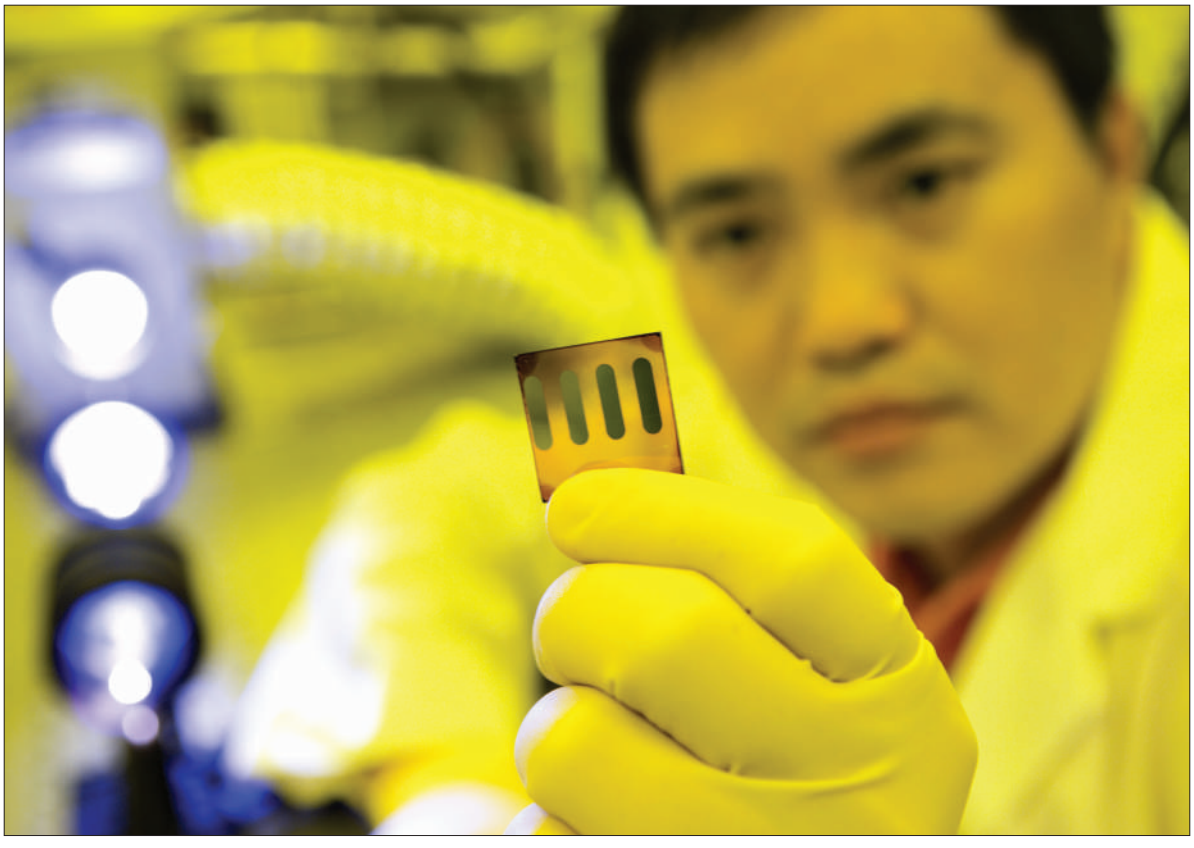

Singapore Journal of

Scientific Research

ISSN: 2010-006x

science alert

http://scialert.net/sjsr

OPEN ACCESS Singapore Journal of Scientific Research

ISSN 2010-006x
DOI: 10.3923/sjsres.2020.79.87

Research Article
Screening of Egyptian Okra Genotypes for Salinity Tolerance at the Seedling Stage

Ehab A. Ibrahim and Mohamed Y. Abed

Department of Cross Pollinated Vegetable Crops Research, Horticulture Research Institute, Agricultural Research Center, Giza, Egypt

Abstract

Background and Objective: The success of an okra breeding program in developing salt tolerant varieties depends on genetic variation and the salt stress response of adapted and donor okra germplasm. The present study was undertaken to identify salt-tolerant genotypes. **Materials and Methods:** Fourteen Egyptian okra genotypes were screened for salinity tolerance at the seedling stage. **Results:** The results showed significant effects of salinity (EC 8 dS m^{-1}) on all studied morphological and physiological traits of seedlings. Under salt stress, all genotypes showed a decrease in growth parameters and the contents of potassium ion in their tissues. By contrast, salinity stress increased the content of sodium ion and potassium/sodium ion ratio as well as the ion leakage percentage in tissues of the stressed plants. The relationships among all studied traits were tested. The results showed that significant correlations existed among most studied traits. The results suggested that the content of sodium and potassium ions, potassium/sodium ion ratio and the ion leakage percentage in tissues of seedling could be used as reference indicators in the selection of salt adaptive genotypes. **Conclusion:** Based on the results, the S14, S13, S9 and S8 genotypes were identified as the most tolerant genotypes to salinity stress as compared to others. Thus, they are recommended as useful and novel sources of salinity tolerance for Egyptian okra breeding programs.

Key words: Okra, *Abelmoschus esculentus*, seedling stage, salinity tolerance, genotypes

Citation: Ehab A. Ibrahim and Mohamed Y. Abed, 2020. Screening of Egyptian okra genotypes for salinity tolerance at the seedling stage. Singapore J. Sci. Res., 10: 79-87.

