The Journal of Animal & Plant Sciences, 28(5): 2018, Page: 1466-1475
ISSN: 1018-7081

GENETIC ANALYSIS OF SOME POLYGENIC TRAITS FOR DROUGHT TOLERANCE IN *GOSSYPIUM HIRSUTUM* L.

A. Rehman[12], M. T. Azhar[1!*], A. Shakeel[1] and S. M. A. Basra[3]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad (Pakistan),[2]College of Agriculture,
Bahauddin Zakariya University, Bahadur Sub-campus, Layyah, [3]Department of Agronomy, University of Agriculture,
Faisalabad Pakistan).[!]School of Biological Sciences M084, The University of Western Australia
[*]Corresponding author’s e-mail: tehseenazhar@gmail.com

ABSTRACT

The present study was conducted to develop high yielding cotton genotypes having desirable fiber quality traits under water stress conditions. Ten upland cotton genotypes were identified as drought tolerant whereas six as drought susceptible based on root and shoot related traits. These sixteen genotypes were grown in the field conditions and crossed following line ×tester mating fashion. In the next cotton season, these sixty hybrids along with parents were grown in the field conditions. Analysis of variance revealed the presence of significant differences among the genotypes for all of the traits i.e., boll weight, ginning out turn, fiber length, fiber strength and fiber fineness. Further, the lines i.e., NIAB-111, CP-15/2, CIM-482 and CIM-446, and testers i.e., CIM-506, FH-1000 and MNH-129 had better performance under drought conditions. The cross combinations viz., CIM-707 × S-12, CIM-707 × NIAB Karishma, CIM-707, CIM-446 × NIAB Karishma, CIM-446 × S-12, and CRIS-134 × S-12 were also identified as best specific combinations and superior for yield contributing parameters. These cross combinations may be exploited on large scale for the development of new germplasm of upland cotton suitable for planting under drought conditions of the Punjab.

Key words: *Gossypium hirsutum* L.; Genetic analysis; Line × Tester; Water stress.

INTRODUCTION

Upland cotton (*Gossypium hirsutum* L.) is grown as an important fiber and cash crop around the globe. It is cultivated in more than 80 countries in tropical and sub-tropical regions including America, India, Pakistan, China and Brazil (Singh, 2004). Cotton crop was cultivated on an area of 2489 thousand hectares which is 14.2% less than previous year’s area. The production of seed cotton was recorded 10.671 million bales which is 7.6% increase than previous year production that was 9.917 million bales. It accounts for 1.0% in gross domestic product (GDP) and 5.2% of the value added in agriculture of Pakistan (Anonymous, 2016-17) In cotton, seed germination, seedling emergence, and flowering stages are more sensitive to water stress than the vegetative stages (Loka and Oosterhuis, 2012). Cotton is not classified as a drought tolerant crop and it is not efficient in water use as sorghum (Allen Jr *et al*., 2011). Nevertheless, cotton does have mechanisms that make it well adapted to semi-arid regions due to having deep penetrating and extensive root system (Bruner, 2015). Zhang *et al.* (2016) investigated the effects of drought stress during various stages of cotton growth. Water stress adversely affected the fiber length. Likewise, Papastylianou and Argyrokastritis, (2014) have studied the physiological and morphological factors involved in reduction of yield of seed cotton and reported that boll weight was less affected under normal conditions. The pattern of inheritance of ginning out-turn has been studied by many research scientists. Prasad *et al*. (2005) reported the presence of additive and non-additive gene action whereas Mukhtar *et al*. (2000a) and Esmail (2007) have mentioned the role of additive, dominance and epistatic effects along with partial dominance in the inheritance of boll weight. Ginning out-turn was influenced by additive gene action (Ali *et al*., 2008; Khan *et al*., 2009).

Azhar *et al*. (2004) indicated the presence of additive and non-additive gene action for fiber length. Nimbalkar *et al*. (2004) observed that fiber length was under the control of additive gene effects, but over dominant gene action was noted in the inheritance of the trait (Ahmed *et al*., 2006). Ali *et al*. (2008) analyzed gene action of fiber quality traits in *G. hirsutum* L. followed by Mather and Jinks approach and confirmed the role of additive gene action. Whereas Zhang *et al.* (2014) observed epistatic effects for fiber length. Kumar *et al.* (2014) estimated gene action of upland cotton for bundle strength and confirmed the stability of non-additive genetic effects. Bertini *et al*. (2001), Singh and Chahal (2005), and Minhas *et al*. (2008) observed additive and dominant gene action along with epistasis for fiber strength. Several researchers have highlighted the presence of additive genetic effects as well as partial dominance for fiber fineness (Mukhtar *et al.* 2000b; Singh and Chahal 2005; Minhas *et al*. 2008; Akhtar *et al.* 2008, which is important trait in the textile industry. The mentioned literature is important for cotton breeders to start breeding programs. The basic objective of cotton breeding program is to develop new germplasm having more yield with enhanced fiber traits keeping in view the demand of textile industry. The information on gene action and combining ability helps in selection of suitable parents for hybridization program. Therefore, the present study was undertaken in order to understand the nature of gene action and combining ability of existed germplasm of cotton for seed cotton yield and fiber quality traits under water stress conditions.

