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Morpho-Physiological Response of Salt-Tolerant Chili (*Capsicum annuum* L.) Genotypes Under Saline Conditions

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Abstract— *Salinity is a major challenge in crop cultivation, but tolerant genotypes can adapt physiologically to cope with stress. A pot culture experiment conducted during the period of July 2021 to June 2022 at Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, evaluated the impact of salt stress on eight chili genotypes at three salinity levels (T_1=3 dS/m, T_2=6 dS/m, T_3=9 dS/m NaCl) compared to a control (T_0=0 dS/m NaCl). Varieties and stress interaction were estimated based on agromorphogenic and physiological traits. Increasing salinity levels significantly reduced plant growth traits like height, number of branches, days to first flowering, and leaf area, as well as fruit traits such as length, girth, weight, and number per plant. Among the genotypes, G4 was highly tolerant to salinity, while G5 and G6 are recommended for mild to moderately saline prone areas.*

Keywords*— *Chili, different salinity levels, genotypes, screening salt tolerance, yield

I. INTRODUCTION

Chili (*Capsicum annuum* L.), an essential vegetable crop globally and in Bangladesh, is consumed fresh as a salad and dried as a condiment. Its high market demand and value are due to its vibrant colors, flavors, and pungency (Conforti et al., 2007). Belonging to the Solanaceae family, which includes tomatoes, potatoes, and eggplants, *Capsicum annuum* is widely cultivated for its herbaceous growth and white, star-shaped flowers leading to diverse fruit types. With a diploid chromosome number of 2n=24, the genetic traits influencing fruit characteristics are crucial for breeding new varieties. Chili peppers are nutrient-rich, particularly in vitamin C, which supports immune health and collagen synthesis, and contain capsaicin, known for potential health benefits like pain relief and metabolism enhancement. These peppers are low in calories and carbohydrates, making them a versatile ingredient in various dishes.

The UN Environment Program estimates that 20% of agricultural land and 50% of cropland globally are salt-stressed (Flowers and Yeo, 2005). Salt stress significantly impacts crop productivity, posing a major threat where saline water is used for irrigation (Munns, 2002). It affects approximately 800 million hectares of land globally (SRDI, 2010), with Bangladesh having about 2.85 million hectares of coastal land, one million of which are saline (Haque et al., 2014). Salt stress reduces plant growth and yield due to osmotic and ionic effects, disrupting water and nutrient uptake (Greenway and Munns, 1980; Maas, 1996). The predominant salinity due to climate change severely affects crop productivity in Bangladesh's saline regions (Rahman et al., 2007). Salinity affects plant metabolism, enzymatic activities, protein functions, and gene expression, reducing growth and damaging vegetative and productive parts (Parida and Das, 2005; Arefian et al., 2014; Legay et al., 2009).

Chili genotypes show significant variation in salt tolerance (Niu et al., 2010). Understanding cultivar responses to salinity helps elucidate salt tolerance mechanisms and identify suitable cultivars for salt-affected soils. High soil salinity decreases plant yield through osmotic stress, ion toxicity, and reactive oxygen species (ROS) production, leading to oxidative damage and impaired cellular functions (Rozema and Flowers, 2008; Mahajan and Tuteja, 2005; Ahmad and Umar, 2011).

Many saline areas in southern Bangladesh remain fallow during the rabi season. Expanding chili cultivation in these areas could help alleviate food scarcity. Identifying suitable chili varieties for these regions is crucial, yet studies on salt-tolerant chili genotypes are limited. This study aims to evaluate the effect of varying NaCl concentrations on growth parameters in chili genotypes to understand plant responses to salt stress and select salt-tolerant varieties.

II. MATERIALS AND METHODS

2.1 Location of the experiment

This experiment was carried out at the research net house, Sher-e-Bangla Agricultural University, Dhaka. The experimental site is situated at 23°46' N latitude and 90°22' E longitude, with an elevation of 8.2 m above sea level, falling within the Agro-ecological Zone "AEZ-28" of Madhupur Tract.

2.2 Planting material

A total of eight genotypes of Chili (Table 1) were collected from Plant Genetic Resource Centre (PGRC) at Bangladesh Agricultural Research Institute (BARI), Gazipur, other local market and personal communication. The purity and germination percentage were leveled around 100% and 95% respectively. The name and origin of these genotypes were presented in (Table 1).