Corresponding Author: Ehab A. Ibrahim, Department of Cross Pollinated Vegetable Crops Research, Horticulture Research Institute, Agricultural Research Center, Giza, Egypt Tel: +20 01225103883

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Salinity is a worldwide problem limiting crop productivity, especially in arid and semi-arid regions such as Egypt[1]. Salt stress is going to increase with the predicted global temperature increase[2].

Salt stress causes adverse physiological and biochemical changes in plants that can delay growth and development and reduce yield[3-5]. Salt stress results in high accumulation of toxic ions like Na^+ and Cl^- in the root zone. These ions induce osmotic stress, ion toxicity and ion imbalance in plants by reducing the uptake of beneficial ions such as K^+. Moreover, salt stress induces oxidative stress by increasing the production of reactive oxygen species in the chloroplast and mitochondria[6-8]. These reactive oxygen species may react with macromolecules and lipid components of membranes causing an adverse effect on plants through lipid peroxidation, membrane injury, protein degradation and enzyme inactivation[9-11].

The response of plants to salinity stress is variable and dependent on various factors such as plant genotype, extent of stress and stage of plant growth when salt stress is experienced[12]. There is a need to enhance crop production under salinity conditions. The development of salt tolerant cultivars is an economical and effective approach to cope with salinity.

Okra (*Abelmoschus esculentus* L. Moench) is a popular summer vegetable crop in Egypt. It serves as a source of carbohydrates, vitamins and minerals[13]. Okra is a moderately tolerant to salinity[14]. Thus, high salt content causes adverse effects on the okra plant morphology, physiology, metabolism, enzyme activity and crop yield[7,15-20]. These effects occur by water deficit (osmotic stress), ion toxicity and ion imbalance (ionic stress) or a combination of these factors[21].

The adverse effect of salt stress appears at almost all growth stages of okra plants. But, seedling stage is more sensitive stage to salinity than adult stage[16,18]. Increasing salinity caused a decrease of shoot and root length and dry weight of okra seedlings[7,22]. In contrast, salinity stress had no significant effect on shoot dry weight[17,20].

However, the okra seedlings could keep the physiological growth attributes considerably well in the presence of relatively high salinity stress during the seedling stage[17,20]. The okra genotypes selected at this stage for salt tolerance maintained their tolerance during the ontogeny of whole plant[12].

The physiological adjustment to salt stress in okra seedlings is associated with the accumulation of Na^+, transport and selectivity of K^+, sodium to potassium ion ratio and osmotic adjustment[7,12].

The genetic variation for tolerance to NaCl salinity existed among the okra genotypes[12,23]. Variation in salinity tolerance of okra genotype is found from sensitive (EC 1.0 dS m^{-1})[24] to the tolerant genotypes (EC 3.48 dS m^{-1})[14]. Therefore, it becomes imperative to screen okra genotypes at the seedling stage under salinity conditions to identify tolerant genotypes for early seedling establishment, to minimize salinity effects and get higher yields[12,18].

Screening of available local germplasm for stress tolerance is the first step to identify tolerant parental genotypes. Approaches used to screen okra genotypes for salt tolerance at the seedling stage include the higher levels of K, low levels of Na within tissue and higher K/Na ratios[12] and electrolyte leakage in tissues[20].

The variation of the agronomic and physiological parameters among the genotypes confirmed that tolerance to salt is a complex trait. So, the cluster analysis has been employed in genotypic classification for salinity tolerance based on Euclidean distance of the salt tolerance indices[12,23]. Therefore, the present study was undertaken to evaluate the morpho-physiological responses of 14 okra genotypes to salinity stress condition at the seedling stage and further to identify ideal tolerant genotypes suited for breeding programs in Egypt.

MATERIALS AND METHODS

Plant materials and growth conditions: The genetic materials used in this study were 14 okra genotypes in the S4 generation, which were developed from a previous research work conducted by using a pedigree selection program on 14 local open-pollinated cultivars[25]. These genotypes were denoted (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13 and S14).

The experiment was carried out in net house at Mansoura Horticulture Research Station, Dakahlia Governorate, Egypt (longitude 31°37 85" E, latitude 31°04 09" N and altitude 19 m.a.s.l) during the summer season of 2018 (from May-June 5th).

The seeds were surface-sterilized with sodium hypochlorite (2% v/v) for 5 min and washed with distilled water. Five seeds of each genotype were sown in plastic pots of 250 mL capacity filled with washed fine sand as growing medium. After 15 days of germination, the seedlings were thinned out to 2 plants/pot.

Experimental design and treatments: The experiment was arranged in a randomized block design with 3 replicates. Six pots were used per replication of each plot. Seeds of 14 okra genotypes were subjected to zero (control) and 8 dS m^{-1} NaCl salinity. Sodium chloride was dissolved in distilled water to obtain final content of 8 dS m^{-1} and then this solution was applied to create the salinity while half strength Hoagland solution was applied as nutrient medium[26].

Salinity treatments started immediately after sowing by irrigation along with 0 or 8 dS m^{-1} NaCl according to the need of the seedlings by regularly observing the wetness extent of sand. Control plants were irrigated with nutrient solutions without NaCl.

Growth measurements: At 30 days after sowing, 5 seedlings were randomly collected from each plot. Seedlings were thoroughly washed with deionized water to remove dirt and other contaminants. Shoots and roots were separated then oven-dried at 65°C for 24 h. The plants materials were then weighed, ground and stored in clean sealed glasses at room temperature for later analysis.

