Pak. J. Agri. Sci., Vol. 54(3), 619-626; 2017
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/17.6324
http://www.pakjas.com.pk

BREEDING POTENTIAL OF UPLAND COTTON FOR WATER STRESS TOLERANCE

Abdul Rehman[1], Muhammad Tehseen Azhar[1,*], Amir Shakeel[1] and Shahzad Maqsood Ahmad Basra[2]

[1]Department of Plant Breeding and Genetics, [*]Climate Change Chair, U.S. Pakistan Center for Advanced Studies in Agriculture and Food Security, [*]School of Biological Sciences M084, The University of Western Australia, Australia; [2]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.
[*]Corresponding author's e-mail: tehseenazhar@gmail.com

To develop genotypes that can yield, better under water stress conditions, plant breeders must have knowledge about gene action and combining abilities of parents for various quantitative traits related to drought tolerance. The objective of the study was to provoke genetic information which may be used in cotton breeding program to enhance drought tolerance. Thirty cotton genotypes were screened on the basis of root and shoot length at seedling stage in glasshouse. Ten cotton genotypes namely NIAB-111, CP-15/2, BH-160, CIM-1100, CRIS-134, CIM-446, FH-900, MNH-93, CIM-707 and CIM-482 were declared to be drought tolerant due to overwhelming performance. In contrast, CIM-506, NIAB Karishma, MNH-129, FH-1000, S-12 and Acala-1517C were identified as drought sensitive, later on they were hybridized following Line × Tester mating fashion. Breeding potential of sixty families along with parents was assessed for plant height, monopodial branches per plant, sympodial branches per plant, number of bolls per plant, seed index, uniformity index and excised leaf water loss. Analysis of variance revealed the predominance of non-additive genetic effects in the inheritance of characters studied. The plants selected in early segregating generation may not be dependable, but selection at later segregating generations may show good level of tolerance to water stress.
Keywords: Combining ability, cotton, gene action, line × tester, water stress

INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is widely grown as an important fiber and cash crop around the globe. Cotton is harvested in the form of seed cotton, which is ginned to separate seeds and lint. Long staple fibers are processed by spinning to produce yarn, later on used for knitting. Cotton seed oil has been in use since 19th century and achieved GRAS (Gradually recognized as safe) status. In addition, cotton seed contains 30% starch, 18.5 to 22.4% oil contents and 16.20% protein (Cobley and Steele, 1976). Being an important fiber crop, it is seriously affected by biotic and abiotic stresses that exert negative impact on cotton production. Effects of drought could be overcome by developing varieties which give higher yield under water stress or providing irrigation to crop (Christiansen and Lewis, 1982). In cotton, diploid species have high degree of drought tolerance by virtue of their deep root system (Bhatt and Andal, 1979). Generally deep rooted plants exhibit greater drought tolerance than shallow rooted genotypes. Therefore, first irrigation is usually delayed in cotton up to forty days, this allows the roots to become longer in search of soil water. Keeping in view the importance of roots, it is used efficiently for the identification of genotypes adoptable in water stress conditions (Riaz *et al.*, 2013). While excised leaf water loss (ELWL) and relative water content (RWC) have been preferred because their ease to measure in large number of segregating populations (Malik *et al.*, 2006). Ali *et al*. (2005) reported the presence of positive association of plant height with number of irrigations at critical stages. Monopodial branches are not important but non-significant contributors towards the yield of cotton plant. Although this trait is genetically controlled but it is greatly influenced by environment. Sympodial branches are considered important plant trait due to significant contribution in yield of seed cotton. A strong association of these branches with number of bolls was reported by Rahman *et al.* (2013). Reduction in number of bolls were observed under water stress (Pettigrew 2004). Genetic basis of drought tolerance in cotton has been elaborated by several researchers (Javaid *et al.*, 2014; Hassan *et al.*, 2015). Additive and non-additive type of gene action were involved in the inheritance of various plant characters involved in water stress tolerance. Cotton farmers require high yielding cotton cultivars that are agronomically adaptive and physiologically efficient under normal and drought conditions. To achieve this objective, cotton plants should have to maintain a balance between water availability in soil, and evaporative demand for balanced growth of various plant organs. Keeping in view the importance of this stress the present study was conducted to develop a new germplasm having enhanced water stress. Information from this study will provide comprehensive information about the role of root and plant traits effected due to water stress, but findings from this experiment may be helpful to plant breeder to design research and breeding programs for the development of drought tolerant genotypes.

METERIALS AND METHODS

Thirty genotypes of cotton of diverse genetic background were collected from Central Cotton Research Institute, Multan; Cotton Research Institute, Multan; Cotton Research Station, Bahawalpur; Nuclear Institute for Agriculture and Biology, Faisalabad; Cotton Research Station, Faisalabad and Cotton Research Group in the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan (Table 1).