MATERIALS AND METHODS

The current study was carried out in the experimental area at the University of Agriculture, Faisalabad, Pakistan. Germplasm used herein was collected from Central Cotton Research Institute, Multan; Cotton Research Station, Multan; Cotton Research Station, Bahawalpur; Nuclear Institute for Agriculture and Biology, Faisalabad; and Cotton Research Institute, Faisalabad. Ten drought tolerant upland cotton lines (NIAB-111, CP-15/2, BH-160, CIM-1100, CRIS-134, CIM-446, FH-900, MNH-93, CIM-707 and CIM-482) and six testers (CIM-506, NIAB Karishma, MNH-129, FH-1000, S-12 and Acala-1517C) were planted in field conditions during cotton growing season 2014-15. All of agronomic and plant protection measures were taken to get healthy plant population. Drought tolerant genotypes were considered as female while susceptible were used as male parents. At the time of flowering, these 16 genotypes were hybridized in Line × Tester mating fashion. Unopened flowers known as buds of female parents were hand-emasculated in the evening to avoid contamination and out crossing. Stamens were removed, and carpels were covered with soda straw tubes. Emasculated flowers were pollinated in the following morning with pollen grains from male parents and again covered with soda straw tubes. Self-pollination of some of buds (to develop selfed seed) was achieved by tying a piece of thread around the buds in the evening. At maturity, F_0 seeds from all the crosses were collected for plantation. F_0 seed along with parental material was planted in two regimes i.e., irrigated (control) and drought in three replication following split plot under randomized complete block design (RCBD). 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 irrigations to cotton crop was considered as drought stress (Kirda *et al.*, 2005). All recommended production practices and plant protection measures were adopted during the experiment. Data on morphological traits in the field as well as in laboratory conditions were collected on seven plants from each family. The detailed protocol of each parameter is mentioned below.

Boll weight (g): Average weight per boll was obtained by dividing the total yield of seed cotton per plant by the number of the bolls picked from every plant.

$$Average\ boll\ weight = \frac{Yield\ of\ seed\ cotton\ per\ plant}{Number\ of\ bolls\ per\ plant}$$

Ginning out turn (%): Ginning out-turn (lint %) defined as the weight of lint obtained from a given weight of seed cotton and is expressed as percentage. Samples of seed cotton obtained from individual plants were ginned separately with ginning machine and weighed in the cotton laboratory. Lint weighed values were used for determination of GOT percentage by using formula given below.

$$GOT\% = \frac{Weight\ of\ lint\ in\ a\ sample}{Weight\ of\ seed\ cotton\ in\ a\ sample} \times 100$$

Fiber characters: The fiber characters like staple length, staple fineness and staple strength were measured using high volume instrument (HVI-900, Uster technologies Ltd., Switzerland). It is a computerized instrument which provides the comprehensive profile of raw fiber. It measured the important fiber characteristics such as fiber length, fiber fineness and fiber strength according to the International Trading Standards.

The collected data on traits mentioned of each treatment (controlled and stressed) were subjected to analysis of variance technique proposed by Steel *et al.* (1997) in order to see the presence of genotypic differences for selected quantitative traits, and also among the treatments. Later on, data were analyzed according to Line × Tester technique (Kempthorne, 1957) to assess the populations for genetic components, general combining ability (GCA), specific combining ability (SCA) effects, the contribution of each parent and their interaction for the expression of certain traits.

RESULTS

Genetic analysis of plant material under normal water conditions: Analysis of variance following line × tester technique was carried out to assess the presence of genetic variations among plant material grown in normal field conditions. Biometrical analysis revealed that 76 genotypes differed significantly ($P \leq 0.01$) from each other for boll weight, ginning out-turn, fiber length, fiber fineness and fiber strength (Table 1). Mean squares due to GCA effects (parents) were highly significant. The analysis revealed that effects of specific combining ability (crosses) were differed highly significant for boll weight, ginning out-turn, fiber length, fiber fineness and fiber strength. Interaction due to parents vs crosses revealed the presence of highly significant differences for ginning out-turn whilst non-significant differences ($P \geq 0.05$) were noted for boll weight, fiber length, fiber fineness and fiber strength. Statistically significantly ($P \leq 0.01$) differences were present among lines and testers for yield and yield related traits, fiber traits and physiological traits except fiber length in testers. But the interaction of lines and testers revealed the presence of highly significant differences for all of the traits measured under normal water conditions.

Genetic analysis of plant material under water stress condition: Results from ANOVA following line × tester technique was keenly observed for traits measured under water stressed conditions. Seventy-six genotypes of upland cotton differed highly significantly ($P \leq 0.01$) from each other for boll weight, fiber length, fiber fineness, and fiber strength however significant differences were found for ginning out-turn (Table 1). Effect of general combining (ability due to parents) were highly significantly differed for boll weight, ginning out-turn and fiber fineness but rest of them were non-significant. Effect of specific combining ability (due to crosses) were highly significant for all of yield related traits except ginning out-turn. Mean squares due to parents vs crosses in water stress condition appeared to be highly significant for boll weight. Mean squares due to lines were highly significant for boll weight and fiber fineness. Mean squares due to testers were highly significant for boll weight whilst significant effects were observed for fiber strength and fiber fineness. The interaction between lines and testers appeared to be highly significant for all of the traits except ginning out turn.

Estimation of genetic components under normal water condition: The variance due to specific combining ability (σ^2_{sca}) was greater than variance due to general combining ability (σ^2_{gca}) for all of traits measured indicating the role the of non-additive genes in the inheritance (Table 2). For instance, σ^2_{sca} for number of bolls per plant revealed the importance of non-additive genes, and presence of positive sign indicated that dominance was directed towards superior parent, whereas negative sign indicated the direction of dominance towards the lower parent. The ratio of variance ($\sigma^2_{gca}/\sigma^2_{sca}$) was found to be below unity, indicated that inheritance of traits was influenced by non-additive gene action.