Table 1. Name and origin of eight Chili genotypes used in the study

Genotypes No.	**Name/Acc No.**	**Origin**
G1	Tufan	Local market
G2	Surjamukhi	Local market
G3	Kalo Manik	Local market
G4	Bulet lonka	Local market
G5	Rocket	Local market
G6	Super	Local market
G7	SRCO 9	PGRC, BARI
G8	SRCO 13	PGRC, BARI

PGRC=Plant Genetic Resource Centre, BARI=Bangladesh Agricultural Research Institute

2.3 Saline treatment

The seeds were sown in plastic pots of 10-liter (L) volume filled with sand during spring in net house under both normal and salt stress conditions. Salt treatments were achieved via the gradual addition of NaCl. One control and three levels of salt were: T_0 = 0 dS/m (control), T_1= 3.00 dS/m, T_2= 6.00 dS/m and T_3=9.00 dS/m. After 20 days of transplanting, treatment was applied and irrigated every two days intervals.

2.4 Experimental design and layout

The experiment was laid out and evaluated during Rabi season 2021-22 in completely randomized design (CRD) using two factors. Factor A included eight genotypes and Factor B included 3 salt treatments with one control. The experiment was conducted in 3 replications.

2.5 Intercultural operation

Some intercultural operations are irrigation and drainage, gap filling, weeding, staking, spraying of insecticides and fungicides, and protection of crops from other pests.

2.6 Data Collection

Different morpho-physiological and yield contributing characters were recorded viz., plant height(cm), number of branches plant^{-1}, days to first flowering, number of fruits per plant, average fruit length (mm), average fruit diameter (mm), average fruit weight, leaf area (cm^2), days to maturity, chlorophyll content(mg/cm^2) and yield per plant (g).

2.7 Statistical Analysis

The data of observation were analyzed using analysis of variance (ANOVA). The Statistics 10 computer program was employed for the statistical analysis of the data derived from the experiment's diverse parameters. Mean values for each parameter were computed, and an analysis of variance was conducted. The Duncan Multiple Range Test was utilized at a 5% probability level to assess the significance of differences among treatment mean.

III. RESULTS

3.1 Plant height (cm)

The study demonstrated that salt stress had a detrimental effect on the performance of plant height of eight chili genotypes when compared to the control group. Among the genotypes, the mean plant height ranged from 27.33 cm to 40.00 cm in 9.00 dS/m NaCl treatment and 68.67 cm to 90.00 cm in control. Under 9.00 dS/m saline water treatment the highest plant height was observed by the genotype G3 (40.00cm) followed by the genotype G1 (38.33 cm).

3.2 Number of branches per plant

The number of branches per plant was found statistically significant in interaction among salt and genotypes. Mean number of branches per plant was ranged between 27.33 to 38.33 (control) and 5.33 to 11.67 in treatment T_4. As expected, the control condition yielded the highest number of branches per plant, while the highest NaCl concentration (9.00 dS/m NaCl) resulted in the lowest number of branches.

3.3 Days to first flowering

Significant differences were observed for days to first flowering in all the treatments which in an important criterion to assess the earliness for flowering. Earliness for flowering was registered between 28.67 days in control and 43 days under 9 dS/m NaCl. Under control treatment, it varied from 28.67 days (G4) to 40.67 days (G1). At the highest saline stress level (9 dS/m of NaCl), G4 took 43 days for flowering followed by G5 and G6 as 47.67 days and 48 days respectively (Table 2). which was on par with var. CO1 (88.50 days). G4 and G5 were produced flowers and showed tolerance to salinity upto the highest concentration of 9 dS/m of NaCl.

Table 2. Variation in morphological parameters of chili genotypes to increasing salinity levels