The experiment was conducted in the glass house and field of the Department of Plant Breeding and Genetics, University of Agriculture, (latitude 31°25´N, longitude 73°09´E and altitude 184.4 m from sea level) Faisalabad, Pakistan. Initially these genotypes of upland cotton were examined under glasshouse equipped with electric mercury bulbs to maintain night/day temperature of 28°C/35°C. Polythene bags (7″×4″) were filled with soil + sand (1:1) of known water holding capacity. Pot capacity was calculated following gravimetric and volumetric direct measurement of soil water content method (Reynolds, 1970). Approximately hundred cotton seeds of each genotype were water soaked overnight before sowing. Accessions were planted in polythene bags in three replications following split plot design. Three seeds were sown in a bag, and later on two seedlings were thinned out at third leaf stage to keep one seedling. All of recommended agronomic and plant protection measures were adopted to avoid weeds and pests. Pot capacity was maintained on alternate days, and this experiment was completed in forty-five days. After 45 days, heavy irrigation was applied to all of bags before uprooting to avoid damage to the roots. Seedlings of each genotypes from controlled and water stressed (fifty percent of normal irrigation) bags were spread on white board to measure root length (cm), and shoot length (cm) by using measuring tape.

Sixteen selected parents were planted in field conditions during cotton season 2014-15. At the time of flowering, these genotypes were hybridized in Line × Tester mating fashion. Drought tolerant genotypes (NIAB-111, CP-15/2, BH-160, CIM-1100, CRIS-134, CIM-446, FH-900, MNH-93, CIM-707 and CIM-482) were considered as female while susceptible genotypes (CIM-506, NIAB Karishma, MNH-129, FH-1000, S-12 and Acala-1517C) were used as male parents. In order to investigate the genetic basis of drought tolerance of new population, half of seed of F_0 along with parental material was planted in two regimes i.e. irrigated (control) and drought in triplicate following split plot under randomized complete block design in next cotton season 2015-16. Ten plants of each genotype were planted in one row keeping plant to plant distance of 30cm while row to row 75cm. Half dose of normal irrigation to cotton plant was considered as drought stress (Kirda *et al.*, 2005). All recommended production practices and plant protection measures were adopted to raise healthy population. Data from these populations were collected on various plant morphological and physiological traits at appropriate time in field and laboratory conditions. Protocol of each parameter is mentioned below,

***Plant height (cm)*:** The final height of the plant was measured with measuring rod from the first cotyledonary node to the apical bud, when the growth ceased.

***Monopodial branches per plant*:** The monopodial branches are the vegetative branches in cotton. At maturity the monopodial branches per plant were counted for all the selected plants.

***Sympodial branches per plant*:** The sympodial branches are the direct fruit bearing branches. At maturity the sympodial branches from each genotype were counted for all selected plants.

***Bolls per plant*:** The number of effective mature bolls from all the picks was counted and the cumulative record was maintained for each plant separately.

***Seed index (g)*:** Seed index is the 100 seed weight. 100 cotton seeds were taken at random for each sample from each genotype and weighed.

***Uniformity index (%)*:** The fiber sample was put in to an optical sensor HVI-900 and reading of optical density of the

Table 1. List of genotypes of upland cotton planted in glass house conditions.

Sr. #	Genotypes	Sr. #	Genotypes	Sr. #	Genotypes	Sr. #	Genotypes
1	FH-1000	9	BH-160	17	FH-900	25	CIM-506
2	S-12	10	MNH-886	18	PB-899	26	FH-942
3	Acala-1517-C	11	CIM-1100	19	MNH-93	27	NIAB Karishma
4	CIM-496	12	CRSM-58	20	FH-941	28	FH-114
5	NIAB-111	13	CRIS-134	21	CIM-707	29	MNH-129
6	MSK-12	14	FH-4243	22	BH-118	30	CIM-473
7	CP-15/2	15	CIM-446	23	CIM-482		
8	MSK-15	16	NIAB-78	24	RH-510		

sample was displayed on the system screen. Recording readings were then averaged for statistical analysis.

***Excised leaf water loss*:** Three fully developed leaf samples were taken from each selected plants grown under controlled and drought conditions. The samples were kept in polythene bags after excision, and fresh weight was recorded using electronic balance. The leaf samples were left on working bench in laboratory at room temperature (25°C) for 24 hours. The weight of the wilted leaf samples was recorded. Then the same leaf samples were oven dried at 70°C for 72 hours for recording weight, and excised leaf water loss was calculated using the following formula as by Clarke and McCaige (1982).

ELWL= (Fresh weight – Wilted weight) / Dry weight

Data were subjected to analysis of variance technique followed by Steel *et al.* (1997) to see the presence of genotypic differences for certain traits. Same data were utilized to determine genetic components and combining ability by using Line × Tester analyzed (Kempthorne, 1957).