Estimation of genetic components under water stress condition: Under water stress conditions, the higher estimates of σ^2_{sca} for the number of bolls indicated the role of non-additive genes, and dominance was directed towards superior parent (Table 2). The inheritance of boll weight, ginning out-turn, fiber length, fiber fineness, and fiber strength was predominantly controlled by non-additive genes.

General combining ability under normal water conditions: The numerical values assigned to ten lines and six testers indicated their general combining ability (GCA) for boll weight, ginning out-turn, fiber length, fiber fineness and fiber strength measured under normal water conditions (Table 3). Comparison of the estimates reveal that NIAB-111 showed positive value for ginning out-turn (0.14), fiber length (0.12) and fiber strength (0.05) reflected good general combining abilities for these characters while poor combiner for fiber fineness (-0.01) and boll weight (-0.01). Due to greater magnitude for fiber length (0.34), ginning out-turn (0.28) and boll weight (0.05), CP-15/2 displayed its superiority for general combining ability whilst poor combiner for fiber fineness (-0.01) and fiber strength (-0.17). Line BH-160 was found to be superior for general combining ability for ginning out-turn (0.59) while exhibited poor combiner for remaining traits. CIM-1100 possessed good general combining ability for ginning out-turn (0.47) and fiber length (0.28). CRIS-134 was identified as good combiner for fiber strength (1.11) only. CIM-446 exhibited high GCA for fiber strength (0.55) and fiber fineness (0.15) but poor combiner for rest of traits. General combining ability coefficient of FH-900 was high for fiber fineness (0.08). MNH-93 showed good GCA for boll weight and fiber fineness with estimates of 0.06 and 0.09 respectively. CIM-707 possessed good general combining ability for fiber length (1.78) and fiber strength (0.77) as compared to other characters. CIM-482 showed highest estimates of fiber strength (1.11), ginning out-turn (0.53) and boll weight (0.13). Among testers, CIM-506 displayed positive GCA for all the traits except ginning out-turn (-0.44). NIAB Karishma with highest GCA for fiber fineness (0.18) but appeared poor combiner for remaining traits included in the study. Tester MNH-129 having numerical values of 0.06 and 0.12, thus showed best GCA for fiber length and fiber strength, respectively. FH-1000 showed poor general combining abilities for all traits except boll weight (0.16) and fiber strength (0.76). An exotic tester, Acala-1517C with high GCA estimates i.e., 0.06, 0.14 and 0.36 was found to be good general combiner for boll weight, ginning out-turn and fiber length, respectively.

General combining ability under water stress regimes: Estimates of general combining abilities of ten lines and six testers for various yield, fiber and physiological traits under water stress treatment were given in Table 3. Comparison of cultivars showed that NIAB-111 with positive estimates were displayed better GCA effects for boll weight (0.02) and fiber length (0.50). The exotic genotype, CP-15/2 got highest positive values for fiber length (0.56) and revealed to be a good general combiner while exhibited poor response for other traits. BH-160 exhibited negative GCA effects for all of the traits except ginning out-turn (1.37). Among lines CIM-1100 was displayed good GCA estimates for ginning out turn (0.93) and fiber length (0.11). CRIS-134 showed its best general combining ability for fiber fineness and fiber strength with values of 0.18 and 2.88, respectively. The genotype

CIM-446 was identified to be a good general combiner for boll weight (0.14), fiber fineness (0.08) and fiber strength (1.16). FH-900 exhibited maximum positive GCA effects for fiber strength (0.16), fiber fineness (0.09) and ginning out-turn (0.09). MNH-93 showed good general combining ability except for boll weight (0.09) and fiber fineness (0.01). Highest positive GCA effects for fiber length (1.22) were shown by line CIM-707. Similar trend was observed in case of CIM-482 which had scored of 1.37 for ginning out-turn. Among testers, CIM-506 showed positive GCA coefficients of 0.29, 0.20 and 0.14 for fiber fineness, fiber length and boll weight, respectively however, for ginning out-turn, fiber strength the negative effects i.e., -0.08, and -0.01 were noted respectively. Higher values of GCA effects by MNH-129 exhibited good general combining ability for all of traits except boll weight (-0.17). Tester FH-1000 attained highest positive coefficient for boll weight (0.18), ginning out-turn (0.45) and fiber strength (0.32). S-12 was identified to be best general combiner for fiber length (0.33), fiber fineness (0.04) and fiber strength (1.98). Similarly, Acala-1517C expressed its better GCA for ginning out-turn (0.01) than other characters.

Estimation of SCA under normal water regimes: Higher SCA effects for boll weight were exhibited by crosses CIM-1100 × MNH-129, CRIS-134 × NIAB Karishma, CIM-707 × S-12, CIM-446 × MNH-129, FH-900 × S-12 AND FH-900 × NIAB Karishma (Table 4). For fiber length, significant and positive SCA effects were found for BH-160 × CIM-506, CRIS-134 × FH-1000, CIM-707 × NIAB Karishma and FH-900 × Acala-1517C. For fiber strength, NIAB-111 × CIM-506, CIM-482 × Acala-1517C and CIM-707 × Acala-1517C expressed the best SCA estimates. For fiber fineness, cross combinations i.e., CIM-1100 × NIAB Karishma, BH-160 × NIAB Karishma, CRIS-134 × MNH-129, CIM-482 × CIM-506 and CIM-446 × FH-1000 exhibited significant positive SCA values.