Ion leakage percentage: Membrane leakage of cells was assessed by measuring the content of the ions that leaked from the leaf tissue using an electrical conductivity meter[27].

At 30 days after sowing, leaf samples of 3 plant/replicate were taken and cut into 1 cm^2 segments. The samples were thoroughly washed and incubated in 10 mL distilled water on a shaker (100 rpm) for 24 h at room temperature. After this incubation, electrical conductivity (EC) of bathing solution (EC1) was recorded. The leaf samples were then placed in an autoclave at 120°C for 20 min. After cooling the solution to room temperature, the second reading (EC2) was taken. The electrolyte leakage was calculated as EC1/EC2 and expressed as percentage[28].

Contents of Na^+ and K^+ ions in seedling parts: Dried powder samples were digested with 5 mL of nitric acid and 3 mL hydrogen peroxide at 152-155°C for 3 h in a hood. The digested tissues were diluted to a final volume of 12.5 mL and the content of sodium and potassium were quantified using a flame photometer[29]. Potassium uptake in relation to sodium (Na^+/ K^+ ratio) was calculated from the data of Na^+ and K^+ ions.

Statistical analysis: Data were analyzed by analysis of variance (ANOVA). The means were compared for significant differences using the least significant differences (LSD) at 5% probability level[30]. Pearson correlations were calculated to determine the relationship among the studied traits using number cruncher statistical system (NCSS). Discriminating traits between the tested genotypes for the response to 8 dS m^{-1} NaCl were identified through cluster analysis of the tolerance indices data matrix. The cluster analysis was carried out based on Euclidean distance of the salt tolerance indices. Euclidean distances between all pairs of genotypes were computed from standardized nine seedling traits and the phenogram of okra genotypes was formed based on the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) The similarities revealed ranged from 0 (high similarity) to 3.5 (low similarity). The Number Cruncher Statistical System (NCSS) was used to generate a dendrogram.

RESULTS

Seedling growth characteristics: The genotypes had significant differences for shoot and root dry weight of seedlings under control and salinity stress (Table 1). Data cleared that dry weights of shoot and root in all the genotypes were adversely affected by salinity stress. The genotypes S13 and S14 showed minimum reduction in dry weight of shoot (34 and 33%) and root (11 and 13.5%). While S2 genotype exhibited the highest reduction in shoot and root dry weight of seedlings by 43 and 21%. The shoot dry weight was found to be more adversely affected than the root dry weight (Fig. 1).

Ion leakage: Significant differences were observed for ion leakage percentage among genotypes and this trait was dramatically increased under salt stress in comparison with the control (Fig. 2). The highest ion leakage percentage values (36.4 and 36.2) were found in S1 and S7 genotypes, respectively. Whereas the lowest values (13.4 and 13.6) were found in S13 and S14 genotypes, respectively.

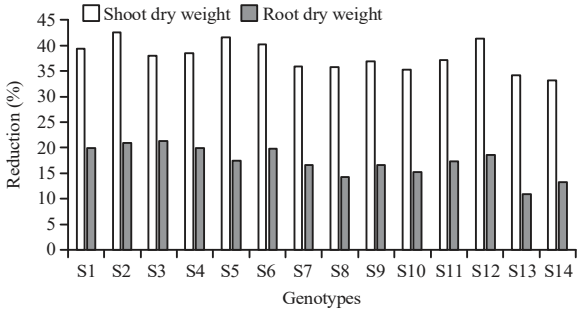

Fig. 1: Reduction percentage in shoot and root dry weight of seedlings under salinity stress for 14 okra genotypes

Table 1: Seedling growth characteristics of 14 okra genotypes grown under control and 8 dS m^{-1} NaCl

	Shoot dry weight (g/plant)		Root dry weight (g/plant)	
Genotypes	Control	8 dS m^{-1} NaCl	Control	8 dS m^{-1} NaCl
S1	0.38	0.23	0.20	0.16
S2	0.37	0.21	0.19	0.15
S3	0.31	0.19	0.14	0.11
S4	0.44	0.27	0.25	0.20
S5	0.36	0.21	0.19	0.16
S6	0.33	0.20	0.15	0.12
S7	0.30	0.19	0.18	0.15
S8	0.39	0.25	0.16	0.13
S9	0.37	0.23	0.16	0.13
S10	0.33	0.21	0.15	0.13
S11	0.43	0.27	0.21	0.17
S12	0.46	0.27	0.27	0.22
S13	0.38	0.25	0.15	0.13
S14	0.39	0.26	0.17	0.15
LSD 0.05	0.021		0.013	

Table 2: Contents of Na^+ and K^+ ions in seedling shoot of 14 okra genotypes grown under control and 8 dS m^{-1} NaCl

	Na content in shoot (mg g^{-1} d.wt.)		K^+ content in shoot (mg g^{-1} d.wt.)		Na^+/K^+ ratio in shoot	
Genotypes	Control	8 dS m^{-1} NaCl	Control	8 dS m^{-1} NaCl	Control	8 dS m^{-1} NaCl
S1	1.2	1.8	22.6	18.8	5.3	9.4
S2	1.1	1.7	22.5	18.6	4.9	9.1
S3	0.8	1.5	23.3	19.5	3.4	7.7
S4	1.1	1.8	22.2	18.6	5.0	9.7
S5	1.1	1.8	22.3	18.7	4.8	9.5
S6	0.9	1.7	22.8	19.2	4.1	8.9
S7	1.0	1.8	22.5	18.5	4.6	9.9
S8	0.9	1.6	23.0	19.4	4.1	8.3
S9	0.9	1.6	23.1	19.2	3.8	8.3
S10	1.0	1.7	22.9	19.1	4.5	8.9
S11	1.0	1.7	22.8	19.3	4.2	8.6
S12	1.2	1.6	22.5	19.1	5.3	8.6
S13	0.8	1.5	23.2	19.7	3.6	7.6
S14	0.8	1.5	23.4	19.7	3.2	7.6
LSD 0.05	0.13		0.38		0.65	

Contents of Na^+ and K^+ ions in seedling parts: The means of the genotypes for Na^+ and K^+ contents as well as Na^+/K^+ ratio in shoot and root under control and saline conditions are presented in Table 2 and 3. Obtained results clear that the content of Na^+ and Na^+/K^+ ratio were increased while the K^+ content was decreased in all the genotypes under salinity contents.

