

Exploring influential plant traits for enhancing upland cotton yield under salt stress

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Abstract This research was conducted to explore genetic material that can yield better under salt stress conditions. The experiment was laid out using 27 upland cotton genotypes in a RCBD 2 factorial arrangement with two replications. Saline water (NaCl at 20 dS/m) was applied after satisfactory emergence was achieved. The crop was raised to maturity and data relating to yield, fiber quality and ionic traits were recorded. Analysis of variance showed significant variations in the germplasm. Plant height, bolls per plant, boll weight, GOT%, staple length, staple strength, K⁺ and K⁺/Na⁺ ratio under salinity stress showed a highly significant correlation with seed-cotton yield. The highest direct effect on seed-cotton yield per plant was exhibited by bolls per plant and boll weight. The results from the correlation and path coefficient analyses revealed that although the K⁺/Na⁺ ratio had a strong positively significant association with seed-cotton yield, its direct effect on the seed-cotton yield was negative and thus selection on the basis of K⁺/Na⁺ may not be fruitful. Hence, only indirect selection through bolls per plant and boll weight may be effective in increasing the seed-cotton yield per plant under salinity stress.

Keywords cotton, genotypic correlation, path coefficients, yield traits, fibre traits, ionic traits

Introduction

Among major abiotic environmental stresses influencing crop production, salinity in top soil and sub soil is of major consideration (Cha-um et al., 2006; Grewal, 2010). Nearly 20% of the world's area and about half of the irrigated lands suffer salinity stress (Zhu, 2001). The adverse effects of salinity on various plant growth and developmental processes include seed germination, seedling growth and flowering, ultimately resulting in reduced yield and quality (Jampeetong and Brix, 2009; Gorai et al., 2010).

The cotton crop has been declared as a fairly salt-tolerant crop at the vegetative stage (Maas and Hoffman, 1977), but its

low germination along with abnormal growth at the seedling stage appeals to cotton breeders for enriching its salt tolerance characteristics, resulting in comparatively higher seed-cotton yield than the existing cultivars (Ali et al., 2005).

Pakistan is basically an agriculturally dominant country, as agriculture here is vital to the national economy, accounting for 23% of the GDP and employing 44% of the labor force. Upland cotton, being a cash crop, accounts for 8.6% of value added in the agriculture sector and 1.6% to the overall GDP of the country. In 2009, cotton was sown in the country on an area of 3.1 million hectares with a production of 12.7 million bales, comprising a per unit yield of 695 kg/hm² (Anonymous, 2010). At present, the country is facing a severe problem in national food security because of the loss of precious arable land caused by drought, water logging and salinity. It is a matter of great concern that salt affected land is increasing at a more rapid rate (20%) under irrigated regions than aridity in semi-arid regions (2%). According to the

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reports of Qureshi and Barrett-Lennard (1998), approximately 6.3×10^6 of irrigated land was severely affected by salinity, resulting in low agricultural productivity and a loss of 20 billion rupees yearly (Qayyum and Malik, 1988). It is a point of great concern that the deterioration of 6.173 million hectares affected land has resulted in a Rs.176.05 billion GDP loss (PCST, 2003).

Various earlier researchers suggested the development of salt tolerant cultivars either through conventional techniques of plant breeding or through non-conventional techniques of molecular biology (Flowers and Yeo, 1995; Khan et al., 2001). Earlier findings of various researchers suggested the presence of sufficient variation in various crop species, e.g., in cotton (Ashraf and Ahmad, 2000; Noor et al., 2001; Bhatti and Azhar, 2002; Saqib et al., 2002).

Rapid and reliable improvement in breeding for salt tolerance requires information about the genetic architecture of salt tolerance. To bring effective progress in obtaining salt tolerance, the knowledge of correlation and path coefficients are very necessary, which collectively help cotton breeders in the selection of marker traits to find salt tolerant parental genotypes and various F_1 populations. Thus, considering the importance of the evolution of salt tolerant cotton genotypes, the present study was planned with the following objectives to identify F_1 cotton genotype with higher yield potential than existing cultivars for regions exposed to salinity.

Hence, keeping in view the rapid spread of salinity in the country and the importance of cotton as a cash and export value crop, the research work was planned to study the genetic basis of salinity tolerance in cotton genotypes. Only a part of the research work reflecting the degree of association along with cause and effect relationship between various seed-cotton yields, fiber quality and ionic traits is presented in this paper.