RESULTS

***Variability for drought stress*:** Based on comparison of mean values of root length, NIAB-111 (12.40) was identified as drought tolerant having longest roots length. While CIM-482 (11.63), BH-160 (11.40), CIM-1100 (10.77), CIM-707 (10.53), CP-15/2 (10.50), CIM-446 (10.37), MNH-93 (9.83), FH-900 (8.87) and CRIS-134 (8.70) were appeared to be less affected under water deficit conditions (Table 2). Cultivars which showed significant reduction in root length were CIM-506 (5.53), S-12 (5.40), Acala-1517-C (5.37), NIAB Karishma (4.77), FH-1000 (4.73) and MNH-129 (4.73).

***Genetic analysis of plant material for various quantitative traits*:** Mean squares estimates from analysis of variance exhibited highly significant differences among sixteen parents and sixty F_1 hybrids ($P \leq 0.01$) for plant height, monopodial branches per plant, sympodial branches per plant, excised leaf water loss, bolls per plant, seed index and uniformity index under water stress conditions (Table 3). Statistical analysis revealed that mean squares due to GCA effects (parents) differed significantly ($P \leq 0.01$) for plant height, number of sympodial branches, excised leaf water loss, seed index, uniformity index but number of monopodial branches and umber of bolls per plant showed non-significant differences ($P \geq 0.05$). Effect of specific combining ability (due to crosses) were highly significant for all of yield related and physiological traits. Mean squares due to parent's vs crosses in water stress condition appeared to be highly

Table 2. Mean values of root and shoot length of thirty cotton genotypes planted in glass house conditions.

Genotypes	Root length (cm)	Shoot length (cm)	Genotypes	Root length (cm)	Shoot length (cm)
FH-1000	4.73	13.43	NIAB-78	6.80	16.50
S-12	5.40	14.77	FH-900	8.87	23.30
Acala-1517-C	5.37	14.13	PB-899	6.83	16.23
CIM-496	6.07	18.23	MNH-93	9.83	22.23
NIAB-111	12.40	25.00	FH-941	7.27	16.00
MSK-12	6.63	18.33	CIM-707	10.53	23.27
CP-15/2	10.50	22.13	BH-160	7.63	15.97
MSK-15	7.33	18.40	CIM-482	11.63	23.83
BH-160	11.40	22.50	RH-510	8.03	17.37
MNH-886	7.73	17.10	CIM-506	5.53	15.40
CIM-1100	10.77	21.67	FH-942	7.90	17.40
CRSM-58	6.70	17.10	NIAB Karishma	4.77	15.80
CRIS-134	8.70	23.30	FH-114	7.87	18.03
FH-4243	6.37	16.27	MNH-129	4.73	14.43
CIM-446	10.37	24.27	CIM-473	7.37	14.57

Table 3. Mean squares of various quantitative traits of cotton grown under water stress conditions.

SOV	DF	PH	MB	SB	ELWL	NOB	SI	UI
Replications	2	2.59	0.03	0.35	0.12	52.45^{**}	0.26	3.66
Genotypes	75	41.08^{**}	2.19^{*}	5.73^{**}	0.49^{**}	24.42^{**}	1.45^{**}	11.96^{**}
Parents	15	70.75^{**}	1.86	4.50^{**}	0.41^{**}	5.24	1.25^{**}	19.17^{**}
Crosses	59	32.75^{**}	2.26^{*}	3.47^{**}	0.50^{**}	29.63^{**}	1.47^{**}	10.07^{**}
Parents Vs Crosses	1	87.32^{**}	2.64	157.75^{**}	1.17^{**}	5.05	3.04^{**}	15.56^{*}
Lines	9	33.95^{**}	1.44	2.91^{*}	0.46^{**}	5.09	2.00^{**}	5.48
Testers	5	17.73^{**}	2.59	5.20^{**}	0.34^{**}	3.25	0.14	23.86^{**}
Lines × Testers	45	34.18^{**}	2.39^{**}	3.39^{**}	0.53^{**}	37.47^{**}	1.52^{**}	9.46^{**}
Error	150	5.80	1.40	1.49	0.05	5.55	0.12	3.44

df stands for degree of freedom; * and **, denote difference significant at 5% at 1% probability level respectively; PH stands for plant height, MB - monopodial branches, SB - sympodial branches, ELWL - excised leaf water loss, NOB - number of bolls, SI - seed index and UI - uniformity Index.

significant for plant height, number of sympodial branches, excised leaf water loss, seed index, while significant differences were observed for uniformity index. Mean squares due to lines were found to be highly significant for plant height, excised leaf water loss and seed index. Mean squares due to testers were highly significant for plant height, number of sympodial branches, excised leaf water loss and uniformity index. Interaction between lines and testers appeared to be highly significant ($P \leq 0.01$) for all of the traits included in this study.