Under salt stress, Na^+ content and Na^+/K^+ ratio in shoot and root were higher in S1 and S7 genotypes, while the lowest were S13 and S14 genotypes. Seedlings of S13 and S14 genotypes grown in salinized medium showed an increased K^+ content in roots and shoots compared to non-salinized condition. In general, the shoot Na^+ content was more than the content of Na^+ in roots under salt stress.

Correlation of traits related to salinity tolerance: Correlation coefficients among the studied traits (Table 4) indicated that shoot dry weight has a significant positive correlation with root dry weight ($r^2 = 0.627$) and root K^+ content ($r^2 = 0.553$) while it has no significant negative correlation with other traits. Ion leakage showed highly positive correlations with Na^+

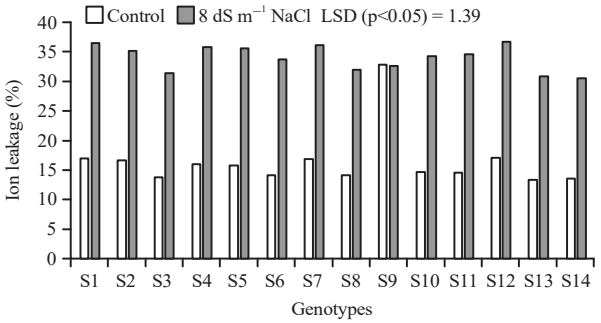

Fig. 2: Ion leakage percentage of 30 days old 14 okra genotypes grown under control and 8 dS m^{-1} NaCl

Table 3: Contents of Na^+ and K^+ ions in seedling root of 14 okra genotypes grown under control and 8 dS m^{-1} NaCl

	Na^+ content in root (mg g^{-1} d.wt.)		K^+ content in root (mg g^{-1} d.wt.)		Na^+/K^+ ratio in root	
Genotypes	Control	8 dS m^{-1} NaCl	Control	8 dS m^{-1} NaCl	Control	8 dS m^{-1} NaCl
S1	1.5	2.8	16.0	12.2	12.2	22.6
S2	1.5	2.7	16.2	12.4	12.4	21.8
S3	1.3	2.4	16.5	12.4	12.4	19.4
S4	1.4	2.6	16.3	12.5	12.5	20.8
S5	1.6	2.6	16.2	12.6	12.6	20.7
S6	1.3	2.5	16.3	12.9	12.9	19.4
S7	1.4	2.8	16.1	12.1	12.1	22.9
S8	1.3	2.2	16.4	13.3	13.3	16.5
S9	1.3	2.3	16.4	13.2	13.2	17.2
S10	1.2	2.6	16.3	13.0	13.0	20.1
S11	1.2	2.5	16.3	13.1	13.1	19.1
S12	1.6	2.6	16.0	13.0	13.0	20.3
S13	1.1	2.4	16.5	13.6	13.6	17.7
S14	1.2	2.3	16.6	13.7	13.7	16.6
LSD 0.05	0.21		0.29		2.02	

Table 4: Pearson correlation matrix of seedling traits in response to salt stress at 8 dS m^{-1} NaCl in 14 okra genotypes

Traits	Root dry weight (g/plant)	Ion leakage (%)	Na^+ content in shoot (mg g^{-1} d.wt.)	K^+ content in shoot (mg g^{-1} d.wt.)	Na^+/K^+ ratio in shoot	Na^+ content in root (mg g^{-1} d.wt.)	K^+ content in root (mg g^{-1} d.wt.)	Na^+/K^+ ratio in root
Shoot dry wt. (g/plant)	0.627*	-0.028	-0.206	0.296	-0.246	-0.310	0.553*	-0.404
Root dry wt. (g/plant)		0.677**	0.359	-0.416	0.409	0.407	-0.143	0.353
Ion leakage (%)			0.835**	-0.856**	0.872**	0.842**	-0.681**	0.834**
Na^+ content in shoot (mg g^{-1} d.wt.)				-0.890**	0.973**	0.763**	-0.692**	0.765**
K^+ content in shoot (mg g^{-1} d.wt.)					-0.952**	-0.811**	0.810**	-0.849**
Na^+/K^+ ratio in shoot						0.799**	-0.745**	0.815**
Na^+ content in root (mg g^{-1} d.wt.)							-0.784**	0.977**
K^+ content in root (mg g^{-1} d.wt.)								-0.894**

*, **Significant at 5 and 1% probability level, respectively

and Na^+/K^+ ratio in shoot and root as well as root dry weight, while it has highly negative correlations with K^+ content in shoot and root. Shoot Na^+ content showed highly positive correlations with root Na^+ content and Na^+/K^+ ratio in shoot and root, while it has highly negative correlations with K^+ content in shoot and root. Shoot K^+ content has highly negative correlations with root Na^+ content and Na^+/K^+ ratio in shoot and root, while it showed highly positive correlations with root K^+ content. Shoot Na^+/K^+ ratio was positive and highly correlated to root Na^+ content and Na^+/K^+ ratio but negatively correlated to root K^+ content. Root Na^+ content had a strong positive correlation with root Na^+/K^+ ratio but it had a strong negative correlation with root K^+ content. A similar correlation was observed for root K^+ content and root Na^+/K^+ ratio.