Materials and methods

Experimental design and NaCl treatment

Because of the risk of contamination, the fertile soils, along with spatial and temporal variations present in the naturally salt-affected soil, the present research was conducted in earthen pots (mature crop experiment) filled with normal field soils and an environment very close to the natural saline soils was created by drenching the soil with a calculated quantity of brine (NaCl solution) in the medium.

Soaked seeds of 27 genotypes were sown during June 2009 in earthen pots (12 × 10 inches) and these pots were laid out according to the randomized complete block (RCB) design in a 2 factorial (Genotypes and Salinity) arrangement with 2 replications. After a desirable emergence was achieved, an initial dose of the calculated amount of brine solution (NaCl at 10 dS/m) was applied to two-week old seedlings, whereas the final increment in the salinity concentration of NaCl at 20

dS/m was applied four weeks after sowing. All kinds of recommended crop husbandry practices from seed sowing to seed cotton picking were provided.

Sampling and measurement

At maturity, the main stems of cotton plants ceased further elongation, at which time plant height from the cotyledonary node to the apical bud was recorded with a measuring tape in centimeters and the average plant height from 5 plants was calculated. After measuring plant height, a number of mature bolls picked from 5 plants were counted and the average was worked out for each genotype. Seed cotton picked from 5 plants of each genotype per salinity level was weighed on an electronic balance to calculate the average yield per plant. Data regarding individual boll weight were calculated by dividing total weight of seed cotton picked over total number of bolls picked.

A particular sample of seed cotton was weighed and ginned with a single roller ginning machine. The lint was separated in the ginning process and weighed with a ginning outturn (GOT) calculated in percentage by dividing the lint weight over the seed cotton weight of a sample. Ginned samples were used for measuring fiber traits viz., staple length, strength and fiber maturity.

The leaf samples for measuring Na and K were collected just after seed-cotton picking followed by washing in distilled water and blotting dry on newspaper. The dried samples were transferred to micro-tubes and frozen to determine the concentrations of Na^+ and K^+ . After collection of the data on field and fiber parameters, frozen samples were thawed and crushed using a stainless steel rod to extract sap from leaves. The sap was centrifuged at 7000 r/min for 10 min and the supernatant was stored in other micro-tubes for ionic concentration analysis. A sample from the above sap was taken and diluted as all requirements and the concentrations of Na^+ and K^+ was determined through Flame Photometer. The K^+/Na^+ ratio was calculated by dividing the concentration of K^+ over the concentration of Na^+ in the leaves.

Data analysis

After getting absolute and relative mean values, the data were analyzed by Analysis of Variance (ANOVA) with 2 factorial RCB Design as described by Steel et al. (1997). Genotypic association (r_g) between yield, fiber and ionic traits at the control level and salinity of NaCl at 20 dS/m was determined by the following formula:

$$r_g = \{(Cov.g_{xy})/(Vg_x \times Vg_y)\}^{1/2},$$

where, $Cov.g_{xy}$, Vg_x and Vg_y are the genotypic covariance, variances of trait 'x' and 'y'. Correlations were considered significant if ' r (calc.)' using the above formula exceeded the ' r (tab.)' value (Nadarajan and Gunasekaran, 2005) at 5% and

1% probability level with $n-2$ degree of freedom. To find out the direct and indirect contribution/share of all studied traits on the seed-cotton yield, path coefficient analysis was performed as first utilized in plant selection by Dewey and Lu (1959) and discussed by Nadarajan and Gunasekaran (2005).

Results

Cotton yield, fiber traits and ionic concentration in leaves under salinity stress

The results of the analysis of variance from Table 1 indicate that in the replications, no significant differences were found among all the varieties for plant height, number of bolls per plant, staple length, staple strength and Na. Mean square values from the analysis of variance with respect to all the accessions for all the traits presented in Table 1 indicate that all the accessions/genotypes showed significant ($P \leq 0.05$) differences for all the traits studied. Interaction between accession \times concentrations was found to be non-significant for all fiber quality traits reflecting that all the genotypes showed a uniform effect for each fiber trait. The interaction between accession \times concentrations was found high for Na^+ and K^+/Na^+ ratio but non-significant for K^+ in the leaves, which clearly revealed that all the varieties (whether susceptible or tolerant) showed a consistent behavior with respect to K^+ concentration in their leaves in control and increased salinity stress plants.

