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Salinity Tolerance in Cotton (*Gossypium hirsutum* L.) Genotypes

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Abstract: Tolerances of seven diverse genotypes of cotton (*Gossypium hirsutum* L.) and their 21F_1 progenies were evaluated in non-saline and saline environments. Adding incremental levels of NaCl to Hogland's solution in a sand culture electrical conductivity of 24 dS m^{-1} was attained inducing salinity Stress. Combined analysis based on two salinity levels revealed significant salinity-level effects for shoot dry weight, plant height, shoot fresh weight and contents of ions in shoot tissues, including sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), K^+/Na^+, Ca^{2+}/Na^+, shoot dry weight/shoot fresh weight (SDW/SFW), root length/shoot height (RL/SH). Salinity had no significant effect on root length. Estimation of Stress Intensity (SI) indicated larger values for shoot fresh weight, plant height, Ca^{2+}/Na^+, K^+/Na^+ (0.27, 0.31, 0.39 and 0.55, respectively). Negative and high index of SI for Na^+ indicated that its mean in a saline environment was more than two times from the mean in a non-saline environment. Low estimates of negative SI index for root length, Ca^{2+}, SDW/SFW and RL/SH indicated the effects of a saline environment for these traits were better than the other traits. Significant interactions of genotypes and salinity levels were observed for all studied traits. The result of factor analysis based on minimum eigenvalue by means of principle component analysis extraction method and rotation method of Varimax with Kaiser Normalization revealed four factors for eleven studied traits in a saline environment. Factor one and two were detected as morphological and nutritional factors, respectively. Factor three and four were detected as morphological and nutritional factors dependent on their high coefficients factor loading simultaneously. The results of factor analysis indicated that selection for morphological traits, specifically; that selection based on K^+, Ca^{2+} and K^+/Na^+ should be more efficient than other traits. Cluster classification of genotypes on the basis of value of four principal for each genotype by means of principle component analysis of correlation matrix distinguished genotypes Sahel×Belizovar, Siokra and Sindose×Koker from other genotypes in salinity tolerance. On the basis of low estimates of the tolerance index (TOL) for shoot dry weight (its large value represents more sensitivity to stress), it was concluded that the above genotypes have had suitable salinity tolerance in early stages of growth.

Key words: Salinity, cotton, tolerance

INTRODUCTION

Cotton is a dual-purpose crop, widely used for fiber and oil throughout the world. It is placed in the moderately salt-tolerant group of plant species with a salinity threshold level 7.7 dS m^{-1}. Its growth and seed yield being severely reduced at high salinity levels and different salts affect the cotton growth to a variable extent. Salinity of agricultural lands and irrigation water is a major environmental constraint to crop productivity in many arid and semiarid regions of the world. It is especially prevalent in irrigated agriculture and in marginal lands associated with poor drainage on high water tables. Estimates for the extent of salinity damage vary from 25 to 50% of the world's irrigated land (Postel, 1989). The stresses imposed by salinity are mainly due to ion compositions and concentrations in rhizosphere and also in plant tissues (Volkamar *et al*., 1998). Salinity occurs mainly as a result of either an accelerated redistribution of salts in the soil profile due to high water tables in most areas, or the use of insufficient irrigation water to leach salts out of the soil (Ashraf, 1994). Further selection of some genotypes that could be tolerance for growing in salinity lands is necessary for the establishment of plants at the early stage of growth. Saline environments affect plant growth in different ways, including a decrease in water uptake, an accumulation of ions to toxic levels and a reduction of nutrient availability (Ashraf, 1994). Ca^{2+} and K^+ ameliorate the adverse effects of salinity on plants (Volkamar *et al*., 1998). Salinity impairs the uptake of Ca^{2+} by plants, possibly by displacing it from the cell membrane or in some way affecting membrane function (Lauchli, 1990). Gorham (1993) claimed that all plants discriminate to some extent between Na^+ and K^+. Sodium

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can be substituted for K^+ for uptake and it is believed that similar mechanisms of uptake may operate for both ions (Schroeder *et al*., 1994). High levels of K^+ in young expanding tissue are associated with salt tolerance in many plant species (Khatum and Flowers, 1995). Closely allied to salt exclusion and its relationship to salt tolerance is the regulation of ion selectivity, in particular the role of Ca^{2+}/Na^+ and K^+/Na^+ discrimination in salt tolerance (Maas and Grieve, 1989). Porcelli *et al.* (1995) reported that when soil salinity and Sodium Adsorption Ratios (SAR) increased K^+/Na^+ and Ca^{2+}/Na^+ ratios in plants and also K^+/Na^+ and Ca^{2+}/Na^+ selectivity decreased. Ahmad *et al.* (2002) reported that salinity increases Na^+ and Cl^- and decreases K^+, Ca^{2+} and Mg^{2+} in leaves of cotton on the other hand reduces uptake of Nitrogen and Phosphor in cotton. They also have been used K^+/Na^+ as a successful selection criterion for salt tolerance in cotton.

An analysis of principal components often reveals relationships that were not previously suspected and thereby allows interpretations that would not ordinarily result. Analyses of principal components are more of a means to an end rather than an end in them, because they frequently serve as intermediate steps in much larger investigations. (Johnson and Wichern, 2002). The essential purpose of factor analysis is to describe, if possible, the covariance relationships among many variables in terms of a few underlying, but unobservable, random quantities called factors (Johnson and Wichern, 2002). Means for determining the relationship between traits in a stress environment, factor analysis can be efficient. The main applications of factor-analytic techniques are to define a few factors (less than the number of studied traits) (Dillon and Goldstein, 1984). Factor analysis has been used to determine structural factors related to growth traits and yield components in some crop.