Classification of 14 okra genotypes for salinity tolerance: The phenogram generated by UPGMA computed from the studied traits summarized the genetic relationship between the okra genotypes based on salinity stress (Fig. 3). A Euclidian distance-based phenogram assigned 14 okra genotypes into three main clusters. The first cluster included 2 subgroups. The first subgroup was classified as highly tolerant, which contained S14, S13, S9 and S8 genotypes. While the second one encompassed the S3 genotype that was considered as tolerant. The second cluster grouped the moderately tolerant genotypes such as S11, S10, S6, S5, S4 and S2 genotypes. The third cluster included two subgroups. The first subgroup was classified as sensitive where S12 and S7 genotypes were placed. While the second one, which contained was classified as highly sensitive.

DISCUSSION

Genetic description of useful germplasm is the first step toward releasing tolerant cultivars. To assess the salt tolerance of okra genotypes some morphological and physiological traits related to seedlings were used. Salinity stress had significant effect on all the measured traits. The pattern of genotype responses varied within each trait. These results are similar to those researchers reported that okra genotypes were significantly different in their biomass production and ionic accumulation when grown under saline conditions[7,23,31].

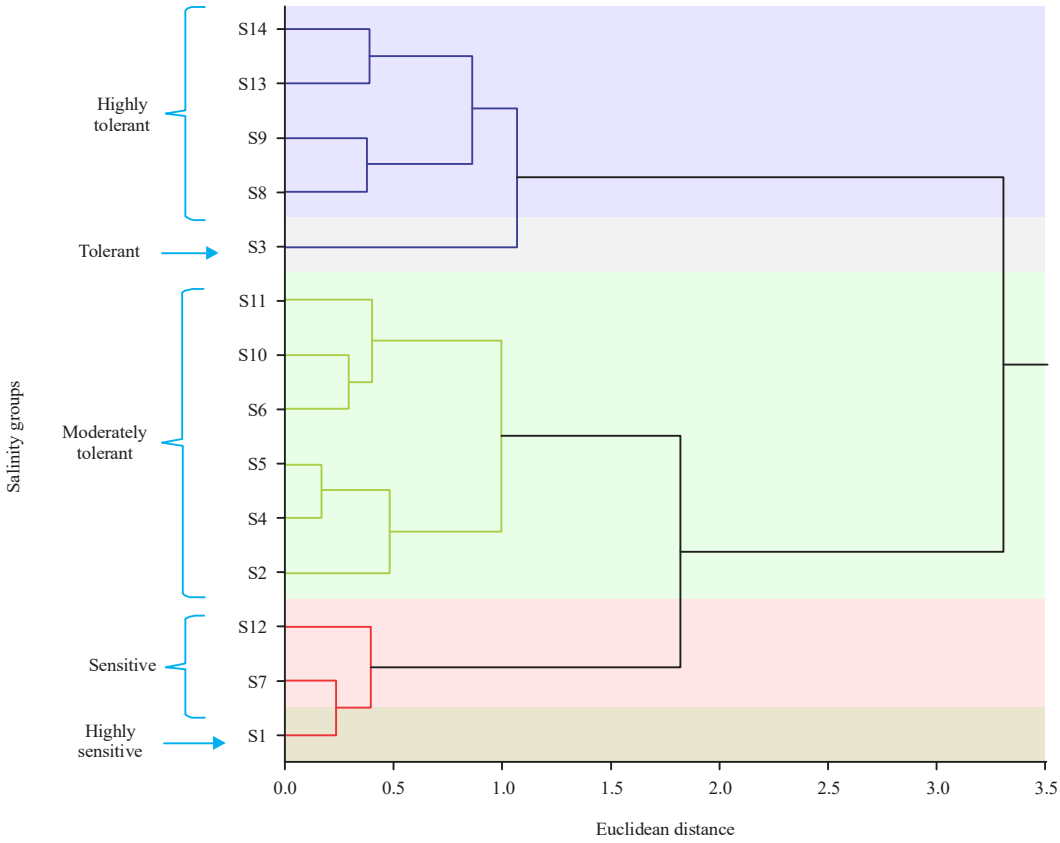

Fig. 3: Clustering of 14 okra genotypes by UPGMA based on Euclidean distance of nine morphological and physiological traits responses to salinity stress

The significant reduction in shoot and root dry weight of seedlings under salinity stress may be attributed to the Na^+ toxicity, which adversely affects metabolic and physiological processes.

The physiological impairments caused by Na toxicity include disruption of other mineral nutrients such as K^+, development of water stress and induction of oxidative cell damage. Thus, maintenance of low Na^+ content by reducing Na^+ uptake or regulating Na^+ homeostasis in the cells by lower Na^+/K^+ ratios or isolating Na ions in vacuole are the major mechanisms of plants against Na^+ stress[7,32,33].