Correlation coefficients between various traits

Correlation, as a useful measure to determine the degree of association among two or more variables, is useful in finding the value of different plant traits for carrying out the selection procedure. When the direct selection on the basis of seed-cotton yield per plant is not possible either because of low variability or low heritability, then it is suggested that indirect selection for yield enhancement should be carried out using component traits like plant height, and thus the correlation is vital in determining the importance of yield contributing traits.

Plant height can show a positive and highly significant correlation with K^+ and staple strength along with a significant positive correlation with fiber fineness, GOT and seed-cotton yield per plant under the control level (Table 2). The number of bolls per plant shows a significant and highly significant association with fiber fineness, GOT and seed-cotton yield per plant while a negative and significant association was observed for plant height, Na^+ and K^+ . Individual boll weight exhibits a highly significant and positive correlation with GOT, staple length, staple strength and seed-cotton yield per plant while the correlation with number of bolls per plant and seed-cotton yield per plant and association with staple length, strength, Na^+ and K^+ in the leaves was negative and highly significant. GOT exhibits an association with the number of bolls per plant, individual boll weight, staple length, staple strength and seed-cotton yield per plant. In our study, a positive and highly significant association was observed for individual boll weight, GOT and staple strength. Staple strength showed a positive and highly significant association with plant height, individual boll weight, GOT, staple length and seed-cotton yield per plant while the association with Na^+ was negative but highly significant and the association with the number of bolls per plant, individual boll weight, staple length and staple strength was non-significant but negative. Na^+ exhibited a significant and positive association with plant height and individual boll weight besides a negative but highly significant association with fiber fineness and K^+/Na^+ ratio. A highly significant but positive association of K^+ with plant height and K^+/Na^+ ratio and a negative but highly significant correlation with number of bolls per plant were found. Yield per plant exhibited a positive but highly significant correlation with the number of bolls per plant, individual boll weight, fiber fineness, GOT and staple strength, a negative but highly significant correlation with K^+/Na^+ ratio and a negative association with plant height and K^+ concentration in the leaves.

Plant height showed a significant but positive association with the number of bolls per plant, individual boll weight, GOT, staple length, staple strength, K^+/Na^+ , K^+ and seed-cotton yield per plant but a negative correlation with fiber fineness and Na in their leaves under salinity stress (Table 3). A highly significant but positive association of the number of

Table 1 Genotypic correlation coefficient estimates for various yield, fiber and ionic concentration traits in 9 parents and 18 F_1 crosses grown in control level for *Gossypium hirsutum* L.

SOV	d.f.	Plant height (cm)	The number of bolls per plant	Individual boll weight (g)	Yield per plant (g)	GOT %	Staple length (mm)	Staple strength (tpsi)	Fiber fineness ($\mu\text{g}/\text{inch}$)	Na^+	K^+	K^+/Na^+ ratio
Replications	1	39.194	0.182**	0.093**	23.561**	17.036*	1.942	41.005	0.15*	0.086	64.2**	0.50**
Accessions (Acc.)	26	596.664**	6.571**	0.082**	68.32**	16.94**	10.008**	34.581**	0.092**	1.73**	8.29**	0.19**
Concentrations† (Conc.)	1	53616.51**	332.63**	23.63**	10143.57**	886.3**	805.42**	4855.1**	3.94**	327.4**	37.3**	34.6**
Acc. \times Conc.	26	59.282**	0.666**	0.033**	5.946*	2.812	0.64	3.335	0.005	2.29**	1.20	0.20**
Error	54	10.111	0.25	0.005	3.035	2.824	0.97	12.313	0.031	0.29	0.768	0.025

*, ** = Significant at 5% and 1% probability levels, respectively. n.s = non-significant. † = Control (salinity at 2.3 dS/m) and NaCl at 20 dS/m.

Table 2 Genotypic correlation coefficient estimates for various yield, fiber and ionic concentration traits in 9 parents and 18 F₁ crosses grown in Control level for *Gossypium hirsutum* L.