In order to obtain selection criteria based on stress and non-stress environment, some selection criteria, including Geometric Mean Productivity (GMP), Stress Intensity (SI), (Fischer and Murrer, 1978) Stress Tolerance Index (STI), (Fernandez, 1993) and tolerance index (TOL) (Rosielle and Hamblin, 1981) were defined. The range of SI estimates is between zero and one and the larger value of SI indicates the more severe stress intensity. A larger value of TOL represents relatively more sensitivity to stress, thus a smaller value of TOL is favoured. The higher value of GMP and STI for a genotype indicates its stress tolerance and yield potential. The objectives of this study one hand were to determine the traits and stress tolerance indices that were more related to salinity in *Gossypium hirsutum* cultivars and their F_1 in early stages of growth and the other hand to identify salt-tolerant lines and their F1 in early stages of growth.

MATERIALS AND METHODS

Seven diverse cotton (*Gossypium hirsutum* L.) genotypes were crossed in a half diallel fashion and then their 21 F_1 progenies along with their parents were evaluated in sand cultures under normal and saline environments in a Randomized Complete Block Design (RCBD) with three replications at the greenhouse of Research Farm of Botany Department of Pune University. (73°, 51' E longitude, 18°, 31' N latitude and altitude 559 m) during January to February 2005. Sterilized seeds were germinated in Petri dishes at 25±2°C for 4 days. Eight uniform seedlings were transplanted into plots that separated in two sandboxes filled with washed and sterilized river sand, covered with polythene beads and after establishment, five plants were maintained for evaluation. Temperatures during the experiment were averaged 30.21/9.6°C (day/night) and relative humidity was 39.43-86.04% and the photoperiod was 14 h. Plants were given deionized water up to 10 days after transplanting and saline and non-saline (control) grown plants were irrigated thereafter every 2 days with half-strength Hogland's nutrient solution (Hoagland and Arnon, 1950) with NaCl (EC = 23.8 dS m^{-1}) and without it (EC = 0.94 dS m^{-1}) and pH = 7. Electrical conductivity of the saline treatment was increased to the desired level by incremental addition of the salt over 10 day period to avoid osmotic shock to the seedlings. Plants in both environments were irrigated until saturated, with the excess solution allowed to drain under sandboxes. Plants in both environments were harvested 50 days after planting at 7-8 leaf stages. The characteristics were shoot dry weight (SDW) in g/plot, plant height (cm), root length (cm), shoot dry weight Ca^{2+}, K^+ and Na^+ contents (mg g^{-1}), Ca^{2+}/Na^+ and K^+/Na^+. The harvested plants were washed with distilled water and then they were dried in an oven for 72 h at 80°C to a constant weight. Plant samples were ground by mill and then dried in a furnace at 500°C for 2 h in order of ion extraction. After that, plant samples were added to 5 mL of 2 M HCL for digestion and then digested solutions were filtered and diluted by distilled water. The final volume of each sample was 100 mL. Sodium and K^+ levels of each sample were measured by flame photometry and Ca^{2+} was measured by atomic absorption spectrophotometry (Isaac and Kerber, 1971). Selection criteria indices, including geometric mean productivity as GMP = $\sqrt{(Yp)\times(Ys)}$, (Fischer and Murrer, 1978) stress tolerance index as STI = $(Yp)\times(Ys)/Yp^2$, (Rosielle and Hamblin, 1981) and tolerance index TOL = Yp-Ys (Fernandez, 1993) were calculated for yield of shoot dry weight in non-saline (Yp) and saline (Ys) environments. TOL was also calculated for Ca^{2+}, K^+, Na^+, Ca^{2+}/Na^+ and K^+/Na^+. Stress intensity as (SI = 1-(Ys/Yp)), (Fischer and Murrer, 1978) was estimated for all studied characteristics (Ys and Yp are the means of shoot dry weight in saline and non-saline environments, respectively). All studied traits were combined analysis based on two environments (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Combined analysis based on salinity levels revealed significant environment effects for all studied traits except for root length (Table 1). Root length mean in saline environment was more than non- saline environment. Significant effects of genotypes and their interactions with salinity levels were observed for all studied traits except root length and RL/SH, which indicated that genotypes have had diverse behavior in two salinity levels. Stress-intensity estimates for Shoot Dry Weight (SDW), root length, plant height, shoot dry weight Ca^{2+}, K^+ and Na^+ contents, Ca^{2+}/Na^+ and K^+/Na^+ were 0.19, -0.056, 0.31, 0.27, -1.15, 0.05, -0.31, 0.55, 0.39, -0.22 and -0.52, respectively (Table 1). On the basis of SI, it was concluded that root length, Na^+, Ca^{2+}, Ca^{2+}/Na^+ and K^+/Na^+ were increased and shoot dry weight was decrease more than other rest traits by salinity (Table 1). The mean of Na^+ in a saline environment was two times more than the mean of Na^+ in a non-saline environment; therefore, although SI was not calculable for it and other traits but negative index of SI is indicator of increasing of traits in salinity environment (Table 1). However, Porcelli (1995) has reported that with increasing salinity, plant height, root length, Ca^{2+}/Na^+ and K^+/Na^+ were decreased and Na^+ was increased.

In a non-stress environment, no significant correlations were observed between shoot dry weight and all traits except Ca^{2+}/Na^+ (0.604**) and SDW/SH (0.51**). The means of shoot dry weight in a non-saline environment varied between 1.040 and 2.023 g (Table 2) and the three top crosses and one top parental cultivar for shoot dry weight were Kiokorova× Koker, Sindose× Koker and Sahel×Kiokorova and Belizovar, respectively in a non-saline environment. The means of root length in a non-saline environment varied between 7.167 and 12.167 cm (Table 2) and the three top crosses and two top parental cultivars for root length were Kiokorova×Belizovar, Sahel×Tabladila, Tabladila×Sindose, Belizovar and Koker in a non-saline environment, respectively. The means of plant height in a non-saline environment varied between 19.20 and 32.30 cm (Table 2) and the three top crosses and one top parental cultivar for plant height were Kiokorova×Sindose, Siokra×Belizovar, Siokra×Koker and Kiokorova in a non-saline environment, respectively (Table 2).