Specific combining ability under water stress regimes: For ginning out-turn, cross combinations i.e., CIM-707 × NIAB Karishma, CRIS-134 × CIM-506, BH-160 × S-12, MNH-93 × NIAB Karishma, NIAB-111 × CIM-506 and CRIS 134 × ACALA-1517C scored highest and significant coefficients of SCA, and appeared to be best specific combinations (Table 5). For fiber length, best specific combining ability was displayed by CIM-446 × NIAB-Karishma, CP-15/2 × Acala-1517C, CIM-482 × FH-1000, and NIAB-111 × CIM-506 due to having highest values. The combinations of CIM-446 × S-12, CIM-707 × ACALA-1517-C and NIAB-111 × NIAB Karishma presented significant and positive SCA effects for fiber fineness, and found to be good specific combinations for this trait.

Table 1. Mean squares of various quantitative traits of cotton grown under normal and water stress conditions

SOV	DF	BW	GOT	FL	FF	FS	BW	GOT	FL	FF	FS
Replications	2	0.11	0.82	0.36	0.09	4.07	0.14	9.57	2.62	0.07	0.56
Genotypes	75	0.41**	4.29**	3.75**	0.15**	6.30**	0.39**	6.39*	2.97**	0.53**	24.47**
Parents	15	0.47**	7.72**	5.14**	0.28**	10.37**	0.26**	9.53**	2.48	0.81**	11.77
Crosses	59	0.40**	3.28**	3.43**	0.12**	5.37**	0.40**	5.7	3.14**	0.47**	28.10**
P Vs C	1	0.01	11.99**	1.73	0.08	0.18	1.73**	0.17	0.41	0.32	0.49
Lines	9	0.22**	7.59**	7.17**	0.19**	5.89**	0.26**	8.98*	3.56*	0.98**	6.22
Testers	5	0.72**	5.56**	0.46	0.22**	17.56**	0.25**	2.62	0.86	0.21*	19.42*
L × T	45	0.40**	2.17**	3.01**	0.10**	3.92**	0.44**	5.39	3.31**	0.39**	33.44**
Error	150	0.05	0.7	0.74	0.05	2.1	0.07	4.4	1.76	0.08	8.01

DF stands for degree of freedom, BW- boll weight, GOT- ginning out-turn, FL-fiber length, FF- fiber fineness, FS- fiber strength

Table 2. General combining abilities of various quantitative traits of cotton grown under normal and water stress conditions.

	Normal water conditions					**Water stress conditions**				
PARENTS	BW	GOT	FL	FF	FS	BW	GOT	FL	FF	FS
LINES										
NIAB-111	-0.01	0.14	0.12	-0.01	0.05	0.02	-0.35	0.50	0.01	-1.01
CP-15/2	0.05	0.28	0.34	-0.01	-0.17	-0.06	0.04	0.56	0.10	-0.01
BH-160	-0.09	0.59	-0.27	-0.08	-0.67	-0.08	1.37	-0.28	-0.09	-0.68
CIM-1100	-0.12	0.47	0.28	-0.12	-1.28	-0.11	0.93	0.11	-0.18	-0.62
CRIS-134	-0.07	-0.97	-0.44	-0.02	1.11	-0.05	-2.29	-0.61	0.18	2.88
CIM-446	0.12	-0.66	-0.66	0.15	0.55	0.14	-1.35	-0.83	0.08	1.16
FH-900	-0.03	-0.13	-0.52	0.08	-0.39	-0.01	0.09	-0.56	0.09	0.16

MNH-93	0.06	-0.19	-0.52	0.09	-1.06	0.09	-0.13	-0.39	0.01	-0.68
CIM-707	-0.05	-0.05	1.78	-0.03	0.77	-0.03	0.32	1.22	-0.13	-0.62
CIM-482	0.13	0.53	-0.11	-0.04	1.11	0.08	1.37	0.28	-0.06	-0.57
Standard Error	0.46	5.34	1.97	1.75	0.37	6.39	0.25	0.62	2.5	0.31
TESTERS										
CIM-506	0.11	-0.44	0.19	0.04	1.09	0.14	-0.08	0.20	0.29	-0.01
NIAB Karishma	-0.05	-0.83	-0.3	0.18	-0.73	-0.04	-0.38	-0.30	-0.10	-0.77
MNH-129	-0.19	-0.22	0.06	-0.01	0.12	-0.17	0.08	0.10	0.29	1.08
FH-1000	0.16	-0.32	-0.1	-0.07	0.76	0.18	0.45	-0.16	-0.14	0.32
S-12	-0.07	1.6	-0.2	-0.06	0.19	-0.14	-0.08	0.33	0.04	1.98
Acala-1517-C	0.06	0.14	0.36	-0.08	-1.43	-0.04	0.01	-0.16	-0.38	-2.61
Standard Error	0.66	7.55	2.78	2.48	0.52	9.04	0.35	0.88	3.54	0.45

BW stands for boll weight, GOT- ginning out turn, FL-fiber length, FF- fiber fineness, FS- fiber strength

Table 3. Genetic components of variation of various quantitative traits of cotton grown under normal and water stress conditions.

Traits	Normal water conditions					Water stress conditions				
	σ^2_{gca}	σ^2_{sca}	σ^2_A	σ^2_D	$\sigma^2_{gca}/\sigma^2_{sca}$	σ^2_{gca}	σ^2_{sca}	σ^2_A	σ^2_D	$\sigma^2_{gca}/\sigma^2_{sca}$
BW	-0.0005	0.08	-0.0002	0.08	-0.00625	-0.001	-8.03	-0.0006	-8.03	0.00012
GOT	0.0001	-4.98	0.00006	-4.98	-0.00002	-0.006	1.78	-0.003	1.78	-0.00337
FL	-0.009	0.22	-0.004	0.22	-0.04091	-0.007	1.02	-0.003	1.02	-0.00686
FF	0.00001	-0.58	0.0003	-0.58	-0.00002	-0.001	-1.12	-0.0005	-1.12	0.00089
FS	0.01	1.27	0.005	1.27	0.00787	-0.08	11.12	-0.04	11.12	-0.00719

BW stands for boll weight, GOT- ginning out turn, FL-fiber length, FF- fiber fineness, FS- fiber strength, σ^2_{gca} = estimate of gca variance, σ^2_{sca} = estimate of sca variance, σ^2_A = Additive variance, σ^2_D= Dominance variance, $\sigma^2_{gca}/\sigma^2_{sca}$ = Variance ratio

Table 4. Specific combining ability estimates of various quantitative traits of cotton grown under normal water conditions.

