International Journal of Botany

ISSN: 1811-9700

International Journal of Botany 3 (1): 103-108, 2007
ISSN 1811-9700

Estimation of Genetic Parameters for Salinity Tolerance in Early Growth Stages of Cotton (*Gossypium hirsutum* L.) Genotypes

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Abstract: Genetic parameters for different characteristics related to salinity tolerance were estimated using diallel crosses by seven genotypes of cotton (*Gossypium hirsutum* L.) and their $21F_1$ progenies in saline environment. Adding incremental levels of NaCl to Hoagland's solution in a sand culture electrical conductivity of 24 dS m^{-1} was attained inducing salt stress. Analysis of variance revealed significant general and specific combining ability mean squares for all characteristics that indicated the involvement of additive and non-additive gene actions in the heritance of characters. High ratios of $\sigma^2A/(\sigma^2A+\sigma^2D)$ and high narrow-sense heritability estimates were observed for root length, plant height, Na^+, K^+, Ca^{2+}, K^+/Na^+, Ca^{2+}/Na^+, root length/shoot height and Tolerance Index (TOL), indicating the more involvement of genes additive effects in their genetic control. High differences of $[\sigma^2g/(\sigma^2g+\sigma^2e)]-[2\sigma^2gca+\sigma^2sca/(\sigma^2g+\sigma^2e)]$ were observed for K^+/Na^+ and TOL, whereas σ^2g and σ^2e estimated by expected mean square of ANOVA, indicated non-allelic effects in their genetic control. The results revealed that the parents Koker, Siokra and Belizovar and the crosses Siokra×Koker, Belizovar×Koker and Sindoze×Koker were superior for effective selecting performance for salinity tolerance in the studied cotton varieties.

Key words: Cotton, hybrid, diallel, genetic parameter, salt 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 is severely reduced at high salinity levels and different salts affect the cotton growth to a variable extent. However, inter-and intraspecific variation for salt tolerance in cotton is considerable and thus can be exploited through specific selection and breeding for enhancing salt tolerance of the crop.

Salinity of agricultural lands and irrigation water is one of the factors of environment, which limits the growth and yield of cotton and other crops in many arid and semiarid regions of the world. It is especially prevalent in the 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 (Volkmar *et al*., 1998). Information on the mechanisms involved in salt tolerance and their genetic control is essential to facilitate selection for characteristics and to design an efficient breeding programme for genetic improvement of salinity tolerance (Ashraf, 1994). Plant breeders have focused on finding new resistant cultivars because of detrimental effects of saline soil and irrigation water to reduce quantitative and qualitative cotton crop. Identifying proper selection criteria for salinity tolerance is also a major problem. Rapid screening techniques based on heritable characteristics are needed for selecting salt tolerant plants. Besides measuring ions and metabolites that acts on osmotic adjustment, comparison of yield potentials of genotypes in stress and non-stress condition is a suitable way to identify stress tolerance (Rosielle and Hamblin, 1981). In this respect, some selection criteria including Geometric Mean Productivity (GMP) (Fischer and Murrer, 1978), Stress Tolerance Index (STI) (Fernandez, 1993) and Tolerance Index (TOL) (Rosielle and Hamblin, 1981) have been defined. Significant general combining ability (gca) and specific combining ability (sca) effects of salinity resistance have been reported in *Gossypium hirsutum* (Ahmad *et al*., 2002). The partial dominance and high narrow-sense heritability were reported for salinity resistance (Ashraf and Saghir, 2000).

Despite considerable importance of understanding the genetic basis of variation for salinity tolerance only a

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few studies, indicating the genetic basis of salt tolerance were carried out earlier. For this reason the objective of the present study is to determine the important genetic parameters for shoot dry weight (g/plot), root length (cm), plant height (cm), shoot fresh weight, Ca^{2+}, K^+ and Na^+ contents (mg g^{-1}), Ca^{2+}/Na^+ and K^+/Na^+, shoot dry weight/shoot fresh weight (SDW/SFW), root length/shoot height (RL/SH) and Geometric Mean Productivity (GMP), Stress Tolerance Index (STI) and Tolerance Index (TOL) for shoot dry weight in order to select a suitable breeding program for cotton breeding line and cultivars.