Since, all the tested okra genotypes, exposed to salt stress showed the significant reduction in growth attributes as compared to those grown under non-saline control conditions, therefore these parameters can be used as a screening criteria for salt tolerance at the early growth stage. The shoot growth was affected more adversely than the root growth (Fig. 1). Thus, measurements derived from shoots are seem to be better criterion for relative salt tolerance of the genotypes than those from roots, which may be due to osmotic adjustment occurring in roots more rapidly and loss of turgor more slowly than shoots[34]. Cell membrane stability has been used to differentiate stress-tolerant genotypes[35]. It was measured by ion leakage percentage. Salinity stress induced electrolyte leakage in okra[17,20]. Ion leakage percentage was increased under salinity due to the increment of metabolites and electrolyte leakage in response to the accumulation of sodium chloride together with cumulative entering of Cl^- and Na^+ and the exclusion[36,37] of K^+. High Na^+ accumulation have been reported to result in an enhanced electrolyte leakage, membrane damage and oxidative damage[11,38].

The differences in salinity tolerance among genotypes could be due to genetic differences between them. The S1 and S2 genotype were found to be salt sensitive in terms of higher ion leakage percentage and Na^+ content in shoot and root under salinity condition. A linear relationship between Na^+ content with ion leakage percentage in shoot and root ($r^2 = 0.835$ and 0.842, respectively) indicates that this process is related to Na^+ accumulation due to injured plasma membranes and could be used for the early detection of membrane injury of okra genotypes under salinity stress[12,20].

Under salt stress, all genotypes have higher contents of Na^+ and Na^+/K^+ ratio and lower content of K^+ in their tissues, with a substantial difference among them. The S14 and S13 genotypes maintained lower Na^+ and higher K^+ at the saline conditions than other genotypes. Similar results have been reported on okra[12,39] and on tomato[40] Although salt stress led to a significant drop of K^+ contents in both shoots and roots, Na^+/K^+ ratio within the plant organs remained high. Thus, increment of Na^+/K^+ ratio in shoot and root is because of the antagonistic relation between Na^+ and K^+ at uptake sites in the roots or the effect of Na^+ on K^+ transport into xylem[7,41]. Moreover, the presence of Na^+ in the medium prevents the absorption[42] of K^+.

In the present study, increase of salinity stress triggered an increment in the Na^+ content and a depression in the K^+ content, resulting in reduction in K^+/Na^+ ratio (Table 2). The decrease in K^+ uptake under salinity stress may be due to the repressive influence of the stress on the absorption of this cation and competition of Na^+ ion with K^+ ion for binding sites needful for various cellular functions[43]. A greater salt tolerance in plants was found to be associated with a more efficient system for selective uptake[44,45] of K^+ over Na^+. Thus, the high K^+ content in shoot and root at higher salinity level is a good criterion for selecting salt-tolerant genotypes[12].

The best performance of S14, S13, S9 and S8 genotypes indicated that these genotypes had well maintained their physiological activity under salinity condition due to less accumulation of toxic ions, therefore they showed less reduction in growth attributes in response to salt stress (Fig. 1). Whereas, the genotypes like S1, S12 and S7 presented the highest reduction in growth attributes that may be linked with high negative effect of salinity on the physiological activity, stimulating the growth and development.

Different parameters showed different ranking of genotypes in response to salinity stress, indicating wide natural phenotypic variation among the 14 okra genotypes. The correlation of all traits allowed to identify relationships among traits that described salinity tolerance. The results showed that significant correlations existed among the studied morphological indices and ion contents (Table 4). Although shoot dry weight was poorly associated with shoot K^+ content, shoot dry weight was positively correlated with ion leakage percentage that may be important in defining salt sensitivity in plants. Moreover, the accumulation of Na^+ in roots caused nutrient imbalance in the seedlings tissues as indicated by increased Na^+/K^+ ratio and decreased K^+ content under salinity stress.

Because of the studied parameters had significant differences and high correlations, the multivariate cluster analysis using the 9 quantitative traits across the 14 genotypes instead of characterizing okra genotypes for traits one by one. Genotypic behaviour under 8 dS m^{-1} NaCl indicated that S14 genotype followed by S13 genotype were found to be the more tolerant genotypes based on the investigated characteristics under salinity stress. While S1 was the most sensitive genotype.

Salinity reduced shoot dry matters of all okra genotypes (Table 1), however, the decrease was more prominent in salt sensitive genotype (S1) than in salt tolerant genotypes (S14 and S13). S14 and S13 genotypes showed a suitable and highest shoot and root dry weight. Furthermore, they showed the less amount of sodium in shoot, high amount of potassium in shoot and root and suitable Na^+/K^+ ratio under salinity conditions. These results indicate that S14 and S13 genotypes typically tend to regulate the osmotic pressure by removing sodium ions and absorption of potassium.

Based on the results, tolerant genotypes maintain high contents of K^+ and low contents of Na^+ in their tissues under salt stress, while in sensitive genotypes the ratio of Na^+ increases as compared to the K^+. Consequently, S14 and S13 genotypes are recommended to be used as a genetic resources for the development of okra genotypes with improved growth under salt stress condition.

CONCLUSION

The results of study revealed that salinity stress inhibit the seedling growth of all okra genotypes. Similarly, the calcium content in root and shoot were markedly reduced in all tested okra genotypes under saline conditions. However, important variability in terms of seedling growth and calcium content in their tissues was observed among genotypes. In general, both S14 and S13 genotypes seemed to have better potential for salt tolerance compared with other genotypes. They maintained K^+ uptake in the presence of Na^+ in the rooting medium.