Crosses	BW	GOT	FL	FF	FS
NIAB-111 × CIM-506	0.25*	0.44	-1.08	0.11	1.85*
CP-15/2 × CIM-506	0.03	-0.03	1.03*	0.08	0.74*
BH-160 × CIM-506	0.23*	0.04	1.97*	-0.22	-0.43
CIM-1100 × CIM-506	0.13	-0.22	0.08	-0.21	-0.48
CRIS-134 × CIM-506	-0.49	-0.95	-1.19	-0.04	-0.21
CIM-446 × CIM-506	-0.07	-0.26	-0.64	-0.02	-0.32
FH-900 × CIM-506	0.04	0.55	-0.44	0.02	-0.37
MNH-93 × CIM-506	0.02	0.44	0.56	-0.03	-0.71
CIM-707 × CIM-506	-0.27	0.3	0.25	0.1	-0.54
CIM-482 × CIM-506	0.14	-0.28	-0.53	0.21	0.46*
NIAB-111 × NIAB Karishma	-0.28	-0.16	-0.92	-0.2	-0.65
CP-15/2 × NIAB Karishma	-0.87	-0.13	-1.81	0.17	0.24*
BH-160 × NIAB Karishma	-0.33	-0.11	-0.86	0.38	0.07
CIM-1100 × NIAB Karishma	-0.3	0.17	-0.42	0.48	0.68*
CRIS-134 × NIAB Karishma	0.48*	0.12	0.64	-0.28	-0.71
CIM-446 × NIAB Karishma	0.26*	-0.49	0.53	-0.16	0.18*
FH-900 × NIAB Karishma	0.44*	-0.39	0.89*	-0.02	0.46*
MNH-93 × NIAB Karishma	0.19	0.17	0.22	0.1	0.13
CIM-707 × NIAB Karishma	0.36*	0.37	1.42*	0.03	0.29*
CIM-482 × NIAB Karishma	0.05	0.45	0.31	-0.5	-0.71
NIAB-111 × MNH-129	-0.24	-0.61	0.72	-0.01	0.48*
CP-15/2 × MNH-129	0.30*	0.25	0.16	-0.01	-0.29
BH-160 × MNH-129	0.41*	0.11	-1.23	0.13	0.21*
CIM-1100 × MNH-129	0.50*	-0.28	0.22	-0.03	-0.18

CRIS-134 × MNH-129	0.05	1.33	-0.73	0.37	-0.24
CIM-446 × MNH-129	0.47*	-0.48	-0.51	-0.13	0.65*
FH-900 × MNH-129	-0.12	0.19	0.02	-0.06	-0.07
MNH-93 × MNH-129	-0.74	0.22	0.69	-0.18	0.26
CIM-707 × MNH-129	-0.23	0.08	0.05	-0.08	0.09
CIM-482 × MNH-129	-0.41	-0.83	0.61	-0.01	-0.91
NIAB-111 × FH-1000	0.2	-0.34	0.55	-0.01	-0.15
CP-15/2 × FH-1000	0.11	-0.15	0.99*	-0.11	-0.59
BH-160 × FH-1000	0.28*	-0.12	0.27	-0.07	-0.09
CIM-1100 × FH-1000	0.14	-0.01	0.38	-0.13	-0.15
CRIS-134 × FH-1000	0.16	0.1	1.44*	-0.06	0.79*
CIM-446 × FH-1000	-0.16	0.46	0.66	0.2	0.68*
FH-900 × FH-1000	-0.58	0.27	-1.48	0.01	-0.04
MNH-93 × FH-1000	-0.07	-0.34	-1.14	-0.01	-0.37
CIM-707 × FH-1000	0.01	-0.15	-1.78	0.02	-0.21
CIM-482 × FH-1000	-0.11	0.27	0.11	0.16	0.13
NIAB-111 × S-12	-0.13	0.31	-0.02	0.05	-0.92
CP-15/2 × S-12	0.42	0.17	0.43	0.06	0.64*
BH-160 × S-12	-0.18	0.2	0.37	-0.2	0.47*
CIM-1100 × S-12	-0.68	0.64	-0.52	-0.13	0.08
CRIS-134 × S-12	-0.33	-0.08	0.21	-0.03	0.69*
CIM-446 × S-12	-0.52	0.94	-0.24	0.13	-0.42
FH-900 × S-12	0.46*	-0.92	-0.04	0.04	0.53*
MNH-93 × S-12	0.34*	-0.86	-0.04	0.02	0.19*
CIM-707 × S-12	0.48*	-0.33	-0.35	-0.05	-0.64
CIM-482 × S-12	0.13	-0.08	0.21	0.12	-0.64
NIAB-111 × Acala-1517-C	0.2	0.36	0.75	0.07	-0.62
CP-15/2 × Acala-1517-C	0.01	-0.11	-0.81	-0.2	-0.73
BH-160 × Acala-1517-C	-0.42	-0.09	-0.53	-0.02	-0.23
CIM-1100 × Acala-1517-C	0.21*	-0.31	0.25	0.02	0.05
CRIS-134 × Acala-1517-C	0.13	-0.53	-0.36	0.05	-0.34
CIM-446 × Acala-1517-C	0.01	-0.17	0.19	-0.02	-0.78
FH-900 × Acala-1517-C	-0.25	0.3	1.06*	0.02	-0.51
MNH-93 × Acala-1517-C	0.27*	0.36	-0.28	0.1	0.49*
CIM-707 × Acala-1517-C	-0.36	-0.28	0.42	-0.01	0.99*
CIM-482 × Acala-1517-C	0.19	0.47	-0.69	0.2	1.66*
Standard Error	0.21	2.38	0.88	0.78	0.16