Significant positive correlation was observed between shoot dry weight and root length (0.588**) in a stress environment. The means of shoot dry weight in a saline environment varied between 0.905 and 1.767 g (Table 3) and the two top genotypes and two top parental cultivar for plant height were Siokra×Koker, Sindose× Koker and Siokra in a saline environment, respectively (Table 3). No significant correlation was observed between shoot dry weight and root length in a saline environment. The means of root length in a saline environment varied between 7.733 and 14.730 g (Table 3) and the three top genotypes and one top parental cultivar for root length were Tabladila×Koker, Siokra×Koker, Sindose×Koker and Siokra in a saline environment, respectively. The means of plant height in a saline environment varied between 17.133 and 21.167 cm (Table 3) and the two top crosses and one top parental cultivar for plant height were Sahel × Sindose, Sahel× Belizovar and Kiokorova a saline environment, respectively (Table 3).

Most of the crosses with high shoot dry weight in a saline environment had one of the two parent including Siokra and Sindose , therefore, the shoot dry weights of

Table 1: Analysis of variance for shoot dry weight , root length, plant height, shoot fresh weight, shoot dry weight Na^+, K^+, Ca^{2+}, K^+/Na^+ and Ca^{2+}/Na^+ contents, SDW/SFW, RL/SH in a non-saline and saline environment

		Mean square										
SOV	df	Shoot dry weight (SDW)	Root length (RL)	Plant height (PH)	Shoot fresh weight (SFW)	Na^+	K^+	Ca^{2+}	K^+/Na^+	Ca^{2+}/Na	SDW/ SFW	RL/SH
Salinity levels (E)	1	3.691**	14.34	3030.25**	438.58**	5147.73**	52.96**	5947.49**	77.86**	101.69**	438.58**	16201.83*
Error	4	0.0001	49.84	0.082	0.046	0.014	0.021	0.100	0.001	0.001	0.046	542.28
Genotype (G)	27	0.200**	55.04	15.56**	8.23**	9.20**	44.64**	37.009**	0.29**	0.32**	8.23**	654.85
G×E	27	0.178**	64.24	12.44**	8.69**	12.65**	48.25**	35.91**	0.26**	0.20**	8.69**	830.15
Error	108	0.001	49.22	0.014	0.015	0.008	0.023	0.026	0.001	0.001	0.015	549.39
Meanin non-stress		1.522	10.325	27.63	12.039	9.579	23.575	38.533	2.455	4.029	12.295	37.487
Mean in stress		1.245	10.890	19.136	8.807	20.65	22.452	50.433	1.093	2.473	14.958	57.128
Stress intensity		0.19	-0.056	0.31	0.27	-1.15	0.05	-0.31	0.55	0.39	-0.22	-0.52

*, ** Significant at p = 5 and 1%, respectively

Table 2: Means of shoot dry weight, root length, plant height, shoot fresh weight and shoot ions, including Na^+, K^+, Ca^{2+}, K^+/Na^+ and Ca^{2+}/Na^+, SDW/SFW, RL/SH in a non-saline environment

	Means										
Genotypes	Shoot dry weight (SDW) (g)	Root length (RL) (cm)	Plant height (PH) (cm)	Shoot fresh weight (SFW) (g)	Na^+ (mg g^{-1})	K^+ (mg g^{-1})	Ca^{2+} (mg g^{-1})	K^+/Na^+	Ca^{2+}/Na	SDW/SFW	RL/SH
Sahel	1.550	9.033	29.100	13.133	8.181	16.774	34.6227	2.050	4.232	11.534	31.041
Sahel×Tabladila	1.157	11.100	25.300	10.557	8.034	17.652	35.6393	2.197	4.436	10.958	43.879
Sahel×Kiokurova	1.940	8.900	19.200	14.107	9.277	24.797	37.4303	2.673	4.035	13.754	46.355
Sahel×Siokra	1.475	9.167	29.733	12.920	9.112	20.553	35.1423	2.256	3.857	11.418	30.831
Sahel×Sindose-80	1.278	10.167	30.200	11.387	9.423	22.159	37.0807	2.352	3.935	11.227	33.665
Sahel×Belizovar	1.843	9.167	29.100	13.743	8.625	19.196	33.2983	2.226	3.861	13.413	31.501
Sahel×Koker	1.040	9.933	24.267	9.803	9.815	19.564	42.871	1.993	4.368	10.609	40.934
Tabladila	1.227	6.267	25.367	10.710	7.864	18.629	36.6643	2.369	4.662	11.456	24.704
Tabladila×Kiokurova	1.233	9.833	24.900	10.081	9.169	25.817	38.4720	2.816	4.196	12.234	39.491
Tabladila×Siokra	1.170	9.000	30.100	10.793	8.942	21.322	36.1997	2.384	4.048	10.840	29.900
Tabladila×Sindose-80	1.500	11.100	28.267	11.617	9.245	23.212	38.0893	2.511	4.120	12.913	39.269
Tabladila×Belizovar	1.587	10.100	26.333	11.503	8.446	20.104	34.2600	2.380	4.056	13.735	38.355
Tabladila×Koker	1.157	9.067	27.167	10.564	9.345	20.472	43.8750	2.191	4.695	10.949	33.374
Kiokurova	1.380	7.133	28.333	10.040	10.374	33.051	40.1073	3.186	3.866	13.745	23.672
Kiokurova×Siokra	1.433	9.133	27.167	12.070	10.199	17.733	37.7177	1.739	3.698	11.875	33.619
Kiokurova×Sindose-80	1.867	9.167	32.100	14.540	10.514	30.329	39.7137	2.885	3.777	12.838	28.556
Kiokurova×Belizovar	1.770	12.167	29.100	14.577	9.688	27.466	35.9617	2.835	3.712	11.458	41.810
Kiokurova×Koker	2.023	9.567	26.100	13.123	10.615	27.707	45.6850	2.610	4.304	15.413	36.655
Siokra	1.380	7.237	29.667	10.237	10.025	24.107	35.8120	2.405	3.572	13.481	24.374
Siokra×Sindose-80	1.870	8.933	26.100	7.783	10.358	25.810	37.5620	2.492	3.626	11.178	34.228
Siokra×Belizovar	1.490	9.100	30.333	12.773	9.522	22.792	33.7190	2.394	3.541	11.666	30.000
Siokra×Koker	2.007	7.167	32.300	17.290	10.446	23.382	43.4777	2.238	4.162	11.606	22.188
Sindose-80	1.747	7.833	28.346	10.300	10.628	27.684	39.5657	2.605	3.723	13.463	27.877
Sindose-80×Belizovar	1.590	11.367	29.600	12.497	9.836	38.540	35.6660	3.918	3.626	12.857	35.355
Sindose-80×Koker	1.500	9.100	25.033	14.257	10.736	25.079	45.6607	2.336	4.253	10.522	36.352
Belizovar	1.892	11.100	25.033	11.510	9.033	21.625	31.8097	2.374	3.522	15.736	44.342
Belizovar×Koker	1.317	7.167	25.500	11.433	9.929	22.089	41.5657	2.225	4.186	11.517	28.106
Koker	1.630	11.100	28.333	13.737	10.831	22.459	51.2627	2.074	4.833	11.867	38.177
LSD (0.05)	0.016	1.619	0.263	0.193	0.051	0.146	0.206	0.016	0.016	0.504	0.824
LSD (0.01)	0.021	2.155	0.351	0.257	0.068	0.194	0.275	0.021	0.021	0.671	1.097