Genotypes	Plant Height(cm)				Number of branches /plants				Days to first flowering			
	T_0	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**
G1	89.33	62.33	46.67	38.33	39.67	23.33	16.33	6.33	40.67	44.00	46.67	51.67
G2	72.33	49.67	34.67	27.33	30.67	21.67	13.67	11.33	38.67	40.66	44.67	48.00
G3	84.00	81.33	45.67	40.00	37.33	26.33	21.33	11.67	36.66	39.39	46.66	54.00
G4	68.67	54.33	43.00	36.00	32.67	21.33	11.67	6.33	28.67	32.33	35.66	43.00
G5	74.33	57.00	37.33	29.33	27.33	15.67	11.67	5.33	33.33	35.67	42.00	47.67
G6	89.67	63.33	53.67	31.33	48.33	34.00	22.00	6.67	37.67	40.00	44.33	53.33
G7	90.00	74.33	46.67	37.00	44.33	30.33	14.33	9.67	35.33	39.00	43.66	51.67
G8	89.33	59.33	40.67	31.33	31.33	20.33	11.67	7.67	37.33	37.67	44.67	49.33
Factors	Plant Height(cm)				Number of branches /plants				Days to first flowering			
	G	T	G×T		G	T	G×T		G	T	G×T	
CV %	3.69	3.69	3.69		9.00	9.00	9.00		3.30	3.30	3.30	
LSD 0.05	2.62	1.56	6.62		2.41	1.09	6.10		1.77	1.05	4.47	

T_0 = 0 dS/m (control), T_1= 3.00 dS/m, T_2= 6.00 dS/m and T_3=9.00 dS/m

3.4 Days to first fruit setting

Salinity stress can significantly delay reproductive development in plants, including the setting of the first fruit. Interaction effects of chili genotypes and salt treatments were significant on days to first fruit setting. Maximum days to first fruit set (70.66) was obtained from G_7T_3 whereas minimum days to first fruit set (43.66) was found in G_4T_0 (Table 3).

3.5 Fruit length (mm)

The fruit length was significantly affected and decreased with increasing salinity levels. The highest fruit length of 106.67 mm was recorded in the control by G1 (Tufan). This was followed by Rocket (96.67 mm). At the highest stress level (9 dS/m NaCl) G1 (Tufan) recorded highest fruit length (55.33 mm) whereas the minimum fruit length (28.67) was found in G_8T_3 (Table 3).

3.6 Diameter of fruit (mm)

Fruit diameter showed statistically significant variation in term of interaction among genotypes and different saline levels. The highest fruit diameter (12.66) was found in G_1T_0 whereas the lowest fruit diameter (3.33) was found in G_3T_3 (Table 3).

Table 3. Variation in physiological and yield parameters of chili genotypes to increasing salinity levels

Genotypes	Days to first fruit setting				Length of fruit (mm)				Diameter of fruit (mm)			
	T_0	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**
G1	51.00	54.33	60.33	69.00	106.67	95.00	90.00	55.33	12.66	7.33	5.67	5.33
G2	48.33	47.67	59.00	64.00	86.33	73.67	45.00	31.33	11.33	9.00	6.67	4.00
G3	51.67	50.00	62.00	67.67	66.33	61.00	51.67	32.33	6.67	5.33	4.67	3.33
G4	43.67	47.33	52.67	60.67	57.67	53.67	44.67	34.00	10.33	6.33	4.67	4.33
G5	46.67	48.00	59.33	66.33	96.67	83.33	64.67	44.33	9.00	7.33	5.33	4.67
G6	52.33	55.67	59.33	69.67	65.00	56.33	40.67	29.67	5.33	6.33	5.33	5.67
G7	47.00	51.33	57.67	70.67	90.33	78.33	53.67	35.00	6.33	4.67	5.00	3.67
G8	55.67	58.33	62.67	69.00	55.00	45.33	34.33	28.67	6.67	5.67	5.33	3.67
Factors	Days to first fruit setting				Length of fruit (mm)				Diameter of fruit (mm)			
	G	T	G×T		G	T	G×T		G	T	G×T	
CV %	2.61	2.61	2.61		4.40	4.40	4.40		11.57	11.57	11.57	
LSD 0.05	1.90	1.13	4.80		2.11	1.49	4.21		0.58	0.41	1.17	

T_0 = 0 dS/m (control), T_1= 3.00 dS/m, T_2= 6.00 dS/m and T_3=9.00 dS/m

3.7 Number of fruits per plant

The mean number of fruits per plant ranged between 57.33 (control) to 28.33 (9dS/m NaCl). Interaction of chili genotypes and salt treatments affects significantly on number of fruits per plant. In this case maximum number of fruits were found in G_6T_0 (73.66/plant) and minimum were observed in G_7T_3 (4.66/plant) (Table 4).

3.8 Days to maturity

Salinity stress typically delays the developmental processes in plants, leading to an extended time required to reach maturity. Interaction of chili genotypes and salt treatments affects significantly on days taken to fruit harvest (red). In this case earlier harvesting period (81.00 days) was observed in G_5T_0 whereas delayed in G_3T_3 (111 days) (Table 4).