Comparison of cultivars showed that NIAB-111 with positive values were displayed better GCA effects for number of monopodial branches (0.61), excised leaf water loss (0.53) and number of bolls (0.23) (Table 4). Whereas exotic genotype, CP-15/2 got highest positive values for plant height (2.15) and revealed to be good general combiner but this genotype exhibited poor response for rest of traits. BH-160 exhibited highest positive GCA effects for number of bolls (1.96). Among lines CIM-1100 displayed good GCA estimates for number of sympodial braches (0.53). CRIS-134 showed its best GCA for uniformity index with numerical values 0.73. The genotype CIM-446 was identified to be good combiner for seed index (0.31) whilst MNH-93 showed good general combining ability for seed index (0.42). Among testers, CIM-506 revealed positive GCA coefficients of 0.51, 0.21, 0.06 and 1.24, for number of monopodial braches, number of sympodial branches, excised leaf water loss and number of bolls respectively. NIAB Karishma attained positive value for uniformity index (0.86), and appeared to be good general combiner. Higher values of GCA effects by MNH-129 for sympodial branches (0.84) and seed index (0.52) indicated to be good combiners. Amongst tester, FH-1000 and Acala-1517C exhibited highest positive coefficient for monopodial branches (0.51), and better GCA for plant height (2.43) and number of bolls (0.91) respectively.

Combinations namely CIM-1100 × CIM-506, CP-15/2 × CIM-506, BH-160 × NIAB Karishma, FH-900 × MNH-129 and CIM-446 × S-12 exhibited good SCA effects for plant height (Table 5). Whereas FH-900 × S-12, CIM-446 × CIM-506, CRIS-134 × FH-1000, CIM-482 × CIM-506, CIM-1100 × NIAB Karishma and BH-160 × FH-1000 were found to be good specific combinations for number of monopodial branches. Comparison of estimates of crosses indicated that BH-160 × CIM-506, CIM-482 × CIM-506, MNH-93 × S-12, CIM-446 × S-12, NIAB-111 × MNH-129, FH-900 × S-12 and CIM-1100 × CIM-506 exhibited significant and positive SCA effects for number of bolls. The combinations of CIM-482 × Acala-1517C, CP-15/2 × NIAB Karishma, MNH-93 × MNH-129, CIM-1100 × S-12 and CIM-707 × MNH-129 presented significant and positive SCA effects for uniformity index.

Higher estimates of σ^2sca for number of bolls indicated the predominance of non-additive genes (Table 6). The inheritance of plant height, number of monopodial branches, number of sympodial branches, excised leaf water loss, number of bolls, seed index, and uniformity index was predominantly controlled by non-additive genes. Presence of positive sign indicated that dominance was directed towards superior parent, whereas negative sign indicated the direction of dominance towards lower parent. The ratio of variance (σ^2gca/σ^2sca) was found to be below unity that indicated the inheritance of traits was influenced by non-additive genetic effects.

Table 4. General combining abilities of various quantitative traits of cotton grown under water stress condition.

Parents	PH	MB	SB	ELWL	NOB	SI	UI
Lines							
NIAB-111	0.32	0.61	0.31	0.53	0.23	-0.45	0.04
CP-15/2	2.15	0.44	0.26	0.43	-0.54	0.18	-0.44
BH-160	0.82	-0.06	-0.13	-0.06	1.96	-0.07	-0.26
CIM-1100	0.32	0.39	0.53	-0.16	-0.99	-0.46	0.13
CRIS-134	0.54	-0.61	0.09	-0.19	-0.54	0.06	0.73
CIM-446	-1.96	-0.06	-0.13	-0.19	-0.21	0.31	0.17
FH-900	-0.68	-0.44	-0.13	-0.19	0.01	-0.05	-0.58
MNH-93	-0.68	-0.22	-0.30	0.20	0.01	0.42	0.02
CIM-707	-0.07	0.06	0.20	-0.68	-0.54	0.01	0.08
CIM-482	-0.74	-0.11	-0.69	0.32	0.62	0.04	0.11
Standard Error	5.00	1.76	13.26	6.06	1.23	6.59	2.74
TESTERS							
CIM-506	-0.39	0.51	0.21	0.06	1.24	-0.63	-0.64
NIAB Karishma	-1.26	0.01	-0.28	-0.02	0.24	-0.21	0.86
MNH-129	-0.42	0.17	0.84	0.01	-0.28	0.52	0.08
FH-1000	-0.69	0.51	0.04	0.01	-2.12	-0.19	-0.19
S-12	0.33	-0.12	-0.18	-0.04	0.01	0.28	0.36
Acala-1517-C	2.43	-1.08	-0.62	-0.06	0.91	0.24	0.46
Standard Error	7.07	2.50	18.76	8.57	1.74	9.32	3.88

PH stands for plant height, MB - monopodial branches, SB - sympodial branches, ELWL - excised leaf water loss, NOB - number of bolls, SI - seed index, and UI - uniformity Index.