parents in saline stress can be used as good criteria for the prediction of shoot dry weight in their crosses. On the basis of GMP, STI and TOL indices for the genotypes, it was concluded that Siokra as a parent and Sindose× Koker as a cross had preference to other parents and crosses in shoot dry weight totally (Table 4). Significant positive correlation was observed between fresh weight and shoot dry weight (0.531**) in a stress environment. The means of fresh weight in a saline environment varied between 7.220 and 12.05 g (Table 3) and therefore top genotype and top parental cultivar for fresh weight were Tabladila×Koker and Kiokurova in a saline environment, respectively.

The shoot dry weight Na^+ content varied from 17.768 to 31.112 mg g^{-1} and the two top crosses and one top parental cultivar for shoot dry weight Na^+ content were Sahel×Sindose, Sahel×Belizovar and Sindose, respectively in a saline environment. On the basis of GMP, STI and TOL indices for Sindose (15.83, 2.73 and -12.97, respectively) as a parent and Sahel×Sindose (14.587, 2.319 and -13.161, respectively), Sahel×Belizovar (16.381, 2.92 and -22.487, respectively) as a crosses had preference to other parents and crosses in shoot dry weight Na^+ content totally (Table 3).

The shoot dry weight K^+, Ca^{2+}, K^+/Na^+, Ca^{2+}/Na^+ contents and SDW/SFW, RL/SL traits varied between (17.596 and 28.235), (47.441 and 54.979), (0.849 and 1.313), (1.697 and 2.893), (12.747 and 19.059) and (36.537 and 77.004) mg g^{-1}, respectively.

Significant positive correlation was estimated shoot dry weight with root length (0.588**), Ca^{2+}/Na^+ (0.531*), SDW/SFW (0.545**), RL/SL (0.615**) and significant negative correlation with K^+ (-0.452*) in a saline environment. Therefore this trait can be used as good selection criteria for improving shoot dry weight in a saline environment. Some researchers have emphasized the importance of Ca^{2+}, K^+, Ca^{2+}/Na^+ and K^+/Na^+ for salinity tolerance (Maas and Grieve, 1989).

On the basis of GMP, STI and TOL indices (21.76, 0.852, -11.461), (42.655, -1.225, -18.847), (1.404, 0.327, 0.605) and (3.146, 0.612, 0.711) of shoot dry weight K^+, Ca^{2+}, K^+/Na^+ and Ca^{2+}/Na^+ contents distinguished Sahel as a parent, Tabladila×Belizovar, Kiokorova×Siokra and Belizovar×Koker as a crosses, respectively (Table 4).

High concentrations of K^+ in young expanding tissue are associated with salt tolerance in many plant species, (Khatum and Flowers, 1995) therefore, genotypes with low contents of K^+, are suitable for salinity tolerance. Calcium

Table 3: Means of shoot dry weight, root length, plant height, shoot fresh weight and shoot ions, including Na^+, K^+, Ca^{2+}, K^+/Na^+ and Ca^{2+}/Na^+, SDW/SFW, RL/SH in a saline environment