MATERIALS AND METHODS

Seven diverse cotton (*Gossypium hirsutum* L.) genotypes were crossed in a half diallel fashion and their 21 F_1 progenies along with their parents were evaluated in sand cultures under normal and saline environments in a block design 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 sand boxes filled with washed and sterilized river sand, covered with polythene beads. After the 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 Hoagland'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. The plants in both environments were harvested 50 days after planting at 7-8 leaf stages. The characteristics such as shoot dry weight (SDW) in g/plot, root length (cm), plant height (cm), shoot fresh weight in g/plot, Na^+, K^+ and Ca^{2+} contents (mg g^{-1}), K^+/Na^+, Ca^{2+}/Na^+, shoot dry weight/shoot fresh weight(SDW/SFW), root length/shoot height (RL/SH), Geometric Mean Productivity (GMP), Stress Tolerance Index (STI) and Tolerance Index (TOL) for shoot dry weight were determined. The harvested plants thoroughly washed with distilled water then dried in an oven for 72 h at 80°C to a constant weight. Plant samples were ground by mill and dried in a furnace at 500°C for 2 h for ion extraction. Plant samples were added to 5 mL of 2M HCL for digestion and the 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). The selection criteria indices, including Geometric Mean Productivity as GMP = v (Yp)×(Ys) (Fischer and Murrer, 1978), Stress Tolerance Index as STI = (Yp)×(Ys)/Yp^2 (Rosielle and Hamblin, 1981) and Tolerance Index as TOL = Yp-Ys (Fernandez, 1993) were calculated for yield of shoot dry weight in non-saline (Yp) and saline (Ys) environments. Tolerance Index (TOL) was also calculated for Ca^{2+}, K^+, Na^+, Ca^{2+}/Na^+ and K^+/Na. Data subjected to analysis of variance and means were compared by using the Least Significant Differences (LSD). Variations in general combining ability (gca) of the parental lines and specific combining ability (sca) of crosses for the measured characteristics were partitioned from the total genetic variance using Griffing's Method II, Model I (Griffing, 1956). The components of variance ratio as $\sigma^2A/(\sigma^2A+\sigma^2D)$ and high narrow-sense heritability $[\sigma^2A/(\sigma^2A+\sigma^2D+\sigma^2e)]$ and $[\sigma^2A/(\sigma^2g+\sigma^2e)]$ were computed as *a*($\sigma^2A,\sigma^2D,\sigma^2e$ Estimated from diallel analysis) and *ab*(σ^2g,σ^2e Estimated from Randomized Complete Block Design) method for each characteristic to determine the relative importance of additive and non-additive gene effects, respectively (Baker, 1978). The differences of variance ratios as $[\sigma^2g/(\sigma^2g+\sigma^2e)]^{b}$-$[2\sigma^2gca+\sigma^2sca/(\sigma^2g+\sigma^2e)]^{ab}$ and $[2\sigma^2gca+\sigma^2sca/(2\sigma^2gca+\sigma^2sca+\sigma^2e)]^{a}$ were computed for each characteristic to determine the non-allelic effects in their genetic control. High-parent hetrosis was calculated as mean deviation of a cross performance from the mean of its superior parent (Mather and Jinks, 1982).

RESULTS

Regarding ion composition, the parents Belizovar and Sindose-80 with 1.395 and 1.376 g/plot had superior means for shoot dry weight, respectively, Siokra and Koker with 11.95 and 11.81 cm had superior means for root length, Sindose-80 and Kiokurova with 19.54 and 19.49 cm had superior means for plant height, Koker and Kiokurova with 10.07 and 12.05 g/plot had superior means for shoot fresh weight, Sahel and Sindose-80 with 21.51 and 23.6 mg g^{-1} had superior means for Na^+, Sahel and Kiokurova with 28.23 and 25.25 mg g^{-1} had superior means for K^+, Belizovar and Koker with 54.97 and

Table 1: Two top gca and sca effects of characters of seven genotypes and their diallel crosses