Traits	Plant height (cm)	The number of bolls per plant	Individual boll weight (g)	Fiber fineness (µg/inch)	GOT%	Staple length (mm)	Staple strength (tppi)	K ⁺ /Na ⁺ ratio	Na ⁺	K ⁺	Yield per plant (g)
Plant height (cm)	1.00	-0.32**	0.27*	-0.22	-0.05	0.35*	0.47**	0.07	0.32*	0.54**	-0.11
Number of bolls / plant	-0.32*	1.00	0.18	0.48**	0.45**	-0.01	0.32*	-0.20	-0.07	-0.35*	0.87**
Individual boll weight (g)	0.27*	0.18	1.00	0.27*	0.66**	0.56**	0.45**	-0.19	0.26*	0.09	0.65**
Fiber fineness (µg/i)	-0.22	0.48**	0.27*	1.00	0.07	-0.73**	-0.54**	0.04	-0.54**	-0.60**	0.52**
GOT %	-0.05	0.45**	0.66**	0.07	1.00	0.58**	0.63**	0.06	-0.23	-0.15	0.76**
Staple length (mm)	0.35*	-0.01	0.56**	-0.73**	0.58**	1.00	0.82**	-0.12	0.17	0.09	0.29*
Staple strength (tppi)	0.47**	0.32*	0.45**	-0.54**	0.63**	0.82**	1.00	-0.13	0.04	-0.04	0.79**
K ⁺ /Na ⁺ ratio	0.07	-0.20	0.19	0.04	0.06	-0.12	-0.13	1.00	-0.74**	0.53**	-0.25*
Na ⁺	0.32*	-0.07	0.26*	-0.54**	-0.23	0.17	0.04	-0.74**	1.00	0.18	0.09
K ⁺	0.54**	-0.35*	0.09	-0.60**	-0.15	0.09	-0.04	0.53**	0.18	1.00	-0.21
Yield per Plant (g)	-0.11	0.87**	0.65**	0.52**	0.76**	0.29*	0.79**	-0.25**	0.09	-0.21	1.00

*, ** mean significance at 5% (r tab. value = 0.23) and 1% (r tab. value = 0.32) probability levels, respectively. Absolute control (salinity at 2.3 dS/m).

Table 3 Genotypic correlation coefficient estimates for various yield, fiber and ionic concentration traits in 9 parents and 18 F₁ crosses grown in salinity of NaCl at 20 dS/m for *Gossypium hirsutum* L.

Traits	Plant height (cm)	Number of bolls per plant	Individual boll weight (g)	Fiber fineness (µg/inch)	GOT%	Staple length (mm)	Staple strength (tppi)	K ⁺ /Na ⁺ ratio	Na ⁺	K ⁺	Yield per plant (g)
Slant height (cm)	1.00	0.54**	0.53**	-0.29*	0.37**	0.56**	0.59**	0.81**	-0.73**	0.51**	0.55**
The number of bolls per plant	0.54**	1.00	0.81**	0.15	0.99**	0.48**	0.44**	0.80**	-0.85**	0.41**	0.98**
Individual boll weight (g)	0.53**	0.81**	1.00	0.10	0.88**	0.50**	0.48**	0.69**	-0.84**	0.22	0.90**
Fiber fineness (µg/inch)	-0.29*	0.15	0.10	1.00	-0.43**	-0.57**	-0.68**	0.10	-0.02	0.12	0.17
GOT%	0.37**	0.99**	0.88**	-0.43**	1.00	0.45**	0.09	0.77**	-0.94**	0.13	0.81**
Staple length (mm)	0.56**	0.48**	0.50**	-0.57**	0.45**	1.00	0.93**	0.46**	-0.50**	0.18	0.51**
Staple strength (tppi)	0.59**	0.44**	0.48**	-0.68**	0.09	0.93**	1.00	0.78**	-0.75**	0.27*	0.69**
K ⁺ /Na ⁺ ratio	0.81**	0.80**	0.69**	0.10	0.77**	0.46**	0.78**	1.00	-0.88**	0.71**	0.78**
Na ⁺	-0.73**	-0.85**	-0.84**	-0.02	-0.94**	-0.50**	-0.75**	-0.88**	1.00	-0.30*	0.85**
K ⁺	0.51**	0.41**	0.22	0.12	0.13	0.18	0.27*	0.71**	-0.30*	1.00	0.38**
Yield per plant (g)	0.55**	0.98**	0.90**	0.17	0.81**	0.51**	0.69**	0.78**	-0.85**	0.38**	1.00