	Means										
Genotypes	Shoot dry weight (SDW) (g)	Root length (RL) (cm)	Plant height (PH) (cm)	Shoot fresh weight (SFW) (g)	Na^+ (mg g^{-1})	K^+ (mg g^{-1})	Ca^{2+} (mg g^{-1})	K^+/Na^+	Ca^{2+}/Na	SDW/SFW	RL/SH
Sahel	1.151	8.033	18.167	8.407	21.513	28.235	50.6297	1.313	2.353	13.102	44.220
Sahel×Tabladila	0.905	9.200	17.133	6.380	21.406	24.784	50.6817	1.158	2.368	14.218	53.694
Sahel×Kiokurova	1.130	8.433	18.000	8.300	20.763	26.797	49.5797	1.291	2.388	13.621	46.853
Sahel×Siokra	0.923	10.200	18.000	6.767	19.244	22.711	49.7877	1.180	2.587	13.648	56.670
Sahel×Sindose-80	1.147	10.300	21.067	8.683	22.584	24.806	48.3590	1.098	2.141	15.499	48.893
Sahel×Belizovar	1.130	7.733	21.167	8.460	31.112	26.425	52.7830	0.849	1.697	13.361	36.537
Sahel×Koker	1.020	11.830	20.067	9.203	20.312	23.841	51.8163	1.174	2.551	15.068	58.970
Tabladila	1.033	11.160	17.167	10.060	21.322	21.667	51.1737	1.016	2.400	15.323	65.052
Tabladila×Kiokurova	1.267	11.500	17.967	8.533	20.582	23.442	49.4773	1.139	2.404	15.303	64.008
Tabladila×Siokra	1.130	9.167	19.067	7.623	18.902	19.476	49.7430	1.030	2.632	15.443	48.077
Tabladila×Sindose-80	1.257	12.160	19.033	9.233	22.494	21.671	48.5820	0.963	2.160	13.613	63.923
Tabladila×Belizovar	1.037	10.060	20.067	8.133	20.232	22.774	53.1077	1.126	2.625	12.747	50.167
Tabladila×Koker	1.073	12.860	21.100	11.200	20.185	20.356	52.234	1.008	2.588	18.515	60.981
Kiokurova	1.297	11.430	19.495	12.050	20.284	25.253	48.163	1.245	2.374	19.059	53.763
Kiokurova×Siokra	1.050	12.060	19.067	7.290	18.587	21.086	48.225	1.134	2.595	14.405	63.286
Kiokurova×Sindose-80	0.977	10.167	18.067	7.470	21.836	23.440	47.441	1.074	2.173	13.076	56.273
Kiokurova×Belizovar	1.367	9.833	19.167	9.647	19.636	24.707	51.595	1.258	2.628	14.168	51.304
Kiokurova×Koker	1.043	9.067	20.133	8.150	19.623	21.962	50.673	1.119	2.582	12.805	45.033
Siokra	1.767	11.950	19.133	9.230	16.826	17.596	48.272	1.046	2.869	19.141	77.025
Siokra×Sindose-80	1.337	12.100	20.300	7.860	20.324	19.558	47.651	0.962	2.345	17.018	59.608
Siokra×Belizovar	1.347	12.260	18.133	9.860	18.052	20.767	51.537	1.150	2.855	15.652	67.648
Siokra×Koker	1.423	13.130	19.067	9.543	17.767	17.897	50.426	1.007	2.838	14.809	68.881
Sindose-80	1.375	11.060	19.547	7.220	23.600	21.641	46.777	0.917	1.982	14.083	57.341
Sindose-80×Belizovar	1.247	10.100	19.000	8.663	21.469	22.750	50.913	1.060	2.371	14.392	53.160
Sindose-80×Koker	1.633	14.730	20.067	8.503	21.554	20.166	49.824	0.936	2.312	18.971	73.423
Belizovar	1.396	11.000	19.06	9.350	19.559	24.473	54.979	1.231	2.811	13.94	57.693
Belizovar×Koker	1.260	10.000	18.000	10.007	19.263	21.604	54.167	1.122	2.812	13.758	55.555
Koker	1.427	11.810	18.033	10.077	19.166	18.776	53.524	0.980	2.893	14.084	61.628
LSD (0.05)	0.016	0.163	0.146	0.225	0.206	0.318	0.331	0.016	0.016	1.202	0.941
LSD (0.01)	0.021	0.217	0.194	0.300	0.275	0.424	0.440	0.021	0.021	1.600	1.253

ameliorates the adverse effects of salinity on plants (Volkamar *et al*., 1998; Lauchli, 1990) therefore, the genotypes in which amounts of Ca^{2+} increased in a saline environment can be considered suitable for salinity tolerance. Although shoot dry weight has positive correlation with plant Ca^{2+} content but it is not significant.

On the basis of Significant positive correlation between shoot dry weight with root length, shoot fresh weight and SDW/SFW these characteristics and RL/SH and its significant negative correlation with shoot dry weight K^+ contents can be considered as indirect selection criteria for improving shoot dry weight in a saline environment. Shoot dry weight has not significant correlation with other traits.

Sairam and Tyazi (2004) also reported that Salinity stress response is multigenic, as a number of processes involved in the tolerance mechanism are affected, such as various compatible solutes/osmolytes, polyamines, reactive oxygen species and antioxidant defense mechanism, ion transport and compartmentalization of injurious ions. Various genes/cDNAs encoding proteins involved in the above mentioned processes have been identified and isolated. For this reason recognition of dependent and principal effects of all characteristics on the independent characteristic estimated by factor analysis method. However the result of factor analysis based on minimum eigenvalue by means of principle component analysis extraction method and rotation method of Varimax with Kaiser Normalization revealed four factors for eleven studied traits in a saline environment. Factor one was detected as morphological trait in which RL/SH, SDW/SFW, root length had a high coefficients factor loading, respectively (Table 5). Factor two was detected as nutritional, factor three and four were detected as morphological and nutritional factors dependent on their high coefficients factor loading simultaneously. The results of factor analysis indicated that selection for morphological traits, specifically; that selection based on K^+, Ca^{2+} and K^+/Na^+ should be more efficient than other traits. Cluster classification of genotypes on the basis of value of four principal for each genotype (Table 6) by means of principal component analysis of correlation matrix distinguished genotypes Sahel×Belizovar, Siokra and Sindose×Koker from other genotypes in salinity tolerance (Fig. 1).