	Two top gca effects				Two top sca effects				
Characters	Parents	gca	$SE(g_{i})$	$SE(g_{i}-g_{j})$	Crosses	sca	$SE[s_{ij}]$	$SE[s_{ij}-s_{ik}]$	$SE[s_{ij}-s_{kl}]$
Shoot dry weight (g)	6	0.138	0.07	0.041	3 5	0.446	0.079	0.117	0.109
	5	0.090			5 7	0.307			
Root length (cm)	4	1.234	0.184	0.280	5 7	2.592	0.535	0.794	0.743
	7	0.741			1 7	1.755			
Plant height (cm)	5	0.338	0.166	0.253	2 7	2.294	0.482	0.716	0.670
	3	0.205			1 6	2.112			
Shoot fresh weight (g)	7	0.722	0.140	0.214	1 5	1.148	0.407	0.605	0.565
	3	0.336			2 7	1.451			
Na^+ (mg g^{-1})	4	-2.074	0.253	0.386	3 6	-1.022	0.736	1.093	1.022
	7	-0.906			2 6	-0.905			
K^+ (mg g^{-1})	1	2.913	0.182	0.277	1 7	0.279	0.528	0.784	0.734
	3	1.369			1 6	0.131			
Ca^{2+} (mg g^{-1})	5	-1.904	0.254	0.388	4 7	-0.359	0.739	1.098	1.027
	3	-1.12			1 5	-0.258			
K^+/Na^+ (mg g^{-1})	3	0.084	0.006	0.009	1 7	0.057	0.017	0.025	0.023
	1	0.070			3 6	0.044			
Ca^{2+}/Na (mg g^{-1})	4	0.200	0.033	0.049	1 3	0.093	0.095	0.141	0.132
	7	0.165			3 6	0.092			
SDW/SFW	4	1.065	0.129	0.197	5 7	3.623	0.376	0.559	0.523
	7	0.270			2 7	3.196			
RL/SH	4	6.795	0.325	0.496	5 7	11.642	0.946	0.405	1.314
	7	3.214			2 3	7.858			
GMP (shoot dry weight)	6	0.070	0.020	0.031	4 7	0.238	0.059	0.087	0.082
	4	0.055			1 3	0.200			
STI (shoot dry weight)	6	0.121	0.030	0.058	4 7	0.471	0.111	0.165	0.154
	4	0.111			1 3	0.364			
TOL (shoot dry weight)	2	-0.227	0.013	0.020	5 7	-0.428	0.38	0.057	0.053
	4	-0.101			1 7	-0.337			

*, ** Significant at p = 0.05 and p = 0.01, respectively, Parents' numbers: 1-Sahel, 2-Tabladila, 3-Kiokurova, 4-Siokra, 5-Sindose,-80 6-Belizovar, 7-Koker

53.52 mg g^{-1} had superior means for Ca^{2+}, Kiokurova and Ssahel with 1.24 and 1.31 had superior means for K^+/Na^+, Siokra and Koker with 2.89 and 2.86 had superior means for Ca^{2+}/Na^+, Siokra and Kiokurova with 19.14 and 19.05 had superior means for SDW/SFW and Siokra and Tabladila with 77.02 and 65.05 had also superior means for RL/SH, respectively. These parents also had superior gca effects (Table 1).

The parent belizovar and Sindose-80 were good general combiners for shoot dry weight. Sindose-80 followed by Siokra also exhibited high amounts of (positive) gca effects for GMP and STI (Table 1). Significant differences ($p<0.01$) were observed among the parental lines for SDW. The ratio of range of variability to mean of this characteristic (R/M) was high (0.69). However F_1 progeny differences were higher and the F-test for parent vs. progeny mean square was significant, indicating average heterotic response under salt stress and different gene combinations in parental lines. The parents of Tabladila and Siokra had significant negative gca effects (low amounts) for TOL. So the mentioned cultivars had high salt stress tolerance and high biomass potential in early growth stages. For root length, the parents with superior means were Siokra and Koker with 11.95 and 11.81 cm, respectively. Ratio of R/M for root length was also high (0.65). For Plant height the parents with superior means were Sindose-80 and Kiokurova with 19.54 and 19.49 cm, respectively. Ratio of R/M for this characteristic was very low (0.22) indicating lower coefficient of variation and uniformity of gca and importance of additive genetic effects. For shoot fresh weight the parents with superior means were Koker and Kiokurova with 10.177 and 12.05 cm, respectively. Ratio of R/M for this characteristic was high (0.64). For SDW/SFW the parents with superior means were Siokra and Kiokurova with 19.141 and 19.05, respectively. Ratio of R/M for this characteristic was low (0.43). And for RL/SH the parents with superior means were Siokra and Tabladila with 77.02 and 65.05, respectively. Ratio of R/M for this characteristic was very high (0.71).