Table 5. Specific combining ability estimates of various quantitative traits of cotton grown under water stress conditions.

Crosses	PH	MB	SB	ELWL	NOB	SI	UI
NIAB-111 × CIM-506	2.78*	0.49	-1.21	0.06	-3.97	-0.10	1.14
CP-15/2 × CIM-506	5.95*	0.32	-1.16	0.06	-3.86	-0.20	0.30
BH-160 × CIM-506	1.62	0.16	0.57	0.13	8.98*	-0.15	1.78*
CIM-1100 × CIM-506	6.45*	-0.96	-0.77	-0.15	3.92*	0.08	-0.58
CRIS-134 × CIM-506	3.23*	-1.29	-0.32	-0.04	3.81*	0.53	1.12
CIM-446 × CIM-506	-2.61	1.16*	1.23	0.06	-3.52	0.34	-1.65
FH-900 × CIM-506	-3.88	-0.46	0.90	0.09	-4.74	-1.04	-0.23
MNH-93 × CIM-506	-4.22	-0.34	0.73	-0.03	-3.74	0.36	0.17
CIM-707 × CIM-506	-4.16	0.04	0.57	-0.18	-3.19	-0.29	-0.56
CIM-482 × CIM-506	-5.16	0.88*	-0.54	0.05	6.31*	0.47	-1.49
NIAB-111 × NIAB Karishma	-2.35	0.32	-0.04	0.08	-1.30	-0.36	-3.17
CP-15/2 × NIAB Karishma	-3.52	0.49	1.01	0.03	-0.86	-0.13	3.29*
BH-160 × NIAB Karishma	5.15*	0.32	-1.60	-0.13	-1.36	0.09	-1.40
CIM-1100 × NIAB Karishma	-1.02	0.88*	-1.27	0.11	1.26*	-0.55	1.61*
CRIS-134 × NIAB Karishma	-4.91	-0.12	-0.82	0.23	-0.19	-0.70	-0.89
CIM-446 × NIAB Karishma	2.93*	-0.68	0.73	-0.16	-0.19	-0.35	2.84*
FH-900 × NIAB Karishma	1.32	-0.62	0.40	0.03	0.59*	0.97	0.59
MNH-93 × NIAB Karishma	-2.02	0.49	0.57	-0.07	0.92*	0.73	-0.54
CIM-707 × NIAB Karishma	2.04	-0.79	0.07	-0.29	1.81*	0.08	0.10
CIM-482 × NIAB Karishma	2.37*	-0.29	0.96	0.16	-0.69	0.21	-2.43
NIAB-111 × MNH-129	3.48*	-0.51	-1.18	-0.09	4.23*	0.57	1.07
CP-15/2 × MNH-129	-0.35	0.66	0.54	0.09	3.34*	-0.13	-0.94
BH-160 × MNH-129	-0.02	-0.18	0.93	0.18	-5.16	-0.01	-1.13
CIM-1100 × MNH-129	-5.52	-0.62	0.93	-0.03	-0.88	-0.25	-0.68
CRIS-134 × MNH-129	1.26	0.71	-0.29	-0.12	-1.66	-0.30	-2.18
CIM-446 × MNH-129	-4.57	-0.84	-0.07	-0.18	2.34*	0.02	-2.88
FH-900 × MNH-129	4.15*	0.54	-1.07	0.03	-0.54	0.74	-1.64
MNH-93 × MNH-129	0.82	0.32	-0.23	0.06	-1.54	-0.67	3.27*
CIM-707 × MNH-129	0.54	0.04	0.93	-0.09	-0.66	-0.62	2.87*
CIM-482 × MNH-129	0.21	-0.12	-0.51	0.15	0.51	0.65	2.24*
NIAB-111 × FH-1000	-0.58	0.16	2.29	-0.09	2.73*	-0.54	0.69
CP-15/2 × FH-1000	2.25*	-1.01	-0.32	-0.21	2.84*	-0.11	0.45
BH-160 × FH-1000	-5.75	0.82*	0.07	-0.13	1.34*	0.11	0.99
CIM-1100 × FH-1000	0.42	0.38	0.07	-0.06	-0.38	-0.2	-1.39
CRIS-134 × FH-1000	-2.47	1.04*	-0.49	0.07	0.51	0.75	0.67
CIM-446 × FH-1000	1.03	0.16	-0.93	0.48	-1.82	0.54	0.07
FH-900 × FH-1000	-0.25	-0.46	0.07	-0.12	-1.04	-0.11	2.30*
MNH-93 × FH-1000	1.42	-1.01	0.23	0.04	-2.04	-0.48	-0.94
CIM-707 × FH-1000	2.47*	0.04	-0.60	-0.13	0.18	0.86	-1.84
CIM-482 × FH-1000	1.47	-0.12	-0.38	0.22	-2.32	-0.83	-1.01
NIAB-111 × S-12	-1.28	-0.54	-1.14	-0.02	-3.73	-0.65	-1.03
CP-15/2 × S-12	-5.12	-0.38	-2.09	-0.06	-1.96	0.28	-2.88
BH-160 × S-12	-2.45	-0.54	0.30	0.06	-1.12	-0.74	-2.17
CIM-1100 × S-12	-0.28	0.34	1.30	0.30	-2.51	0.76	2.88*
CRIS-134 × S-12	2.49*	-0.32	2.08	-0.17	-0.29	-0.26	2.68*
CIM-446 × S-12	3.66*	0.12	-0.70	-0.04	4.38*	0.12	2.24*
FH-900 × S-12	0.38	1.18*	0.30	-0.16	4.16*	-0.52	-0.01
MNH-93 × S-12	3.05*	0.29	-0.53	0.02	4.49*	0.61	-0.77
CIM-707 × S-12	-1.56	0.01	-0.37	0.85	-0.96	0.02	0.17
CIM-482 × S-12	1.11	-0.16	0.86	-0.78	-2.46	0.39	-1.10
NIAB-111 × Acala-1517-C	-2.05	0.09	1.29	0.05	2.03*	1.08	1.29*
CP-15/2 × Acala-1517-C	0.78	-0.08	2.01	0.09	0.48	0.28	-0.22
BH-160 × Acala-1517-C	1.45	-0.58	-0.27	-0.12	-2.69	0.70	1.93*
CIM-1100 × Acala-1517-C	-0.05	-0.02	-0.27	-0.16	-1.41	0.16	-1.83
CRIS-134 × Acala-1517-C	0.39	-0.02	-0.16	0.11	-2.19	-0.02	-1.40
CIM-446 × Acala-1517-C	-0.44	0.09	-0.27	-0.09	-1.19	-0.67	-0.63
FH-900 × Acala-1517-C	-1.72	-0.19	-0.60	0.12	1.59*	-0.05	-1.02
MNH-93 × Acala-1517-C	0.95	0.26	-0.77	-0.02	1.92*	-0.56	-1.18
CIM-707 × Acala-1517-C	0.67	0.64	-0.60	-0.17	2.81*	-0.05	-0.74
CIM-482 × Acala-1517-C	0.01	-0.19	-0.38	0.19	-1.36	-0.88	3.79*
Standard Error	2.23	0.79	5.93	2.71	0.55	2.94	1.22