SIGNIFICANCE STATEMENT

This study introduce the salt-tolerant genotypes of okra at the seedling stage that can be beneficial for further breeding programs for tolerance to salinity. This study will help the researcher to establish breeding programs to improve the studied genotypes or to produce new varieties that meet farm and market demands in terms of the salinity tolerance. Moreover, salt tolerance of these genotypes should be further approved during whole growth period along with yield under field condition.

REFERENCES

1. Amer, M.H., S. El-Guindy and W. Rafla, 1989. Economic Justification of Drainage Projects in Egypt. In: Land Drainage in Egypt, Amer, M.H. and N.A. Ridder (Eds.). Drainage Research Institute, Cairo, Egypt, pp: 327-339.
2. Munns, R. and M. Tester, 2008. Mechanisms of salinity tolerance. Annu. Rev. Plant Biol., 59: 651-681.
3. Ambede, J.G., G.W. Netondo, G.N. Mwai and D.M. Musyimi, 2012. NaCl salinity affects germination, growth, physiology and biochemistry of Bambara groundnut. Braz. J. Plant Physiol., 24: 151-160.
4. Abreu, I.A., A.P. Farinha, S. Negrao, N. Goncalves and C. Fonseca *et al*., 2013. Coping with abiotic stress: Proteome changes for crop improvement. J. Proteomics, 93: 145-168.
5. Deinlein, U., A.B. Stephan, T. Horie, W. Luo, G. Xu and J.I. Schroeder, 2014. Plant salt-tolerance mechanisms. Trends Plant Sci., 19: 371-379.
6. Hasegawa, P.M., R.A. Bressan, J.K. Zhu and H.J. Bohnert, 2000. Plant cellular and molecular responses to high salinity. Annu. Rev. Plant Physiol. Plant Mol. Biol., 51: 463-499.
7. Shahid, M.A., M.A. Pervez, R.M. Balal, R. Ahmad, C.M. Ayyub, T. Abbas and N. Akhtar, 2011. Salt stress effects on some morphological and physiological characteristics of okra (*Abelmoschus esculentus* L.). Soil Environ., 30: 66-73.
8. Habib, S.H., H. Kausar and H.M. Saud, 2016. Plant growth-promoting rhizobacteria enhance salinity stress tolerance in okra through ROS-scavenging enzymes. BioMed Res. Int., Vol. 2016. 10.1155/2016/6284547.
9. Gill, S.S. and N. Tuteja, 2010. Reactive oxygen species and antioxidant machinery in abiotic stress tolerance in crop plants. Plant Physiol. Biochem., 48: 909-930.
10. Suzuki, N., S. Koussevitzky, R. Mittler and G. Miller, 2012. ROS and redox signalling in the response of plants to abiotic stress. Plant Cell Environ., 35: 259-270.
11. Farhoudi, R., A. Modhej and A. Afrous, 2015. Effect of salt stress on physiological and morphological parameters of rapeseed cultivars. J. Scient. Res. Dev., 2: 111-117.
12. Ikram-ul-Haq, A.A. Khan and M.A. Azmat, 2012. Comprehensive screening and selection of okra (*Abelmoschus esculentus*) germplasm for salinity tolerance at the seedling stage and during plant ontogeny. J. Zhejiang Univ. Sci. B, 13: 533-544.
13. Moyin-Jesu, E.I., 2007. Use of plant residues for improving soil fertility, pod nutrients, root growth and pod weight of okra (*Abelmoschus esculentum* L). Bioresour. Technol., 98: 2057-2064.
14. Unlukara, A., A. Kurunc, G.D. Kesmez and E. Yurtseven, 2008. Growth and evapotranspiration of okra (*Abelmoschus esculentus* L.) as influenced by salinity of irrigation water. J. Irrig. Drainage Eng., 134: 160-166.
15. Abid, M., S.A. Malik, K. Bilal and R.A. Wajid, 2002. Response of Okra (*Abelmoschus esculentus* L.) to EC and SAR of irrigation water. Int. J. Agric. Biol., 4: 311-314.
16. Dudley, L.M., A. Ben-Gal and U. Shani, 2008. Influence of plant, soil and water on the leaching fraction. Vadose Zone J., 7: 420-425.
17. Dkhil, B.B. and M. Denden, 2012. Effect of salt stress on growth, anthocyanins, membrane permeability and chlorophyll fluorescence of okra (*Abelmoschus esculentus* L.) seedlings. Am. J. Plant Physiol., 7: 174-183.
18. Dkhil, B.B., A. Issa and M. Denden, 2014. Germination and seedling emergence of primed Okra (*Abelmoschus esculentus* L.) seeds under salt stress and low temperature. Am. J. Plant Physiol., 9: 38-45.
19. Ifediora, N.H., H.O. Edeoga and G. Omosun, 2014. Effects of salinity on the growth and visocosity of fruits of okra (*Abelmoschus esculentus* L.). Int. J. Curr. Agric. Res., 3: 81-84.
20. Jeyapraba, J., S. Mahendran and N. Sujirtha, 2016. Growth physiology and membrane permeability of okra (*Abelmoschus esculentus* L.) seedlings as affected by salinity. Int. J. Plant Soil Sci., 9: 1-5.
21. Ibrahim, E.A., 2016. Seed priming to alleviate salinity stress in germinating seeds. J. Plant Physiol., 192: 38-46.
22. Abbas, T., M.A. Pervez, C.M. Ayyub, M.R. Shaheen, S. Tahseen, M.A. Shahid, R.M. Bilal and A. Manan, 2014. Evaluation of different okra genotypes for salt tolerance. Int. J. Plant Anim. Environ. Sci., 4: 23-30.
23. Ikarm-Ul-Haq, 2009. Genetic basis of variation for salinity tolerance in okra (*Abelmoschus esculentus* L.). Ph.D. Thesis, Department of Plant Breeding and Genetics, Faculty of Agriculture, University of Agriculture, Faisalabad, Pakistan.
24. Bresler, E., B.L. McNeal and D.L. Carter, 1982. Saline and Sodic Soils: Principles, Dynamics, Modeling. Springer-Verlag, Berlin, Germany, ISBN-13: 9780387111209, Pages: 236.
25. Ibrahim, E.A.A., M.Y. Abed and A.M. Moghazy, 2013. Genetic behavior of families selected from some local okra (*Abelmoschus esculentus* L. Moench) Populations in Egypt. Plant Breed. Biotechnol., 1: 396-405.
26. Hoagland, D.R. and D.I. Arnon, 1950. The water-culture method for growing plants without soil. California Agric. Exp. Station Circ., 347: 1-32.
27. Lutts, S., J.M. Kinet and J. Bouharmont, 1995. Changes in plant response to NaCl during development of rice (*Oryza sativa* L.) varieties differing in salinity resistance. J. Exp. Bot., 46: 1843-1852.
28. Sreenivasulu, N., R. Grimm, U. Wobus and W. Weschke, 2000. Differential response of antioxidant compounds to salinity stress in salt-tolerant and salt-sensitive seedlings of foxtail millet (*Setaria italica*). Physiol. Plant., 109: 435-442.
29. Williams, V. and S. Twine, 1960. Flame Photometric Method for Sodium, Potassium and Calcium. In: Modern Methods of Plant Analysis, Peach, K. and M.V. Tracey (Eds.). Vol. 5, Springer-Verlag, Berlin, Germany, pp: 3-5.