On the basis of factor analysis, it was suggested that in the first factor as a morphological factor some traits including shoot dry weight, root length, SDW/SFW and

Table 4: Geometric mean productivity (GMP), stress tolerance index (STI) and tolerance index (TOL) estimates for shoot dry weight , shoot dry weight/shoot fresh weight (SDW/SFW) and shoot dry weight ions, including Ca^{2+}, K^+, Na^+, Ca^{2+}/Na^+ and K^+/Na^+

	Shoot dry weight			SDW/SFW			Na^+			K^+		
Genotypes	GMP	STI	TOL	GMP	STI	TOL	GMP	STI	TOL	GMP	STI	TOL
Sahel	1.335	1.198	0.399	12.293	0.999	-1.568	13.266	1.918	-13.332	21.762	0.852	-11.461
Sahel×Tabladila	1.023	0.703	0.252	12.482	1.030	-3.26	13.113	1.874	-13.372	20.916	0.852	-11.461
Sahel×Kiokurova	1.480	1.473	0.81	13.687	1.239	0.133	13.878	2.099	-11.486	25.777	1.195	-2.000
Sahel×Siokra	1.166	0.914	0.552	12.483	1.030	-2.23	13.242	1.911	-10.132	21.605	0.839	-2.158
Sahel×Sindose-80	1.210	0.985	0.131	13.191	1.151	-4.272	14.587	2.319	-13.161	23.445	0.989	-2.647
Sahel×Belizovar	1.443	1.399	0.713	13.386	1.185	0.052	16.381	2.924	-22.487	22.522	0.912	-7.229
Sahel×Koker	1.029	0.712	0.02	12.643	1.057	-4.459	14.119	2.172	-10.497	21.596	0.839	-4.277
Taladila	1.415	1.346	0.406	13.249	1.161	-3.867	12.948	1.827	-13.458	20.090	0.726	-3.038
Tabladila×Kiokurova	1.249	1.049	-0.034	13.682	1.238	-3.069	13.737	2.056	-11.413	24.600	1.088	2.375
Tabladila×Siokra	1.149	0.888	0.04	12.938	1.107	-4.603	13.00	1.842	-9.96	20.378	0.747	1.846
Talbadila×Sindose-80	1.373	1.267	0.243	13.258	1.162	-0.7	14.420	2.266	-13.249	22.428	0.905	1.541
Talbadila×Belizovar	1.282	1.105	0.55	13.231	1.158	0.988	13.072	1.862	-11.786	21.397	0.823	-2.62
Talbadila×Koker	1.114	0.834	0.084	14.238	1.341	-7.566	13.734	2.055	-10.84	20.413	0.749	0.116
Kiokurova	1.337	1.202	0.083	16.185	1.732	-5.314	14.506	2.293	-9.91	28.890	1.501	7.798
Kiokurova×Siokra	1.226	1.011	0.383	13.078	1.131	-2.53	13.768	2.065	-8.388	19.336	0.672	-3.353
Kiokurova×Sindose-80	1.350	1.225	0.89	12.956	1.110	-0.238	15.152	2.502	-11.322	26.662	1.279	6.889
Kiokurova×Belizovar	1.555	1.626	0.403	12.741	1.073	-2.71	13.792	2.073	-9.948	26.05	1.220	2.759
Kiokurova×Koker	1.452	1.418	0.98	14.048	1.305	2.608	14.432	2.270	-9.008	24.667	1.094	5.745
Siokra	1.561	1.638	0.187	16.063	1.706	-5.66	12.987	1.838	-6.801	20.595	0.763	6.511
Siokra×Sindose-80	1.581	1.680	0.533	13.792	1.258	-5.84	14.509	2.294	-9.966	22.467	0.908	6.252
Siokra×Belizovar	1.416	1.348	0.143	13.512	1.207	-3.986	13.110	1.873	-8.53	21.755	0.851	2.025
Siokra×Koker	1.689	1.919	0.584	13.110	1.136	-3.203	13.623	2.022	-7.321	20.456	0.752	5.485
Sindose-80	1.187	0.947	0.37	13.769	1.254	-0.62	15.837	2.733	-12.972	24.476	1.077	6.043
Sindose-80×Belizovar	1.408	1.332	0.343	13.603	1.224	-1.535	14.531	2.301	-11.633	29.610	1.577	15.79
Sindose-80×Koker	1.565	1.646	-0.133	14.128	1.320	-8.449	15.211	2.521	-10.818	22.488	0.909	4.913
Belizovar	1.543	1.601	0.493	14.811	1.451	1.795	13.291	1.925	-10.526	23.004	0.952	-2.848
Belizovar×Koker	1.288	1.115	0.057	12.587	1.048	-2.241	13.829	2.084	-9.334	21.845	0.858	0.485
Koker×Koker	1.525	1.563	0.203	12.928	1.105	-2.217	14.407	2.262	-8.335	20.535	0.758	3.683
LSD ($\alpha = 0.05$)	0.187	0.351	0.121	1.702	0.344	1.023	1.819	0.707	1.702	2.853	0.505	0.254
LSD ($\alpha = 0.01$)	0.249	0.468	0.161	2.267	0.458	1.363	2.424	0.941	2.268	3.802	0.673	0.345

