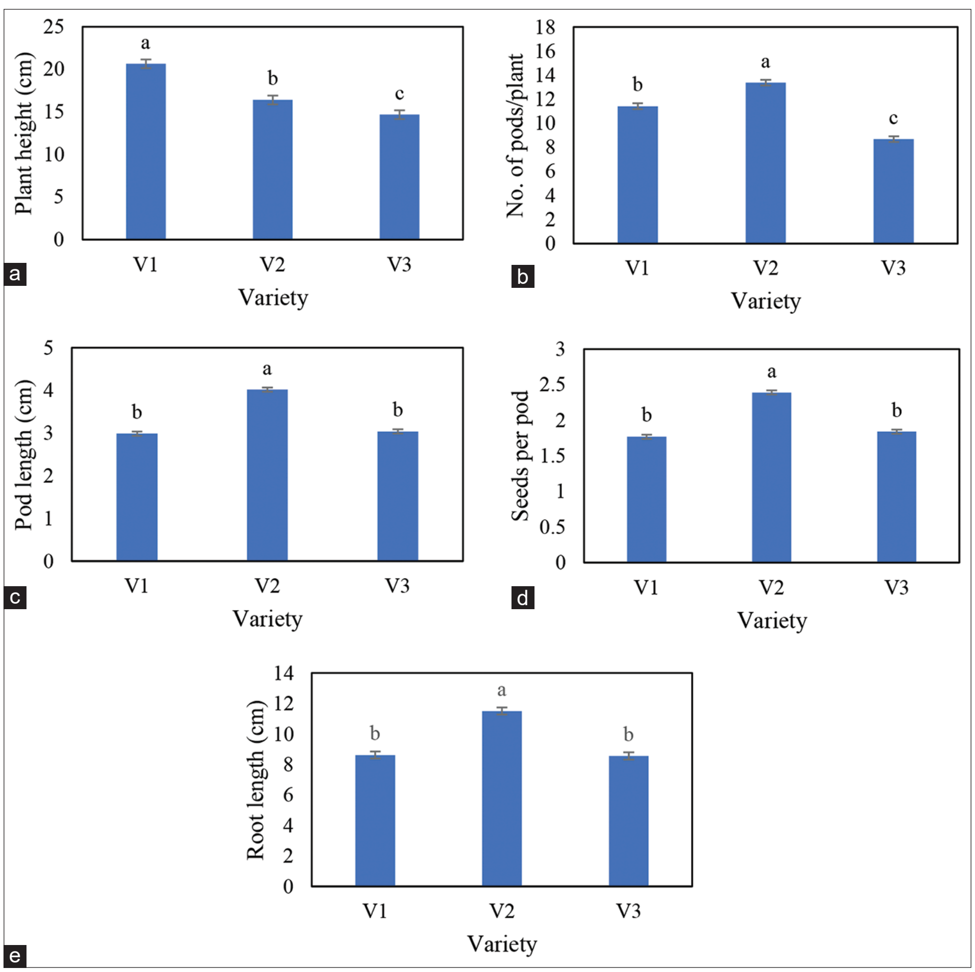

Figure 4: Genotypic performance effect on (a) plant height (cm); (b) no of pods/plant; (c) pod length (cm); (d) seeds/pod; (e) root length (cm); V1: BINA Soybean 1; V2: BINA Soybean 2; V3: BINA Soybean 4. The values are the averages of three replicates ± SE (standard error). One-way ANOVA (analysis of variance) was used to find the mean, standard error mean, and p-value. Tukey's HSD of post-hoc test was used to find the significant differences between treatments. Different letters (a, b, c) show significant differences according to the homogenous subsets of Tukey's HSD test at 0.05 level of significance

Table 6: Effects of different levels of salt concentration on plant height (cm), number of pods per plant, pod length (cm), seeds per pod, and root length (cm)