PH stands for plant height, MB - monopodial branches, SB - sympodial branches, ELWL - excised leaf water loss, NOB - number of bolls, SI - seed index, and UI - uniformity Index.

Table 6. Genetic components of variation of various quantitative traits of cotton grown under water stress condition.

Traits	Water Stress Conditions				
	σ^2_{gca}	σ^2_{sca}	σ^2_A	σ^2_D	$\sigma^2_{gca}/\sigma^2_{sca}$
PH	-1.450	219.59	-0.7200	219.59	-0.00660
MB	-0.002	0.17	-0.0010	0.17	-0.01176
SB	-0.003	-34.08	-0.0010	-34.08	0.00009
ELWL	-0.005	-7.16	-0.0007	-7.16	0.00070
NOB	-0.680	14.25	-0.3400	14.25	-0.04772
SI	-0.005	-8.19	-0.0020	-8.19	0.00061
UI	0.001	1.64	0.0005	1.64	0.00061

σ^2_{gca} - estimate of gca variance, σ^2_{sca} - estimate of sca variance, σ^2A - Additive variance, σ^2_D - Dominance variance, $\sigma^2_{gca}/\sigma^2_{sca}$ -Variance ratio, PH stands for plant height, MB - monopodial branches, SB - sympodial branches, ELWL - excised leaf water loss, NOB - number of bolls, SI - seed index and UI - uniformity Index.

DISCUSSION

In present study, shoot and root length data at seedling stage were used to study variation in available germplasm of *G. hirsutum* for water stress tolerance. These two traits are adversely affected by water stress than any other plant part, and slow down the supply of water to aerial organs of plant (Pace *et al*., 1999; Benjamin *et al.*, 2014). Furthermore, it was observed that effect of water stress on shoot growth was higher than root growth. Huang and Gao (2000) reported adverse effect of water shortage on root growth in *Festuca arundinacea*. Root related traits are important organs in plant-water relationship and being considered important criteria for screening of germplasm of field crops, because these are genetically controlled (Pace *et al*., 1999; Riaz *et al*., 2013).