Mean performance of the crosses (Table 2) and the estimates of their sca effects (Table 1) indicated that no crosses had both high sca effect and high mean value (low value for Na^+, Ca^{2+} and TOL) for all the characters, although a few crosses revealed to be the best combinations for more than one character. The cross Sindose-80×Koker was one of the best combinations based on its significant positive sca effect for SDW, Root length and ratios of SDW/SFW and RL/SH. Meanwhile one of its parents (Koker) exhibited high positive gca effects for these characteristics except SDW (Table 1), on the other hand Koker with high gca effect was one of the parents that contributed in crosses based on shoot dry weight and GMP, STI and TOL indices. Most of the crosses with high sca effects for SDW and

Table 2: Range, mean and two top high parents heterosis for characters of seven genotypes and their diallel crosses

			Two top high parent heterosis				
Characters	Range/Mean	Mean±SE	Crosses		Heterosis	LSD ($\alpha = 0.05$)	LSD ($\alpha = 0.01$)
Shoot dry weight (g)	0.69	1.24±0.0016	3	5	0.75	0.248	0.331
			5	7	0.606		
Root length (cm)	0.69	10.890±0.087	5	7	3.633	1.691	2.252
			2	5	1.033		
Plant height (cm)	0.22	19.13±0.0081	2	7	3.066	1.524	2.031
			1	6	2.100		
Shoot fresh weight (g)	0.64	8.80±0.014	2	7	0.540	1.287	1.714
			4	6	0.510		
Na^+ (mg g^{-1})	0.69	20.64±0.013	4	5	-3.276	2.326	3.099
			2	4	-2.419		
K^+ (mg g^{-1})	0.47	22.45±0.021	2	5	0.004	1.670	2.225
			3	6	-0.545		
Ca^{2+} (mg g^{-1})	0.16	50.43±0.020	5	6	-4.066	2.337	3.114
			5	7	-3.700		
K^+/Na^+ (mg g^{-1})	0.42	1.093±0.001	3	6	0.006	0.054	0.072
			2	4	-0.015		
Ca^{2+}/Na (mg g^{-1})	0.47	2.472±0.001	1	3	0.013	0.300	0.400
			2	3	0.004		
SDW/SFW	0.43	14.957±0.079	5	7	4.886	1.189	1.584
			2	7	3.192		
RL/SH	0.71	57.127±0.063	5	7	11.869	2.991	3.984
			2	3	-1.044		
GMP (shoot dry weight)	0.49	1.355±0.006	1	3	0.143	0.187	0.249
			4	7	0.127		
STI (shoot dry weight)	0.96	1.254±0.001	4	7	0.281	0.351	0.468
			1	3	0.271		
TOL (shoot dry weight)	4.68	0.296±0.0008	5	7	-0.502	0.121	0.162
			6	7	-0.436		

*, ** Significant at p = 0.05 and p = 0.01, respectively, Parents numbers: 1-Sahel, 2-Tabladila, 3-Kiokurova, 4-Siokra, 5-Sindose-80, 6-Belizovar, 7-Koker

GMP, STI and TOL indices had at least one or two parents with positive or significant positive high-parent hetrosis (Table 2). In general, most of the crosses involving Koker had negative high-parent hetrosis for TOL and positive and significant high-parent hetrosis for GMP and STI.

The Siokra×Koker was the best combination for Ca^{2+}, GMP and STI; also this cross had the highest mean value and high-parent hetrosis for GMP and STI but the highest cross and high-parent hetrosis for Ca^{2+} were Kiokurova×Sindose-80 and Sindose-80×Belizovar. One of the parents of this cross (Siokra) had also the highest gca effects. With respect to higher gca effect of Siokra indicating the involvement of both additive and non-additive gene action in the heritance of this characteristic. GMP and STI seemed to be predominantly under the control of additive and non-additive genetic effects. This cross had salt stress tolerance and high shoot dry weight in non-stress condition after Kiokurova×Koker and also gave positive and significant high-heterosis (Table 2). The cross Sindose×Koker, with positive sca effect and the highest heterosis and Sindose-80×Koker with the highest mean were good in specific combinations for root length. The cross Tabladila×Koker exhibited the highest sca effects, high-parent hetrosis and mean performance after Sahel×Belizovar for shoot height and shoot fresh weight. The cross Kiokurova×Belizovar had highest sca effect for K^+/Na^+ and Ca^{2+}/Na^+ and lowest sca effect for Na^+,the highest hetrosis for K^+ and K^+/Na^+ and the second highest mean were observed for K^+/Na^+ for this cross. So it can be used for improving this characteristic. With the respect to parents of lower negative and non-significant sca effects and on the other hand lower negative and significant gca effects of different parent for Na^+ may be because of the presence of genetic diversity among the parents and could be some complementation indicating importance of non-additive effects.