Salt concentration	Plant height (cm)	Number of pods per plant	Pod length (cm)	Seeds per pod	Root length (cm)
T_0	32.63a	23.26a	5.59a	4.24a	18.19a
T_1	26.44b	16.85b	4.89b	2.80b	13.63b
T_2	17.66c	10.99c	3.41c	1.69c	9.37c
T_3	6.96d	3.41d	1.7d	0.92d	4.78d
T_4	2.52e	1.3e	1.09e	0.35e	1.88e
Level of significant	*	*	*	*	*
SE (±)	0.65	0.31	0.06	0.04	0.31
CV (%)	1.90	0.89	0.20	0.14	0.90

*=Significant at 5% level of probability, CV=Co-efficient of variations, SE(±)=Standard Error. T_0=0 mM NaCl, T_1=50 mM NaCl, T_2=100 mM NaCl, T_3=150 mM NaCl, T_4=200 mM NaCl, Here, values in the column having a similar letter (s) are statistically identical (Tukey's HSD test at $p<0.05$)

Table 7: Combined effects of variety and different levels of salt concentration on plant height (cm), number of pods per plant, pod length (cm), seeds per pod, and root length (cm)

Treatment combination	Plant height (cm)	Number of pods per plant	Pod length (cm)	Seeds per pod	Root length (cm)
V_1T_0	34.67a	24.22a	5.17bc	4.29b	18.44ab
V_1T_1	30.78a	18.00b	4.61de	2.67d	13.89de
V_1T_2	22.33b	10.22d	2.73g	1.07g	7.66f
V_1T_3	11.67d	3.67ef	1.47h	0.50h	2.11gh
V_1T_4	3.78e	1.00g	1.02ij	0.29h	0.99h
V_2T_0	32.00a	25.89a	6.41a	4.77a	19.67a
V_2T_1	26.00b	19.56b	5.30b	2.89d	14.56cd
V_2T_2	16.44c	14.33c	4.29e	2.26e	12.11e
V_2T_3	5.33e	5.00e	2.59g	1.67f	8.44f
V_2T_4	2.22e	2.11fg	1.50h	0.39h	2.78gh
V_3T_0	31.22a	19.67b	5.22b	3.67c	16.44bc
V_3T_1	22.55b	12.99c	4.77cd	2.83d	12.45e
V_3T_2	14.22cd	8.44d	3.21f	1.74f	8.33f
V_3T_3	3.89e	1.56g	1.22hi	0.61h	3.79g
V_3T_4	1.55e	0.79g	0.78 j	0.37h	1.88gh
Level of significant	*	*	*	*	*
SE (±)	1.13	0.53	0.12	0.08	0.54
CV (%)	4.20	1.97	0.44	0.31	2.00

*=Significant at 5% level of probability, NS=Non-significant, CV=Co-efficient of variations, SE(±)=Standard Error. V_1=BINA Soybean 1, V_2=BINA Soybean 2, V_3=BINA Soybean 4, T_0=0 mM NaCl, T_1=50 mM NaCl, T_2=100 mM NaCl, T_3=150 mM NaCl, T_4=200 mM NaCl, Here, values in the column having a similar letter (s) are statistically identical (Tukey's HSD test at $p<0.05$)

was found in V_2 (BINA Soybean 2) variety. Different salt stress also affects the pod quantity in the plant. Maximum pods per plant (23.26) were found in T_1 (0 mM NaCl) treatments while the minimum (1.3) was found in T_4 (200 mM NaCl) treatment (Table 6). The combined effects of variety and salinity also showed significant variation (Table 7). The extreme number of pods per plant (25.89) was collected from the combination of BINA Soybean 2×0 mM NaCl (V_2T_0) which was statistically similar to the V_1T_0 treatment combination and the lowest number of pods per plant (0.79) was collected from the V_3T_4 which was statistically similar to the V_3T_3 and V_1T_4 treatment combinations. Ghassemi-Golezani *et al.* (2009) revealed that salinity stress limited the production of pods and grains per plant in soybeans. Mannan *et al.* (2013) observed that the reduction in the number of pods per plant at 50 mM NaCl ranged from 29% to 61%, and at 100 mM NaCl ranged from 48% to 80%.