3.9 Chlorophyll content (mg/cm^2)

Salinity stress often leads to a reduction in chlorophyll content, adversely affecting photosynthetic efficiency and overall plant growth. Chlorophyll content showed statistically significant variation among the interactions of treatments and genotypes. The highest chlorophyll content (64.56) was found in G_6T_0 whereas the lowest chlorophyll content (39.26) was found in G_6T_3 combination (Table 4).

Table 4. Variation in physiological and yield parameters of chili genotypes to increasing salinity levels

Genotypes	Number of fruits /plants				Days to maturity				Chlorophyll content (mg/cm^2)			
	T_0	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**
G1	57.33	40.67	23.67	11.67	92.00	94.67	103.33	105.33	61.90	57.37	48.60	41.60
G2	39.33	30.67	15.67	6.33	95.33	98.33	103.33	108.67	60.43	51.70	49.90	41.70
G3	44.67	38.33	25.67	9.67	97.00	99.33	107.33	111.00	43.93	47.83	40.40	41.37

G4	51.67	43.33	25.67	8.67	86.67	89.67	93.33	101.00	57.73	53.50	45.77	40.63
G5	35.00	28.67	19.33	5.33	81.00	83.67	96.00	104.67	47.47	45.36	41.73	38.70
G6	73.67	61.33	38.67	13.67	88.67	89.67	98.67	105.67	64.57	57.13	51.17	39.27
G7	28.33	19.67	9.33	4.67	86.33	89.00	92.67	102.00	53.50	54.30	50.46	41.17
G8	38.33	33.00	15.67	6.67	89.33	92.00	94.33	100.33	51.83	46.57	39.40	31.87
Factors	Number of fruits /plants				Days to maturity				Chlorophyll content (mg/cm^2)			
	G	T	G×T		G	T	G×T		G	T	G×T	
CV %	6.62	6.62	6.62		1.60	1.60	1.60		4.35	4.35	4.35	
LSD 0.05	1.53	1.08	3.05		1.25	0.89	2.51		1.71	1.21	3.41	

T_0 = 0 dS/m (control), T_1= 3.00 dS/m, T_2= 6.00 dS/m and T_3=9.00 dS/m

3.10 Leaf area (cm^2)

The study results showed that salt stress impacted the leaf area drastically in all the chili genotypes across the three saline treatments. In the control group, leaf area varied from 20.67 cm² per plant (G2) to 36.67 cm² (G3). Leaf area performed significant variation among interaction between genotypes and treatments. The highest leaf area was found in G_3T_0 (35.66) whereas the lowest leaf area was found in G_8T_3 (12.00) (Table 5).

3.11 Yield per plant (g)

Salinity stress generally leads to a reduction in yield per plant due to its adverse effects on various physiological and biochemical processes. Interaction of chili genotypes and salt treatments significantly affects the yield per plant of chili. Maximum yield (335.67) was obtained in the genotypes G_1T_0 from while minimum yield (9.17) from G_7T_3 (Table 5).

Table 5. Variation in physiological and yield parameters of chili genotypes to increasing salinity levels

Genotypes	Leaf area (cm^2)				Yield per plant (g)			
	T_0	**T_1**	**T_2**	**T_3**	**T_0**	**T_1**	**T_2**	**T_3**
G1	27.67	19.33	18.00	17.00	335.67	156.00	78.00	32.33
G2	20.67	20.33	16.67	12.67	168.33	126.00	59.33	11.50
G3	35.67	26.33	16.67	15.67	189.67	165.16	81.33	21.67
G4	22.33	18.00	16.33	12.33	247.33	208.33	78.67	17.00
G5	27.67	22.00	19.00	13.00	145.00	112.33	56.00	10.50
G6	23.00	19.00	16.00	13.00	331.33	252.67	135.00	29.50
G7	31.33	25.00	23.00	16.33	123.33	75.33	27.00	9.17
G8	27.00	22.00	16.00	12.00	124.33	101.33	41.00	12.67
Factor	Leaf area (cm^2)				Yield per plant (g)			
	G	T	G×T		G	T	G×T	
CV %	8.62	8.62	8.62		6.65	6.65	6.65	
LSD0.05	1.41	1.00	2.82		6.04	4.27	12.08	

T_0 = 0 dS/m (control), T_1= 3.00 dS/m, T_2= 6.00 dS/m and T_3=9.00 dS/m

3.11 Yield per plant (g)

Salinity stress generally leads to a reduction in yield per plant due to its adverse effects on various physiological and biochemical processes. Interaction of chili genotypes and salt treatments significantly affects the yield per plant of chili. Maximum yield (335.67) was obtained in the genotypes G_1T_0 from while minimum yield (9.17) from G_7T_3 (Table 5).