Later on potential of these genotypes was exploited through hybridization. Genetic analysis of the data of various parameters were used to determine the genetic components controlling these traits. In the previous work, data on whole plant responses to stress were not available in *G. hirsutum* (Iqbal *et al*., 2010), and therefore the present study was continued up to plant maturity. Genetic analysis partitioned different genetic components of variation. The variance due to GCA was lower than due to SCA for plant height, number of monopodial branches, number of sympodial branches, excised leaf water loss, number of bolls, seed index, and uniformity index which indicated the predominant role of non-additive genes (Javaid *et al.*, 2014). The presence of greater magnitude of SCA variance for all of traits is supported by Saidi *et al.* (2008), and signifies the importance of non-additive genes in controlling expression of the traits in upland cotton. Previous studies on drought tolerance in cotton also indicated the influence of non-additive genetic effects for these traits, and consistent with the findings of Shakoor *et al*. (2010).

Comparison of GCA for sixteen parents (ten lines and six testers) revealed that NIAB-111, CIM-1100, CRIS-134 and CIM-446, and CIM-506, NIAB Karishma and MNH-129 were best general combiners for most of the traits. These genotypes may be used in breeding program for the improvement of high yield having enhanced drought tolerance in upland cotton. Comparison of various combinations showed that CP-15/2 × CIM-506 found to be best for plant height due to the involvement of CIM-506 which have good GCA but CP-15/2 with poor GCA. The contribution of plant height to increase seed cotton has been reported by cotton researchers to increase number of fruiting branches that led to more fruiting points (Soomro *et al.*, 2008). Nonetheless due to delayed maturity and more water requirements of tallness became undesirable traits for incorporating drought tolerance in upland cotton. Therefore, genotypes having negative GCA for plant height is considered in breeding programs (Rauf *et al.*, 2006). The crosses of BH-160 × CIM-506, CIM-482 × CIM-506 and MNH-93 × S-12 revealed to be good combinations for number of bolls due to involvement of parents having high × high, low × high, and low × low general combiners respectively. SCA effects represent dominant gene action because SCA effects are limited to selection of superior parents of certain traits (Caixeta *et al.*, 2001). The parents having high SCA effects indicated the role of dominant effects that allow the opportunity to the breeder for the development of hybrids or hybrid seed production program (Ali *et al.*, 2013; Khan, 2014). Therefore, GCA effects should be considered important besides the SCA effects. The involvement of one of parent having high GCA would tend to increase the frequency of favorable alleles. Most of crosses with good SCA effects may be either due to good GCA of parents, indicating the preponderance of additive genetic effects (Kenga *et al.*, 2004). High SCA effects due to parents with low GCA revealed the influence of non-additive genetic effects, and warns the researcher to avoid selection in early generations (Saidaiah *et al.*, 2010). In contrary involvement of parents with having significant SCA effects guide for selection in early generations (Roy *et al*., 2002). Differential performance of parents and hybrids are due to differences in genetic combinations and environmental conditions (Pettersen *et al*., 2006). Significance of non-additive gene action revealed the use of this plant material for development of hybrids (Singh and Sanjeev, 1999).

***Conclusions*:** Based on information from biometrical approaches used herein, it is concluded that selection of desirable traits must not be executed till later generations. These results are limited to the plant material studied and therefore, may not be generalized most of cotton growing areas facing shortage of irrigation water in Pakistan. Therefore, it is suggested that this information must be substantiated by another genetic experiment which may involve a reasonable sample of cotton cultivars, evaluated under diverse environments in order to enhance stress adaptations of our existing commercial cultivars of cotton and to develop plant material with improved drought tolerance.

***Acknowledgments*:** The authors are grateful to the personnel involved in the maintenance of glasshouse, and field for the conduct of experiments in the Department of Plant Breeding and Genetics. The departmental development funds were utilized for the conduct of these experiments.

REFRENCES

Ali, Y., G. Sarwar, Z. Aslam, F. Hussain and T. Rafique. 2005. Evaluation of advanced rice germplasm under water stress environment. Int. J. Environ. Sci. Technol. 2:27-33.

Ali, Q., M. Ahsan, F. Ali, M. Aslam, N.H. Khan, M. Munzoor, H.S.B. Mustafa and S. Muhammad. 2013. Heritability, heterosis and heterobeltiosis studies for morphological traits of maize (*Zea mays* L.) seedlings. Adv. Life Sci. 1:52-63.

Benjamin, J., D. Nielsen, M. Vigil, M. Mikha and F. Calderon. 2014. Water deficit stress effects on corn (*Zea mays* L.) root: shoot ratio. Open J. Soil Sci. 4:151-160.

Bhatt, J.G. and R. Andal. 1979. Variation in foliar anatomy of cotton. Proc. Ind. Acad. Sci. 8:451-453.

Caixeta, F.M., S. Tulio Cassini, V. Rodrigues Oliveira, C. Vieira, S.M. Tsai and C.D. Cruz. 2001. Combining ability for nodulation in common bean (*Phaseolus vulgaris* L.) genotypes from Andean and Middle American gene pools. Euphytica 118:265-270.