Table 4: Continued

	Ca^{2+}			K^+/Na^+			Ca^{2+}/Na^+		
Genotypes	GMP	STI	TOL	GMP	STI	TOL	GMP	STI	TOL
Sahel	41.868	-1.180	-16.007	1.640	0.446	0.737	3.155	0.616	1.879
Sahel×Tabladila	42.500	-1.216	-15.042	1.595	0.422	1.039	3.241	0.65	2.068
Sahel×Kiokurova	43.078	-1.249	-12.149	1.595	0.572	1.382	3.104	0.596	1.647
Sahel×Siokra	41.828	-1.178	-14.645	1.631	0.441	1.076	3.158	0.617	1.27
Sahel×Sindose-80	42.346	-1.207	-11.278	1.607	0.428	1.254	2.902	0.521	1.794
Sahel×Belizovar	41.923	-1.183	-19.484	1.374	0.313	1.377	2.559	0.405	2.164
Sahel×Koker	47.131	-1.496	-8.945	1.529	0.388	0.819	3.338	0.689	1.817
Taladila	43.315	-1.263	-14.509	1.551	0.399	1.353	3.344	0.692	2.262
Tabladila×Kiokurova	43.629	-1.281	-11.005	1.790	0.532	1.677	3.176	0.624	1.792
Tabladila×Siokra	42.434	-1.212	-13.543	1.567	0.407	1.354	3.264	0.659	1.416
Talbadila×Sindose-80	43.016	-1.246	-10.492	1.555	0.401	1.548	2.983	0.550	1.96
Talbadila×Belizovar	42.655	-1.225	-18.847	1.637	0.444	1.254	3.262	0.658	1.431
Talbadila×Koker	47.872	-1.543	-8.359	1.486	0.366	1.183	3.485	0.751	2.107
Kiokurova	43.951	-1.301	-8.056	1.991	0.658	1.941	3.029	0.567	1.492
Kiokurova×Siokra	42.649	-1.225	-10.508	1.404	0.327	0.605	3.097	0.593	1.103
Kiokurova×Sindose-80	43.406	-1.268	-7.728	1.760	0.514	1.811	2.864	0.507	1.604
Kiokurova×Belizovar	43.074	-1.249	-15.633	1.888	0.591	1.577	3.123	0.603	1.084
Kiokurova×Koker	48.114	-1.559	-4.988	1.708	0.484	1.491	3.333	0.687	1.722
Siokra	41.578	-1.164	-12.460	1.586	0.417	1.359	3.201	0.634	0.703
Siokra×Sindose-80	42.307	-1.205	-10.089	1.548	0.397	1.53	2.915	0.526	1.281
Siokra×Belizovar	41.686	-1.170	-17.818	1.659	0.456	1.244	3.179	0.625	0.686
Siokra×Koker	46.823	-1.476	-6.948	1.501	0.373	1.231	3.436	0.730	1.324
Sindose-80	43.020	-1.246	-7.211	1.545	0.396	1.688	2.716	0.456	1.741
Sindose-80×Belizovar	42.612	-1.222	-15.246	2.037	0.689	2.858	2.932	0.532	1.255
Sindose-80×Koker	47.696	-1.532	-4.163	1.478	0.362	1.4	3.135	0.608	1.941
Belizovar	41.819	-1.177	-23.169	1.730	0.496	1.143	3.146	0.612	0.711
Belizovar×Koker	47.449	-1.516	-12.601	1.580	0.414	1.103	3.430	0.728	1.374
Koker×Koker	52.381	-1.847	-2.261	1.425	0.337	1.094	3.635	0.818	1.94
LSD ($\alpha = 0.05$)	3.258	0.226	1.660	0.201	0.129	0.180	0.973	0.147	0.378
LSD ($\alpha = 0.01$)	4.341	0.301	2.211	0.207	0.172	0.240	0.297	0.197	0.502

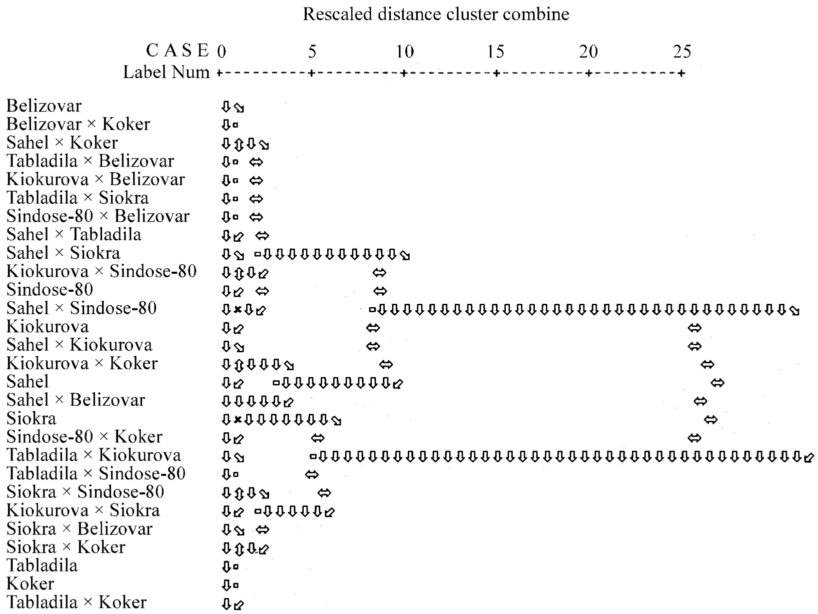

Fig. 1: Cluster classification of genotypes on the basis of value of four principal for each genotype by using ward method

Table 5: Estimated factor loadings for eleven studied traits in *Gossypium hirsutum* cultivars and their F_1 in a saline environment factor analysis

	Factors				
Variables	Morphology	Nutrition	Morphology and nutrition	Morphology and nutrition	Communalities
Shoot dry weight	0.658	0.080	0.348	0.283	0.641
Root length	0.858	0.138	0.351	-0.161	0.905
Plant height	-0.099	-0.369	0.726	-0.086	0.680
Shoot fresh weight	-0.443	-0.854	0.078	0.008	0.932
Na^+	-0.921	-0.007	0.100	-0.021	0.858
K^+	-0.136	0.088	-0.076	0.931	0.899
Ca^{2+}	-0.556	0.813	0.035	0.003	0.971
K^+/Na^+	0.398	0.773	-0.097	0.386	0.915
Ca^{2+}/Na^+	0.198	0.175	0.684	0.542	0.832
SDW/SFW	0.528	0.103	0.728	-0.216	0.866
RL/SH	0.895	0.251	0.077	-0.111	0.882
Eigenvalue	4.378	2.357	1.553	1.092	
Proportion	39.801	21.428	14.120	9.925	
Cumulative	39.801	61.226	75.349	85.274	

Table 6: Values of the four principal components for the all of genotypes with 85.278% cumulative variance