IV. DISCUSSION

Saline-tolerant chili genotypes likely exhibited restricted translocation or exclusion of Na+ and K- ions from root to leaves, leading to increased photosynthate assimilation and osmotic adjustment to the growing conditions. This enabled them to maintain the necessary cell enlargement, resulting in greater plant height and more branches. Similar findings were reported by Shahid et al., (2011), Samira et al., (2012), and Zhani et al., (2012).

Salinity stress can significantly delay reproductive development in plants, including the setting of the first fruit. High salt levels disrupt water uptake, nutrient availability, and hormonal balance, which are essential for flowering and fruit setting (Munns and Tester, 2008). Salinity also induces oxidative stress, which damages cellular structures and impairs metabolic processes crucial for reproductive growth (Zhu, 2001).

High salt levels can disrupt water uptake, nutrient availability, and hormonal balance, resulting in slower growth and delayed fruit maturation (Munns and Tester, 2008). Khan et al., (2016) reported that salt-tolerant chili genotypes reached green maturity faster than salt-sensitive genotypes when exposed to saline conditions. These tolerant genotypes maintained higher photosynthetic rates, better water use efficiency, and more stable hormonal balances, contributing to their quicker development and earlier maturity.

Research on chili genotypes under salt stress has revealed significant variations in chlorophyll content. For instance, Kumar et al., (2017) found that salt-tolerant chili genotypes maintained higher chlorophyll content and exhibited less chlorophyll degradation under saline conditions compared to salt-sensitive genotypes. Additionally, salinity stress disrupts the balance of essential nutrients, such as magnesium, which is a central atom in the chlorophyll molecule, further contributing to chlorophyll degradation (Hussain et al., 2019).

Evidence indicates that salinity increases leaf lamina thickness by enlarging mesophyll cells or adding more layers, leading to salt-induced succulence that reduces resistance to CO_2 uptake and boosts photosynthesis by increasing internal leaf surface area. Salt-tolerant genotypes may increase mesophyll thickness and internal CO_2 absorption surface area, compensating for any stomatal limitations (Kozlowski, 1997). At the highest stress level (9 dS/m NaCl), leaf area decreased to 12.00 cm^2 (G8) to 17.00 cm^2 (G1). Studies by Bandeoglu et al., (2000) and Nizam et al., (2017) showed that high Na ion concentration inhibits cell elongation, leading to retarded growth and leaf development due to membrane disorganization and inhibition of cell division and expansion (Deivanai et al., 2011).

Balanced nutrient uptake and moisture content likely facilitated the enzymatic and protein activities essential for fruit development under salinity. Maintaining turgor even under salinity could have enabled efficient cell division and elongation in these genotypes, resulting in increased yield.

Research on chili genotypes under salt stress has shown significant variation in yield per plant. For instance, Hasanuzzaman et al., (2013) found that salt-tolerant chili genotypes exhibited higher yields under saline conditions compared to salt-sensitive genotypes. These tolerant genotypes were able to maintain higher chlorophyll content, better water use efficiency, and more stable physiological functions, contributing to their improved yield performance.

V. CONCLUSION

The results of the present study demonstrated that NaCl present in the soil affects the physiological processes of growth and yield of chili. The increase in salinity level, decreased the growth, flowering, fruiting and yield and also yield contributing characters like fruit length, fruit girth, number of fruits and fruit weight. From the result of this experiment it has been concluded that G4 performed well under T_2 and T_3 treatment because maximum number of yields were obtained from it. Therefore, G4 varieties may be recommended for salt tolerant variety. The varieties G5 and G7 also given second highest yield under treatment. So, G5 and G7 variety can be recommended for mild to moderate saline prone area. These identified genotypes can also be used in breeding programs for developing superior and saline tolerant hybrids for commercial cultivation under salinity prone soils.

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