Shoot dry matter is an important selection criterion, which combines various responses to salinity into one measure of tolerance. However, this is a destructive method, which can not be used for the selection of early generation. To overcome this difficulty, selection for tolerance could be performed on correlated characteristics. However phenotypic significant positive correlation were estimated between SDW and other characteristics such as root length (0.59**), SFW (0.53**), SDW/SFW (0.55**), RL/SH (0.61**) and significant negative correlation with K^+ (-0.45**) and non-significant negative and positive with Na^+(-0.26), Ca^{2+} (0.06), respectively. The high narrow-sense heritability were estimated for root length and RL/SH through *a* and *ab* method, therefore these characteristics can be used as good selection criteria for improving dry weight in saline condition. In previous studies also the importance of RL, K^+, Na^+ and Ca^{2+} for salinity tolerance have been emphasized. Phenotypic significant positive correlation were observed between Na^+ and K^+ (0.51**) and significant negative correlation with K^+/Na^+ (-0.41*) and also negative and significant correlation were observed between Ca^{2+}/Na^+ and Na^+ (-0.89**), K^+(-0.48**).

Pronounced results regarding selection criteria for salt tolerance were obtained using stress indices (GMP, STI and TOL). The parent Siokra exhibited the lowest (negative) gca effect and mean value for TOL and Na^+ and had the highest significant positive gca for Root length, RL/SH, SDW/SFW and Ca^{2+}/Na^+ ratio. The Koker had the highest gca effects and mean values for root length, SFW, Na^+, Ca^{2+}/Na^+, SDW/SFW and RL/SH. This parent was one of the parental lines of all crosses that had high sca for all of the characteristics except Na^+, Ca^{2+}/Na^+. However the crosses of Siokra and Koker or the crosses involving at least one of these lines gave the best combinations for most of the characteristics. According to Fernandez (1993) a small value of TOL represents relatively more tolerance to stress. The selection based on TOL favour genotypes with low yield potential under non-stress condition. One of the difficulties with the use of plant dry matter to screen tolerant genotypes is that they may differ in their potential growth which under salinity stress it may present their potential capacity rather than specific tolerance (Blum, 1988) Fernandez reported that GMP and STI can be used to identify genotypes that produce high yield under both stress and non-stress condition (Fernandez, 1993). In other words, STI is an overall index of yield potential and stress tolerance. In this case although Belizovar had highest gca effect and mean value for SDW, GMP and STI, fortunately the second highest means for GMP, STI and TOL was Siokra that can be used for improving SDW.

DISCUSSION

Significant variations in general combining ability and specific combining ability estimates were observed for shoot dry weight, root length, plant height, shoot fresh weight, Na^+, K^+ and Ca^{2+} contents, K^+/Na^+, Ca^{2+}/Na^+, shoot dry weight/shoot fresh weight (SDW/SFW), root length/shoot height (RL/SH) and indices of Geometric Mean Productivity (GMP), Stress Tolerance Index (STI), Tolerance Index (TOL) for shoot dry weight (Table 3) indicates the importance of both additive and non-

Table 3: 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 and GMP, STI, TOL indices for shoot dry weight in a saline environment