30. Snedecor, G.W. and W.G. Cochran, 1989. Statistical Methods. 8th Edn., Iowa State University Press, Ames, IA., USA., ISBN-13: 978-0813815619, Pages: 503.
31. Munshi, R., A. Debbarma, P. Acharyya, A. Chattopadhyay, P. Mishra, L. Chakraborty and B. Sahoo, 2019. Salt induced modulation on physio-biochemical attributes in okra (*Abelmoschus esculentus* (L.) Moench. Int. J. Curr. Microbiol. Applied Sci., 8: 2883-2892.
32. Tester, M. and R. Davenport, 2003. Na^+ tolerance and Na^+ transport in higher plants. Ann. Bot., 91: 503-527.
33. Roy, S.J., S. Negrao and M. Tester, 2014. Salt resistant crop plants. Curr. Opin. Biotechnol., 26: 115-124.
34. Ferdose, J., M. Kawasaki, M. Taniguchi and H. Miyake, 2009. Differential sensitivity of rice cultivars to salinity and its relation to ion accumulation and root tip structure. Plant Prod. Sci., 12: 453-461.
35. Gupta, B. and B. Huang, 2014. Mechanism of salinity tolerance in plants: Physiological, biochemical and molecular characterization. Int. J. Genom., Vol. 2014. 10.1155/2014/701596.
36. Iqbal, M., N. Akhtar, S. Zafar and I. Ali, 2008. Genotypic responses for yield and seed oil quality of two *Brassica* species under semi-arid environmental conditions. S. Afr. J. Bot., 74: 567-571.
37. Kaya, C., O. Sonmez, S. Aydemir and M. Dikilitas, 2013. Mitigation effects of glycinebetaine on oxidative stress and some key growth parameters of maize exposed to salt stress. Turk. J. Agric. For., 37: 188-194.
38. Mandhania, S., S. Madan and V. Sawhney, 2006. Antioxidant defense mechanism under salt stress in wheat seedlings. Biol. Plant., 50: 227-231.
39. Lahon, B. and J. Srivastava, 2008. Salinity resistance in cabbage and okra genotypes during germination and early growth stages. Veg. Sci., 35: 21-24.
40. Rehman, F., A. Saeed, M. Yaseen, A. Shakeel and K. Ziaf *et al*., 2019. Genetic evaluation and characterization using cluster heat map to assess NaCl tolerance in tomato germplasm at the seedling stage. Chilean J. Agric. Res., 79: 56-65.
41. Colmer, T.D., R. Munns and T.J. Flowers, 2006. Improving salt tolerance of wheat and barley: Future prospects. Aust. J. Exp. Agric., 45: 1425-1443.
42. Bandeh-Hagh, A., M. Toorchi and A. Mohammadi, 2008. Growth and osmotic adjustment of canola genotypes in response to salinity. J. Food Agric. Environ., 6: 201-208.
43. Azooz, M.M., A. Metwally and M.F. Abou-Elhamd, 2015. Jasmonate-induced tolerance of Hassawi okra seedlings to salinity in brackish water. Acta Physiol. Plant., Vol. 37, No. 4. 10.1007/s11738-015-1828-5.
44. Neill, S., R. Desikan and J. Hancock, 2002. Hydrogen peroxide signalling. Curr. Opin. Plant Biol., 5: 388-395.
45. Chen, C.L., H. van der Schoot, S. Dehghan, C.L.A. Kamei and K.U. Schwarz *et al*., 2017. Genetic diversity of salt tolerance in Miscanthus. Front. Plant Sci., Vol. 8. 10.3389/fpls.2017.00187.