*, ** = Significant at 5% (r tab. value = 0.23) and 1% (r tab. value = 0.32) probability levels, respectively. *Absolute salinity (NaCl at 20 dS/m).

bolts per plant was observed for all the traits except fiber fineness and Na⁺, which were non-significant and negatively highly significant, respectively. Individual boll weight showed a positive and highly significant association with plant height, number of bolts per plant, GOT, staple length and strength, K⁺/Na⁺ ratio and seed-cotton yield per plant, with a non-significant association for fineness and K but negative for Na⁺. There was an observed significant negative correlation of fiber fineness with plant height, GOT, staple

length, staple strength but a non-significant association with the number of bolts per plant, individual boll weight, K⁺ and K⁺/Na⁺ ratio and seed-cotton yield per plant (Table 3). GOT exhibited a highly significant association with plant height, number of bolts per plant, individual boll weight, staple length and seed-cotton yield per plant, but a negative highly significant correlation with fiber fineness and Na⁺ concentration. A highly significant and positive correlation with staple length was observed for all traits except fiber fineness and

Na⁺, which were negative and highly significant. The association with fiber strength was also similar to staple length. Na⁺ showed a highly significant negative correlation with all the traits except for fiber fineness which was non-significant but negative. K⁺ showed a non-significant but negative association with individual boll weight, fiber fineness, GOT and staple length. The highly significant correlation of seed-cotton yield per plant was observed with plant height, number of bolls per plant, individual boll weight, GOT, staple length and strength, K⁺ and K⁺/Na⁺ ratio. The negative and highly significant correlation of seed was observed with Na⁺ and the non-significant positive correlation was with fiber fineness. Salinity affected all the plant traits negatively except fiber fineness and Na⁺ in the leaves as compared to the control level. K⁺/Na⁺ ratio, used as a selection criterion under salinity stress in many earlier experiments, exhibited a negative and significant association with seed-cotton yield per plant under the control level but a positive significant correlation with seed-cotton yield under salinity.

Path coefficients

It is well documented that when several component traits show a significant and positive correlation with complicated and economically variable traits, then the simple correlation coefficient is unable to provide complete information about what trait is more important than others. Thus, selection based on a single trait may be ineffective in improving the seed-cotton yield per plant. In these situations, it becomes necessary to find the contribution of each trait to the improvement of seed-cotton yield per plant. Path coefficient analysis is effective in determining the extent of contribution

of various plant traits on the seed-cotton yield per plant. It partitions the correlation coefficient of various traits into direct and indirect contribution via other traits on the dependent traits (seed-cotton yield per plant).

A perusal of data present in Table 4 under the control level indicates that the genotype correlation between plant height and seed-cotton yield per plant is negative but non-significant. Direct effects of plant height on the seed-cotton yield per plant were very minor (0.011) while its negative and more indirect effects on seed-cotton yield per plant were through the number of bolls per plant that exceeded all other traits for its maximum direct effect on seed-cotton yield per plant (0.816). However, its indirect low effect on seed-cotton yield per plant was through individual boll weight (0.102). Similarly, the individual boll weight had the 2nd highest direct effect on the seed-cotton yield per plant while the positive but less valuable indirect effects of this trait was through the number of bolls per plant (0.566) at the control level. The non-significant correlation of staple length with seed-cotton yield per plant was through its moderate value of indirect effect through individual boll weight. Staple length and GOT were all related with individual boll weight but strongly correlated with seed-cotton yield per plant because of its indirect effect through the number of bolls per plant and individual boll weight. Moderate values of correlation of fiber fineness were also from the indirect effect of the number of bolls per plant. Among ionic concentration traits, Na⁺ and K⁺/Na⁺ ratio had a valuable direct effect on seed-cotton yield per plant but K⁺ showed a negative direct effect (Table 4) while all the traits showed either minor or negative indirect effects via other traits for seed-cotton yield per plant at the control level.

In plants exposed to salinity stress, the genotype correla-

Table 4 Genotypic path analysis estimates for various yield, fiber and ionic concentration traits in 9 parents and 18 F₁ crosses grown in control level for *Gossypium hirsutum* L.