	Principal components			
Genotypes	1	2	3	4
Sahel	10.77	-1.13	39.52	-14.53
Sahel×Tabladila	16.57	-1.73	35.08	-15.64
Sahel×Kiokurova	13.05	-1.44	37.95	-14.11
Sahel×Siokra	19.74	-1.57	33.63	-15.27
Sahel×Sindose-80	15.66	-4.94	38.48	-13.00
Sahel×Belizovar	4.95	-6.13	44.44	-17.78
Sahel×Koker	21.67	-2.68	37.09	-15.14
Tabladila	5.14	-2.57	35.08	-16.75
Tabladila×Kiokurova	23.81	-3.00	33.75	-14.71
Tabladila×Siokra	17.84	-2.22	35.97	-15.20
Tabladila×Sindose-80	23.71	-4.50	33.69	-15.63
Tabladila×Belizovar	16.51	-1.29	38.22	-17.01
Tabladila×Koker	26.01	-4.21	38.26	-14.92
Kiokurova	20.86	-4.96	39.99	-10.77
Kiokurova×Siokra	24.70	-2.97	31.84	-14.25

Table 6: Continued

	Principal components			
Genotypes	1	2	3	4
Kiokurova×Sindose-80	18.42	-3.44	33.57	-14.62
Kiokurova×Belizovar	17.30	-1.26	38.64	-15.15
Kiokurova×Koker	14.45	-1.66	38.00	-15.70
Siokra	36.03	-4.29	30.01	-13.43
Siokra×Sindose-80	24.27	-5.24	33.65	-13.57
Siokra×Belizovar	28.03	-1.58	33.82	-15.94
Siokra×Koker	29.84	-2.44	32.26	-16.29
Sindose-80	19.71	-5.61	33.36	-14.58
Sindose-80×Belizovar	18.19	-2.72	37.04	-15.89
Sindose-80×Koker	31.59	-6.16	32.69	-14.36
Belizovar	20.46	-0.32	38.43	-17.23
Belizovar×Koker	20.40	-0.05	37.74	-18.05
Koker×Koker	24.82	-0.91	35.61	-18.59

RL/SH have high coefficients factor loading could be used for selection criteria and also in second factor as a nutritional factor shoot dry weight Na^+, K^+/Na^+ and Ca^{2+}/Na^+ content that have high coefficients factor loading could be used for selection criteria on the basis of their correlation with shoot dry weight.

Although Salinity tolerance in early stages of plant growth may not necessarily be a good indicator of salt tolerance for adult plants. However, some traits including shoot dry weight and its relation and correlation with root length, SDW/SFW and RL/SH, shoot dry weight Na^+, K^+/Na^+ and Ca^{2+}/Na^+ content as a criteria could be used in early stage of growth.

REFERENCES

Ahmad, S., N.I. Khan, M.Z. Iqbal, A. Hussain and M. Hassan, 2002. Salt tolerance of cotton (*Gossypium hirsutum* L.). Asian J. Plant Sci., 1: 715-719.

Ashraf, M., 1994. Breeding for salinity tolerance in plants. Crit. Rev. Plant Sci., 13: 17-42.

Dillon, W.R. and M. Goldstein, 1984. Multivariate Analysis: Method and Applications. John Wiley Sons: New York.

Fernandez, G.C.J., 1993. Effective Selection Criteria for Assessing Plant Stress Tolerance. In: Adaptation of food Crops to Temperature and Water Stress. Kuo. C.G. (Ed.), AVRDC: Shanhua, Taiwan, pp: 257-270.

Fischer, R.A. and R. Murrer, 1978. Drought resistance in spring wheatcultivars. I. Grainyieldresponse. Aust. J. Agric. Res., 29: 897-912.

Gomez, K.A. and A.A. Gomez, 1984. Statistical Procedures for Agricultural Research. John Wiley Sons: New York.

Gorham, J., 1993. Genetics and Physiology of Enhanced K/Na Discrimination. In: Genetic Aspects of Plant Mineral Nutrition; Randall, P. (Ed.), Kiuwer Academic Publishers: Dordrecht. The Netherlands, pp: 151-159.

Hoagland, D.R. and D.I. Arnon, 1950. The water-culture method for growing plants without soil. Cali. Agric. Exp. Stn. Cric., 307: 32.

Isaac, R.A. and J.D. Kerber, 1971. Atomic Absorption and Flame Photometry: Techniques and Uses in Soil, Plant and Water Analysis. In: Instrumental Methods for Analysis of Soil and Plant Tissue. Walsh, L.M. (Ed.), Soil Sci. Soc. Am. Madison, WI: 17-37.

Johnson, R.A. and D.W. Wichern, 2002. Applied Multivariate Statistical Analysis. Pearson Education.

Khatum, S. and T.J. Flowers, 1995. Effect of salinity on seed set in rice. Plant Cell Environ., 18: 61-87.

Lauchli, A., 1990. Calcium, salinity and the plasma membrane. Curr. Top. Plant Physiol., 4: 26-35.

Maas, E.V. and C.M. Grieve, 1989. Sodium-induced calcium deficiency in salt-stressed corn. Plant Cell Environ., 10: 559-564.

Porcelli, C.A., F.H. Gutierrez-Boem and R.S. Lavado, 1995. The K/Na and Ca/Na ratios and rapeseed yield under soil salinity or sodicity. Plant Soil., 175: 251-255.

Postel, S., 1989. Water for agriculture: Facing the limits. Worldwatch paper 93. Worldwatch Institute, Washington DC.

Rosielle, A.A. and J. Hamblin, 1981. Theoretical aspects of selection for yield in stress and non-stress environment. Crop Sci., 21: 943-946.

Sairam, R.K. and A. Tyagi, 2004. Physiology and molecular biology of salinity stress tolerance in plants. Curr. Sci., 86: 407-421.

Schroeder, J.I., J.M. Ward and W. Gassmann, 1994. Perspectives on the physiology and structure of inward-rectifying K channels in higher plants: Biophysical implications for K uptake. Annu. Rev. Biophys. Biomol. Struct., 23: 441-471.

Volkamar, K.M., Y. Hu and H. Steppuhn, 1998. Physiological response of plants to salinity: A review. Can. J. Plant Sci., 78: 19-27.