BW stands for boll weight, GOT- ginning out turn, FL-fiber length, FF- fiber fineness, FS- fiber strength

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

Crosses	BW	GOT	FL	FF	FS
NIAB-111 × CIM-506	0.18	1.25*	0.97*	0.12	-0.99
CP-15/2 × CIM-506	0.13	0.86*	0.58*	-0.23	-1.99
BH-160 × CIM-506	0.21	-0.14	0.74*	0.24	0.34*
CIM-1100 × CIM-506	0.11	-0.36	-0.98	0.07	-0.71
CRIS-134 × CIM-506	-0.41	1.53*	-0.59	0.09	-3.54
CIM-446 × CIM-506	-0.1	0.58*	0.30*	-0.26	0.84*
FH-900 × CIM-506	0.02	0.14*	0.02	0.03	-1.16
MNH-93 × CIM-506	-0.02	-1.31	0.52*	0.03	0.68*
CIM-707 × CIM-506	-0.3	-1.42	0.58*	-0.1	2.62*
CIM-482 × CIM-506	0.19	-1.14	-2.14	0.01	3.90*
NIAB-111 × NIAB Karishma	-0.3	-0.12	-0.53	0.38	1.11*
CP-15/2 × NIAB Karishma	-0.75	-0.51	-0.59	0.11	0.78*
BH-160 × NIAB Karishma	-0.33	-0.17	0.91*	0.36	0.78*

CIM-1100 × NIAB Karishma	-0.4	-1.06	-0.14	-0.06	0.72*
CRIS-134 × NIAB Karishma	0.47	0.16*	0.91*	0.01	-1.78
CIM-446 × NIAB Karishma	0.25	-0.12	1.47*	0.28	0.28*
FH-900 × NIAB Karishma	0.44	-0.89	-1.14	0.06	0.61*
MNH-93 × NIAB Karishma	0.17	1.33*	-0.98	0.05	-0.22
CIM-707 × NIAB Karishma	0.35	1.88*	0.74*	-0.61	-2.28
CIM-482 × NIAB Karishma	0.11	-0.51	-0.64	-0.58	0.04
NIAB-111 × MNH-129	-0.2	0.75*	-0.93	-0.78	4.24*
CP-15/2 × MNH-129	0.41	0.69*	-1.32	0.11	1.24*
BH-160 × MNH-129	0.33	-0.64	0.84*	-0.79	0.58*
CIM-1100 × MNH-129	0.5	0.14*	0.46*	0.07	-1.48
CRIS-134 × MNH-129	0.04	-0.97	0.51*	0.06	-2.31
CIM-446 × MNH-129	0.45	-0.25	-0.93	0.05	-0.26
FH-900 × MNH-129	-0.13	-0.03	0.12	0.26	-0.92
MNH-93 × MNH-129	-0.77	0.19*	0.29*	0.3	-0.42
CIM-707 × MNH-129	-0.25	-0.25	0.01	0.37	1.19*
CIM-482 × MNH-129	-0.36	0.36*	0.96*	0.36	-1.87
NIAB-111 × FH-1000	0.18	-0.28	0.13	0.13	-5.66
CP-15/2 × FH-1000	0.23	-0.01	-0.39	-0.07	-5.32
BH-160 × FH-1000	0.28	0.66*	-0.89	0.05	3.01*
CIM-1100 × FH-1000	0.14	0.11*	0.72*	0.34	0.29*
CRIS-134 × FH-1000	0.15	-1.01	-0.89	0.15	0.12
CIM-446 × FH-1000	-0.17	0.05	-0.67	-0.06	1.51*
FH-900 × FH-1000	-0.65	0.61*	1.06*	-0.1	0.51*
MNH-93 × FH-1000	-0.09	-0.17	0.89*	-0.08	0.34*
CIM-707 × FH-1000	-0.01	-0.95	-1.06	-0.34	2.29*
CIM-482 × FH-1000	-0.05	0.99*	1.22*	-0.01	2.90*
NIAB-111 × S-12	-0.06	-0.08	0.17	-0.02	-0.99
CP-15/2 × S-12	-0.18	-0.81	0.44*	0.04	2.68*
BH-160 × S-12	-0.1	1.53*	-0.72	0.03	-6.32
CIM-1100 × S-12	-0.6	0.64*	0.56*	-0.61	-1.71
CRIS-134 × S-12	-0.4	-0.81	-0.06	-0.01	7.79*
CIM-446 × S-12	-0.45	-0.08	0.17	0.44	-2.16
FH-900 × S-12	0.54	-0.53	0.56*	0.21	0.84*
MNH-93 × S-12	0.41	-0.31	-1.28	-0.3	0.34*
CIM-707 × S-12	0.55	0.92*	0.11	0.29	-0.38
CIM-482 × S-12	0.28	-0.47	0.06	-0.07	-0.1
NIAB-111 × Acala-1517-C	0.22	-1.52	0.33*	0.17	2.28*
CP-15/2 × Acala-1517-C	0.17	-0.24	1.28*	0.04	2.61*
BH-160 × Acala-1517-C	-0.38	-1.24	-0.89	0.12	1.61*
CIM-1100 × Acala-1517-C	0.25	0.54*	-0.61	0.2	2.89*
CRIS-134 × Acala-1517-C	0.16	1.09*	0.11	-0.31	-0.28
CIM-446 × Acala-1517-C	0.03	-0.18	-0.33	-0.45	-0.22
FH-900 × Acala-1517-C	-0.21	0.71*	-0.61	-0.46	0.11
MNH-93 × Acala-1517-C	0.29	0.26*	0.56*	0.3	-0.72
CIM-707 × Acala-1517-C	-0.33	-0.18	-0.39	0.4	-3.44
CIM-482 × Acala-1517-C	-0.17	0.76*	0.56*	0.29	-4.83
Standard Error	2.86	0.11	0.27	1.12	0.14