		Mean square						
SOV	df	Shoot dry weight (SDW)	Root length (RL)	Plant height (PH)	Shoot fresh weight (SFW)	Na^+	K^+	K^+/Na^+
Crosses	27	0.188**	10.533**	7.640**	5.226**	20.455**	36.951**	0.074**
gca	6	0.279**	24.090**	16.89**	7.784**	49.733**	96.022**	0.221**
cca	21	0.162**	6.66**	4.995**	4.496**	12.090**	20.074*	0.032**
Error	54	0.023	1.065	0.866**	0.617	2.016	1.039	0.001
$\sigma^2A/(\sigma^2A + \sigma^2D)$		0.32	0.51	0.51	0.32	0.54	0.56	0.64
Narrow-sense heritability [a]		0.28	0.45	0.43	0.28	0.48	0.54	0.63
Broad-sense heritability [a]		0.87	0.89	0.88	0.87	0.89	0.97	0.98
CV (%)		12.23	9.47	4.86	8.92	6.86	4.54	3.03
Narrow-sense heritability [ab]		0.21	0.35	0.32	0.21	0.37	0.46	0.55
Broad-sense heritability [ab]		0.65	0.68	0.66	0.66	0.68	0.83	0.85
Broad-sense heritability [b]		0.70	0.75	0.72	0.71	0.75	0.92	0.96
BSH[b]-BSH[ab]		0.05	0.07	0.06	0.05	0.07	0.09	0.11

		Mean square						
SOV	df	Ca^{2+}	Ca^{2+}/Na^+	SDW/SFW	RL/SH	GMP (SDW)	STI (SDW)	TOL (SDW)
Crosses	27	22.655	0.284**	9.420**	253.86**	0.071**	0.314**	0.149**
gca	6	60.109	0.757**	12.620**	596.52**	0.129**	0.405**	0.472**
sca	21	11.955	0.149**	8.506**	155.96**	0.054**	0.289	0.257**
Error	54	2.039	0.033	0.527	3.334	0.013	0.046	0.005
$\sigma^2A/(\sigma^2A + \sigma^2D)$		0.60	0.61	0.27	0.50	0.41	0.27	0.69
Narrow-sense heritability [a]		0.54	0.53	0.26	0.49	0.33	0.23	0.66
Broad-sense heritability [a]		0.09	0.87	0.94	0.98	0.80	0.84	0.96
CV (%)		2.82	7.41	4.85	3.19	8.41	17.10	25.05
Narrow-sense heritability [ab]		0.41	0.40	0.22	0.43	0.23	0.17	0.55
Broad-sense heritability [ab]		0.69	0.63	0.79	0.87	0.55	0.61	0.79
Broad-sense heritability [b]		0.77	0.71	0.85	0.96	0.60	0.66	0.89
BSH[b]-BSH[ab]		0.08	0.08	0.06	0.09	0.05	0.05	0.10

*, ** Significant at p = 0.05 and p = 0.01, respectively; A and D as defined in the text refer to additive and dominance genetic effects, respectively. And also a, b and ab as defined in the text refer to estimation of parameters with diallel assumption, without diallel assumption(RCBD method) and σ^2A, σ^2D with diallel assumption and σ^2P without diallel assumption, respectively

additive genetic effects for these characteristics. High ratios of $\sigma^2A/(\sigma^2A+\sigma^2D)$ and high narrow-sense heritability estimates of root length, plant height, Na^+, K^+, Ca^{2+}, K^+/Na^+, Ca^{2+}/Na^+, root length/shoot height and Tolerance Index (TOL), indicated the more involvement of genes additive effects in their genetic control. Therefore, the efficiency of selection based on these characters is expected to be high but, shoot dry weight, shoot fresh weight, shoot dry weight/shoot fresh weight (SDW/SFW) and indices of Geometric Mean Productivity (GMP), Stress Tolerance Index (STI) were controlled predominantly by non-additive genetic effects (Table 3). When gca effects are not predominant in self-pollinated crops, the major portion of the variability, is due to additive×additive genetic effects or divergence among progenies in the same parental array and therefore, should be delayed to later generation. The high differences of variance ratios $[\sigma^2g/(\sigma^2g+\sigma^2e)] - [2\sigma^2gca+\sigma^2sca/(\sigma^2g+\sigma^2e)]^{ab}$ were observed for those all characteristics that had high narrow-sense heritability, indicating correlation between narrow-sense heritability and non-allelic effects in their genetic control. This is resulted from interaction of many locus of gene additive action in the quantitative characteristics that produce non-allelic effects. Sairam and Tyagi (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 in plants. The high non-allelic estimates for K^+/Na^+ and TOL were 0.11 and 0.10, respectively. The high narrow sense-heritability for these characteristics was 0.64 and 0.69, respectively.

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