Traits	Plant height (cm)	Number of bolls per plant	Individual boll weight (g)	Fiber fineness (µg/inch)	GOT%	Staple length (mm)	Staple strength (tppsi)	K ⁺ /Na ⁺ ratio	Na ⁺	K ⁺	Genotypic correlation with yield per plant (g)
Plant height (cm)	0.011	-0.262	0.155	-0.003	0.003	0.027	-0.023	0.018	0.064	-0.097	-0.106
Number of bolls/plant	-0.004	0.816	0.102	0.006	-0.024	-0.001	-0.015	-0.051	-0.015	0.062	0.876**
Individual boll weight (g)	0.003	0.147	0.566	0.003	-0.034	0.044	-0.050	-0.049	0.052	-0.017	0.665**
Fiber Fineness (µg/inch)	-0.002	0.389	0.155	0.012	-0.004	-0.058	0.026	0.011	-0.110	0.106	0.525**
GOT%	-0.001	0.371	0.374	0.001	-0.052	0.046	0.026	0.017	-0.046	0.027	0.763**
Staple length (mm)	0.004	-0.010	0.318	-0.009	-0.030	0.079	-0.040	-0.030	0.034	-0.017	0.299*
Staple strength (tppsi)	0.005	0.258	0.591	-0.006	-0.033	0.065	-0.048	-0.035	0.009	0.007	0.814**
K ⁺ /Na ⁺ ratio	0.001	-0.161	-0.107	0.001	-0.003	-0.009	0.006	0.261	-0.150	-0.094	-0.256*
Na ⁺	0.003	-0.058	0.146	-0.007	0.012	0.013	-0.002	-0.193	0.203	-0.031	0.086**
K ⁺	0.006	-0.282	0.053	-0.007	0.008	0.007	0.002	0.138	0.036	-0.178	-0.217

Diagonal letters represent direct effects while others are the indirect effects of various traits on seed-cotton yield per plant. *Absolute control (salinity at 2.3 dS/m).

tion of plant height with seed-cotton yield per plant also became strong not only because of an increase in its direct effect (0.106) but also because of the increased indirect effect on seed-cotton yield per plant through the number of bolls per plant (0.410) and individual boll weight (0.187). The number of bolls per plant exerted a stronger genotype correlation with seed-cotton yield per plant (0.985) along with the highest direct effect on seed-cotton yield per plant under salinity stress (Table 5) than the other traits with the value of 0.755, showing its valuable indirect effect through individual boll weight (0.284). The maximum direct effect of individual boll weight on seed-cotton yield per plant was 0.352, with its valuable indirect effect via number of bolls per plant (0.310) and Na^+ ratio under salinity stress. GOT exhibiting a strong correlation with seed-cotton yield per plant (0.812), showed a very low direct effect (0.035) and significantly higher indirect effect through the number of bolls per plant (0.750), individual boll weight (0.311) and Na^+ (0.217). Under salinity stress, staple length and staple strength showed a very low and negative direct effect on seed-cotton yield per plant reflecting an indirect effect through the number of bolls per plant, individual boll weight and Na^+ . It was interesting to find that K/Na ratio showed a strong association with seed-cotton yield per plant (0.786) under salinity stress but exerted the highest negative direct effect (-0.475) on seed-cotton yield per plant in all traits (Table 5). However, its more prominent effect was indirectly through the number of bolls per plant (0.605), individual boll weight (0.242), Na^+ (0.203) and K^+ (0.154). The Na^+ was strongly negatively associated with seed-cotton yield per plant (-0.855) and the positive effect was indirectly through K^+/Na^+ ratio (0.417). The direct effect value of K^+ concentration on seed-cotton yield per plant was 0.216, which showed its valuable indirect effect via number of bolls per plant (0.307) under salinity stress.

Discussion

Na^+ is absorbed in the plants in great amounts except in salt tolerant genotypes. Hence, Na^+ exclusion may be used as a selection criterion for salt tolerance as reported earlier in wheat (Ali et al., 2007) and cotton (Ashraf, 2002). The reduction in the K^+ concentration in the leaves may be because of higher Na^+ concentration in the saline medium, which interferes with the absorption of K^+ (Ashraf and Ahmad, 2000; Pervaiz et al., 2002).

The reduction in the K^+/Na^+ ratio in the leaves under salinity stress may be attributed to the displacement of some anions, e.g. Ca^{++} from the plasma-membrane. As a result, there is disturbance in the membrane integrity and movement of K^+ out of the cell resulting in the decreased K^+/Na^+ ratio (Kent and Lauchli, 1985). The reduction in K^+/Na^+ ratio in cotton (Qadir and Shams, 1997) and wheat (Ali et al., 2007) was also previously known as a reliable selection criterion for screening of salt tolerant genotypes.