BW stands for boll weight, GOT- ginning out turn, FL-fiber length, FF- fiber fineness, FS- fiber strength

DISCUSSION

There are two pre-requisites for the development of cotton against drought either by using natural or induced selection. Firstly, the presence of genetic variability in certain traits and secondly, this variability must be genetically controlled. Here, efforts are being made to grow genetic population upto plant maturity. In the previous work on drought-related studies, data on whole plant responses to stress are not available in *G. hirsutum* (Ahmad *et al*., 2009; Iqbal *et al*., 2010). Keeping in view, ten genotypes i.e., NIAB-111, CP-15/2,

BH-160, CIM-1100, CRIS-134, CIM-446, FH-900, MNH-93, CIM-707 and CIM-482 were identified previously as drought tolerant genotypes. In contrast, CIM-506, NIAB Karishma, MNH-129, FH-1000, S-12 and Acala-1517C were identified as sensitive to water stress. Genetic analysis of the data of various parameters indicated the role of additive and non-additive components in stress and non-stress conditions. The variance due to GCA was lower than due to SCA for boll weight, ginning out-turn, fiber length, fiber strength, and fiber fineness which indicated the preponderant role of non-additive genes. The studies of Shakeel *et al.* (2001), Neelima *et al.* (2004) and Javaid *et al.* (2014) agreed with present investigations, whilst Karademir *et al.* (2009) reported the role of additive effects for fiber length and fiber fineness.

Furthermore, plant breeders must have working knowledge about various gene action (mentioned previously), and combining abilities of parents and combinations for introgression of desirable traits involved for development of drought tolerance in field crops as emphasized by Singh and Narayanam (2000). The presence of greater magnitude of SCA variance for all of traits is supported by Sprague and Tatum (1942) and Griffing (1956), and signifies the importance of non-additive genes in the inheritance of traits. Previous reports (Ahmad *et al*., 2009; Shakoor *et al*., 2010 and Sarwar *et al*., 2012) on drought tolerance in cotton also indicated the presence of non-additive genetic effects for these traits. Comparison of GCA for sixteen parents (ten lines and six testers) revealed that lines namely NIAB-111, CP-15/2, CIM-482 and CIM-446, and testers (CIM-506, FH-1000 and MNH-129) were best general combiners for majority of traits. These genotypes may be used in breeding program for the improvement of high yield having enhanced drought tolerance in upland cotton. Amongst various combinations, CIM-707 × S-12 and CIM-446 × NIAB Karishma proved to be best for boll weight and fiber length, respectively even having both parents had low GCA estimates. Cross of CIM-707 × NIAB Karishma was best for ginning out-turn due to the involvement of CIM-707 which have good GCA but NIAB Karishma had poor GCA. For the fiber fineness, CIM-446 × S-12 showed good performance due to having good general combiners. Likewise, CRIS-134 × S-12 for fiber strength due to the involvement of CRIS-134 and S-12 with high GCA effects (Roy *et al*., 2002). SCA effects represent dominant gene action because SCA effects are limited to the selection of superior parents of certain traits (Caixeta *et al*., 2001). 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 from hybridization of parents having 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). The significance of non-additive gene action revealed the use of this plant material for the development of hybrids (Vaghela *et al*., 2016).

Conclusion: One the basis of information from the data analyzed by using various biometrical approaches, 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 the 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.

REFERENCES

Ahmed, H.M., M.M. Kandhro, S. Laghari and S. Abro (2006). Heritability and genetic advance as selection indicators for improvement in cotton (*G. hirsutum* L.). J. Biol. Sci. 6: 96-99.

Ahmad, R.T., T.A. Malik, I.A. Khan and M.J. Jaskani (2009). Genetic analysis of some morpho-physiological traits related to drought stress in cotton (*G. hirsutum* L.). Int. J. Agric. Biol. 11: 235-240.

Akhtar, M., F. Azhar and Z. Ali (2008). Genetic basis of fiber quality attributes in upland cotton (*G. hirsutum* L.) germplasm. Int. J. Agric. Bio. 10: 217-220.

Allen Jr, L.H., V.G. Kakani, J.C. Vu and K.J. Boote (2011). Elevated CO_2 increases water use efficiency by sustaining photosynthesis of water-limited maize and sorghum. J. Plant Physio. 168: 1909-1918.

Ali, M.A., I.A. Khan, S.I. Awan, S. Ali and S. Niaz (2008). Genetics of fiber quality traits in cotton (*G. hirsutum* L.). Aust. J. Crop Sci. 2: 10-17.

Anonymous (2017). Economic Survey of Pakistan (2016-2017). Government of Pakistan, Finance Division. Economic Advisor's Wing. Islamabad.