Pod Length

The pod length was measured, and the results showed a significant difference among the varieties. The highest pod length (4.02 cm) was recorded in V_2 (BINA Soybean 2), whereas the lowest pod length was recorded as 2.99 cm and 3.04 cm in V_1 and V_3 varieties (Figure 4c). However, the pod length was statistically different and showed a significant reduction under high salinity stress. The highest pod length (5.59 cm) was noted in T_0 (0 mM NaCl) treatment and the lowest pod length (1.09 cm) was noted in T_4 (200 mM NaCl) treatment (Table 6). Considerable variation was obtained by combined effects of variety and different levels of salt concentration on pod length (Table 7). The highest pod length (6.41 cm) was observed in V_2T_0 (BINA Soybean 2×0 mM NaCl) treatment and the lowest pod length (0.78 cm) was observed in the V_3T_4 treatment combination. In another leguminous crop, the most extended pods were found in the control condition compared to the other treatments (Düzdemir *et al.*, 2009).

Seeds per Pod

The findings revealed statistically significant differences in the number of seeds per pod across the three varieties (Figure 4d). The maximum number of seeds (2.39) was produced in V_2 (BINA Soybean 2), which was significantly higher than the other two varieties. Seeds per pod were meaningfully influenced by the different concentrations of NaCl. Seeds per pod reduction were more in T_4 (200 mM NaCl) treatment and less in T_0 (0 mM NaCl) treatment (Table 6). The combined effects of variety and salinity also exhibited significant variation (Table 7). V_2 (BINA Soybean 2) along with T_0 (0 mM NaCl) provided the maximum number of seeds per pod (4.77) and the minimum number of seeds per pod (0.29) was recorded in V_1T_4 treatment which was statistically alike to the V_2T_4, V_3T_3, V_3T_4, and V_1T_3 treatment combinations. Consequently, BINA Soybean 2 outperformed the other two varieties. Ghassemi-Golezani *et al.* (2009) discovered that salinity stress limited the production of pods and grains per plant in soybeans. Similar results were found by Islam *et al.* (2012) in lentil genotypes and Mannan *et al.* (2013) in BARI Soybean 5 under salt stress.

Root Length

The progressive decrease in soybean root length was caused by the deleterious effect of high salinity levels (Figure 4e). The variety V_2 (BINA Soybean 2) exhibited the highest root length (11.51 cm), which was significantly higher compared to the other two varieties. However, the T_0 treatment exhibited the greatest root length, measuring 18.19 cm, while the remaining treatments demonstrated a notable decrease in root length when given high salinity stress (Table 6). In the case of a combination effect, the V_2T_0 (BINA Soybean 2×0 mM NaCl) treatment generated the longest roots (19.67 cm) in comparison to the other combination treatments (Table 7). Chowdhury *et al.* (2018) observed a significant reduction in root and shoot length of plants in response to increasing NaCl concentration, which aligns with the findings of our experimental study. Islam *et al.* (2012) reported comparable findings in their study on the impact of salt stress on lentil genotypes.

CONCLUSION

The impact of salinity stress on various soybean cultivars was assessed during both the vegetative and reproductive stages. In the presence of stressful conditions, the BINA Soybean 2 variety along with 0 mM NaCl, 50 mM NaCl, and 100 mM NaCl treatments demonstrated superior performance across all measured parameters in comparison to the other varieties. The variety of BINA Soybean 2 with a concentration of 100 mM NaCl resulted in seed germination exceeding 70%. Nevertheless, seed germination was reduced under salt treatment as the salt concentration increased. Additionally, the current study revealed that BINA Soybean 1 and BINA Soybean 4 exhibited greater susceptibility and lower tolerance to salinity stress, particularly at a concentration of 100 mM NaCl, compared to BINA Soybean 2. The findings of this study contribute to the advancement of our understanding regarding plant responses to salt-induced stress. These findings are particularly useful for the cultivation of soybean cultivars in coastal areas of Bangladesh.

ACKNOWLEDGMENT

The authors of the research express their gratitude to the Departments of Agriculture at Noakhali Science and Technology University, Bangladesh, and the Bangladesh Institute of Nuclear Agriculture (BINA) for providing the experimental materials used in the study.

CONFLICTS OF INTEREST

All other authors declare no conflict of interest.

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