K^+/Na^+ ratio, as a selection criterion under salinity stress in many earlier experiments, exhibited a negative and significant association with seed-cotton yield per plant in the control but a positive significant correlation with seed-cotton yield under salinity stress.

Plant height, the number of bolls per plant, individual boll weight, GOT%, staple length, staple strength, K^+ and K^+/Na^+ ratio under salinity stress showed a highly significant correlation with seed-cotton yield, while a highly significant negative association was found between Na^+ and all other traits (Ashraf and Ahmad, 2000) except fiber fineness, which was non-significant and negative. Fiber fineness showed a non-significant but negative association with plant height, GOT%, staple length and a non-significant association with all remaining traits under salt stress. The significant

Table 5 Genotypic path analysis estimates for various yield, fiber and ionic concentration traits in 9 parents and 18 F_1 crosses grown in salinity of NaCl at 20 dS/m for *Gossypium hirsutum* L.

Traits	Plant height (cm)	The number of bolls per plant	Individual boll weight (g)	Fiber fineness ($\mu\text{g}/\text{inch}$)	GOT%	Staple length (mm)	Staple strength (tppsi)	K^+/Na^+ ratio	Na^+	K^+	Genotypic correlation with yield per plant (g)
Plant height (cm)	0.106	0.410	0.187	0.001	0.013	-0.002	-0.052	-0.386	0.169	0.110	0.556**
The number of bolls per plant	0.058	0.755	0.284	-0.001	0.035	-0.002	-0.047	-0.380	0.195	0.088	0.985**
Individual boll weight (g)	0.056	0.610	0.352	0.000	0.031	-0.002	-0.062	-0.326	0.194	0.049	0.901**
Fiber Fineness ($\mu\text{g}/\text{inch}$)	-0.031	0.114	0.035	-0.004	-0.015	0.004	0.080	-0.045	0.005	0.025	0.168
GOT%	0.039	0.750	0.311	0.002	0.035	-0.002	0.080	-0.364	0.217	0.028	0.812**
Staple length (mm)	0.059	0.366	0.177	0.004	0.016	-0.004	-0.042	-0.217	0.115	0.039	0.513**
Staple strength (tppsi)	0.122	0.787	0.484	0.007	0.003	-0.004	-0.045	-0.558	0.336	0.058	0.697**
K^+/Na^+ ratio	0.086	0.605	0.242	0.000	0.027	-0.002	-0.053	-0.475	0.203	0.154	0.786**
Na^+	-0.078	-0.638	-0.295	0.000	-0.033	0.002	0.065	0.417	-0.231	-0.064	-0.855**
K^+	0.054	0.307	0.079	0.000	0.005	-0.001	-0.012	-0.338	0.069	0.216	0.378**

Diagonal letters represent direct effects while others are the indirect effects of various traits on seed-cotton yield per plant. *Absolute salinity (NaCl at 20 dS/m).

correlation of seed-cotton yield with all other traits (except Na^+ and fiber fineness) indicated that indirect selection can be made by any of the following positively correlated traits (Khan et al., 1995; Ashraf and Ahmad, 2000).

Selection may become problematic because of the many choices of positively correlated traits. To avoid this problem of choice, path coefficient analysis was performed revealing that the K^+/Na^+ ratio expressed a strong, positively significant association with seed-cotton yield but its direct effect on the seed-cotton yield was negative while its positive correlation was because of indirect effects through the number of bolls per plant, individual boll weight, Na^+ and K^+ . The highest direct effect on seed-cotton yield per plant was exhibited by the number of bolls per plant and individual boll weight.

No previous available information on the determination of direct and indirect effects on seed-cotton yield in cotton under salinity stress conditions was reported. Therefore, it was impossible to make comparisons with earlier findings in this paper.

Conclusion

It may be concluded from the above correlations and path coefficient analysis that selection on the basis of K^+/Na^+ may not be fruitful because of its negative direct effect on seed-cotton yield per plant. Hence, only indirect selection through the number of bolls per plant and individual boll weight may be effective to increase the seed-cotton yield per plant under salinity stress because of their high direct path coefficients.

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