Azhar, F., M. Naveed and A. Ali (2004). Correlation analysis of seed cotton yield with fiber characteristics in *G. hirsutum* L. Int. J. Agric. Biol. 6: 656-658.

Bertini, C.H.C.M., F.P.D. Silva, R.D.P. Nunes and J.H.R.D. Santos (2001). Gene action, heterosis and inbreeding depression of yield characters in mutant lines of upland cotton. Pesq. Agropec. Bras. 36: 941-948.

Bruner, W. (2015). Root development of cotton, peanuts, and tobacco in central Oklahoma. Proceedings of the Oklahoma Academy of Science. 20-37.

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

Esmail, R. (2007). Genetic analysis of yield and its contributing traits in two intra-specific cotton crosses. J. Appl. Sci. Res. 3: 2075-2080.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9: 463-493.

Iqbal, K., F.M. Azhar, I.A. Khan and E. Ullah (2010). Assessment of cotton (*G. hirsutum* L.) 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 *G. hirsutum* L. Pakistan J. Agric. Sci. 51:143-146.

Karademir, C., Karadem, E. Idot, Ek, R. Idot and G. Oktay (2009). Combining ability estimates and heterosis for yield and fiber quality of cotton in line × tester design. Not. Bot. Horti. Agrobot. Cluj-Napoca. 37: 228-233.

Khan, N.U., G. Hassan, K.B. Marwat, K.M.B. Farhatullah, A. Parveen, U. Aiman, M. Khan and Z. Soomro (2009). Diallel analysis of some quantitative traits in *G. hirsutum* L. Pakistan J. Bot. 41: 3009-3022.

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

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

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.

Kumar, K.S., K.A. Kumar and R. Ravikesavan (2014). Genetic effects of combining ability studies for yield and fibre quality traits in diallel crosses of upland cotton (*Gossypium hirsutum* L.). Afr. J. Biotechnol. 13: 119-126.

Loka, D. A. and D. M. Oosterhuis (2012). Water stress and reproductive development in cotton. Flowering and Fruiting in Cotton. Cordova: The Cotton Foundation.51-58.

Neelima, S., V. Reddy and A. Reddy (2004). Combining ability studies for yield and yield components in American cotton (*G. hirsutum* L.). Ann. Agri. Biol. Res. 9:1-6.

Nimbalkar, R. D., A. C. Jadhav and S. S. Mehetra (2004). Combining ability studies in desi cotton (*G. arboreum* and *G. herbaceum*). J. Maharastra Agri. Uni. 29: 166-170.

Minhas, R., I.A. Khan, M.S. Anjam and K. Ali (2008). Genetics of some fiber quality traits among intraspecific crosses of American cotton (*Gossypium hirsutum*). Int. J. Agric. Bio. 10: 196-200

Mukhtar, M., T. Khan and A. Khan (2000a). Genetic analysis of yield and yield components in various crosses of cotton (*G. hirsutum* L.). Int. J. Agric. Biol. 2: 258-260.

Mukhtar, M.S., T.M. Khan and A.S. Khan (2000b). Gene action study in some fiber traits in cotton (*G. hirsutum* L.). Pakistan J. Bio. Sci. 3: 1609-1611.

Papastylianou, P.T. and I.G. Argyrokastritis (2014). Effect of limited drip irrigation regime on yield, yield components, and fiber quality of cotton under Mediterranean conditions. Agric. Water Manag. 142: 127-134.

Prasad, U., V. Reddy and A. Reddy (2005). Studies on genetic variability in American cotton (*G. hirsutum* L.). Karnataka J. Agric. Sci. 18: 1095-1098.

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

Roy, N., V. Jettopujov and N. Solanik (2002). Combining ability for some agronomic characters in alfalfa (*Medicago sativa* L.). Pakistan J. Agric. 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.

Sarwar, M.K.S., M.Y. Ashraf, M. Rahman and Y. Zafar (2012). Genetic variability in different biochemical traits and their relationship with yield and yield parameters of cotton cultivars grown under water stress conditions. Pakistan J. Bot. 44: 515-520.

Shakeel, A., I.A. Khan and F.M. Azhar (2001). Study pertaining to the estimation of gene action controlling yield and related traits in upland cotton. J. Biol. Sci. 1: 67-70.

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.S. Narayanan (2000). Biometrical Techniques in Plant Breeding. Kalyani Publishers, New Delhi, India.

Singh, P. (2004). Cotton Breeding. 2nd ed. Kalyani Publishers, New Delhi India

Singh, P. and G. Chahal (2005). Estimates of additive, dominance and epistatic variation for fiber quality characters in upland cotton (*G. hirsutum* L.). J. Cotton Res. Dev. 19:17-20.

Sprague, G.F. and L.A. Tatum (1942). General vs. specific combining ability in single crosses of corn. Agron. J. 34: 923-932.

Steel, R.G.D., J.H. Torrie and D.A. Dickey (1997). Principles and procedures of statistics: A biometrical approach. (3rd ed.) McGraw Hill, New York.

Vaghela, P., D. Thakkar, H. Bhadauria, D. Sutariya, S. Parmar and D. Prajapati (2016). Heterosis and combining ability for yield and its component traits in Indian mustard (*Brassica juncea* L.). J. Oilseed Brassica. 1: 39-43.

Zhang, D., Z. Luo, S. Liu, W. Li and H. Dong (2016). Effects of deficit irrigation and plant density on the growth, yield and fiber quality of irrigated cotton. Field Crops Res. 197: 1-9.

Zhang, J., R.G. Percy and J.C. Mccarty (2014). Introgression genetics and breeding between Upland and Pima cotton: a review. Euphytica. 198: 1-12.