Christiansen, M.N. and C.F. Lewis 1982. Breeding plants for less favourable environments. John Wiley & Sons, New York, USA.

Clarke, J.M. and T.N. McCaig. 1982. Excised-leaf water retention capability as an indicator of drought resistance of *Triticum* genotypes. Can. J. Plant Sci. 62:571-578.

Cobley, L.S. and W.M. Steele. 1976. Vegetables fibers. In an introduction to the botany of tropical crops, 2nd Ed. Longman, London; pp.252-257.

Hassan, H.M., F.M. Azhar, A.A. Khan, S. Basra and M. Hussain. 2015. Characterization of cotton (*Gossypium hirsutum* L.) germplasm for drought tolerance using seedling traits and molecular markers. Int. J. Agric. Biol. 17:1213-1218.

Huang, B. and H. Gao. 2000. Root physiological characteristics associated with drought resistance in tall fescue cultivars. Crop Sci. 40:196-203.

Iqbal, K., F.M. Azhar, I.A. Khan and E. Ullah. 2010. Assessment of cotton (*Gossypium hirsutum*) germplasm under water stress condition. Int. J. Agric. Biol. 12:251-255.

Javaid, A., F.M. Azhar, I.A. Khan and S.A. Rana. 2014. Genetic basis of some yield components in *Gossypium hirsutum* L. Pak. J. Agri. Sci. 51:143-146.

Kenga, R., S. Alabi and S. Gupta. 2004. Combining ability studies in tropical sorghum (*Sorghum bicolor* (L.) Moench). Field Crop Res. 88:251-260.

Kempthorne, O. 1957. An introduction to genetic statistics. John Wiley and Sons, Inc., New York.

Khan, H. 2014. Genetic variability for yield, its components and quality traits in upland cotton (*Gossypium hirsutum* L.). Nat. Sci. 12:31-35.

Kirda, C., S. Topcu, H. Kaman, A. Ulger, A. Yazici, M. Cetin and M. Derici. 2005. Grain yield response and N-fertilizer recovery of maize under deficit irrigation. Field Crop Res. 93:132-141.

Malik, T.A. and S. Malik. 2006. Genetic linkage studies of drought tolerant and agronomic traits in cotton. Pak. J. Bot. 38:1613-1619.

Pace, P., H.T. Cralle, S.H. El-Halawany, J.T. Cothren and S.A. Senseman. 1999. Drought-induced changes in shoot and root growth of young cotton plants. J. Cotton Sci. 3:183-187.

Pettersen, R., L. Mortensen, R. Moe and H. Gislerod. 2006. Air humidity control essential for rose production under continuous lighting. Acta Hort. 323-331.

Pettigrew, W. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377-383.

Rauf, S., H. Munir, S.M.A. Basra and E. Abdullojon. 2006. Combining ability analysis in upland cotton (*Gossypium hirsutum* L.). Int. J. Agric. Biol. 8:341-343.

Reynolds, S.G. 1970. The gravimetric method of soil moisture determination part I a study of equipment and methodological problems. J. Hydrol. 11:258-273.

Rahman, S.A., M.S. Iqbal, M. Riaz, A. Mahmood, M.R. Shahid, G. Abbas and J. Farooq. 2013. Cause and effect estimates for yield contributing and morphological traits in upland cotton (*Gossypium hirsutum* L.). J. Agric. Res. 51:393-398.

Riaz, M., J. Farooq, G. Sakhawat, A. Mahmood, M. Sadiq and M. Yaseen. 2013. Genotypic variability for root/shoot parameters under water stress in some advanced lines of cotton (*Gossypium hirsutum* L.). Genet. Mol. Res. 12:552-561.

Roy, N., V. Jettopujov and N. Solanik. 2002. Combining ability for some agronomic characters in alfalfa (*Medicago sativa* L.). Pak. J. Agri. Res. 17:346-350.

Saidaiah, P., S.S. Kumar and M. Ramesha. 2010. Combining ability studies for development of new hybrids in rice over environments. J. Agric. Sci. 2:225-233.

Saidi, M., S.D. Warade and T. Prabu. 2008. Combining ability estimates for yield and its contributing traits in tomato (*Lycopersicon esculentum*). Int. J. Agric. Biol. 10:238-240.

Shakoor, M.S., T.A. Malik, F.M. Azhar and M.F. Saleem. 2010. Genetics of agronomic and fiber traits in upland cotton under drought stress. Int. J. Agric. Biol. 12:495-500.

Singh, P. and S. Sanjeev. 1999. Heterosis breeding in cotton. Kalyani Publ., New Delhi, India.

Soomro, Z., A. Larik, M. Kumbhar, N. Khan and N. Panhwar. 2008. Correlation and path analysis in hybrid cotton. Sabrao J. Breed. Genet. 40:49-56.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A biometrical approach, 3rd Ed. McGraw Hill Book Co. Inc., New York.