Pak. J. Agri. Sci., Vol. 56(2), 359-366; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/19.6833
http://www.pakjas.com.pk

COMBINING ABILITY ANALYSIS OF VARIOUS FIBRE QUALITY TRAITS UNDER NORMAL AND WATER DEFICIT CONDITION IN COTTON

Aziz Ullah[1,*], Amir Shakeel[1], Tanwir Ahmad Malik[1] and Muhammad Farrukh Saleem[2]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan; [2]Department of Agronomy, University of Agriculture Faisalabad, Pakistan.
[*]Corresponding author's email: azizullahpbg@gmail.com

The objective of this study was to investigate the general combining ability effects of parents and specific combining ability effects of crosses under normal and water deficit condition for various traits related to fibre quality. For this purpose, 50 F_1 crosses and their 15 parents was field planted under two different moisture regimes i.e. normal and water deficit condition in the experimental area of Department of Plant Breeding and Genetics, UAF. Analysis of variance under normal and drought condition revealed that genotypes showed highly significant differences for all the traits under both conditions. For most of fibre quality traits, under normal condition, among the lines, the good general combiners were IUB-212 and FH-113 and poor general combiners were VH-295 and NS-121. Among the testers, the good general combiners were IR-3, CIM-443 and S-12 and poor general combiners were MNH-147 and FH-1000. Under the drought condition, among the lines, the good general combiner was IUB-212 and poor general combiners were VH-295 and FH-142. Among the testers, the good general combiner was S-12 and poor general combiners were MNH-147 and IR-3. For most of fibre quality traits the best specific combiner were VH-144 × CIM-443 and AA-802 × S-12 under normal condition while under drought condition the best specific combiner were VH-144 × CIM-443, VH-295 × IR-3, VH-144 × FH-1000 and VH-295 × CIM-443. The variance due to specific combining ability was greater as compared to the general combining ability variance for all the traits indicating the dominant role of non-additive genes under normal and drought condition. The crosses VH-144 × CIM-443 and VH-295 × IR-3 can be used in variety development program for drought prone areas of Pakistan with high specific combining ability for fibre quality traits under drought condition. All fibre quality traits having non-additive gene action suggested usage of this material in the hybrid development programme in cotton.
Keywords: Combining ability effects, fibre quality traits, line × tester analysis, gene action, water deficit.

INTRODUCTION

Cotton is a major source of fibre, food and feed in the World as well as in Pakistan. Pakistan ranked at the 4th number among the major cotton producing countries in the whole world (Anonymous, 2015-16). But, in current climatic condition, production of cotton is varying remarkably due to various stresses (biotic and abiotic). Among the various abiotic stresses, water deficiency is an important factor that reduces the seed cotton yield (Haq *et al*., 2017; Chattah *et al*., 2017). The plants response to drought condition depends upon time and place (Cattivelli *et al.*, 2008; Ahmad *et al*., 2009; Rehman *et al*., 2017; Sattar *et al*., 2017). For establishing effective programme related to cotton breeding under drought stress, the potential knowledge about genetic information of various traits is crucial. The gene action is very important regarding various traits which provide necessary information about the selection strategy to breed cotton. For the estimation of the combining ability effects of parents and their crosses, the line × tester analysis is a good tool. Combining ability describes the breeding value of parental lines to produce hybrids. The utility of this mating system is that there is no assumptions except the lines and testers should possess diverse genetic nature for the analysis. Sprague and Tatum (1942) stated that GCA effects are due to additive type of gene action but SCA effects are due to genes which are non-additive (dominant or epistatic).

Previously a lot of research work has been done regarding combining ability effects for various fibre quality traits in cotton under normal irrigation. The glaring examples include Ahuja and Dhayal (2007), Ilyas *et al.* (2007), simon *et al*. (2013), Patel *et al*. (2007), Ali *et al*. (2009), Rauf *et al*. (2006), Green and Culp (1990). Although the research work related to the combining ability effects for various fibre quality traits under water deficit condition is very important but a very little work have been done on combining ability effects for various fibre quality traits under drought stress. However, some researchers (Soomro *et al.*, 2012) have conducted study on combining ability regarding drought stress. The advantage of present research work was to identify the drought tolerant and sensitive genotypes and comparing their combining ability for various fibre quality traits under water deficit condition.

Pushpam and Raveendran (2005) found gene action which was non-additive in nature for, fibre length, fibre strength, fibre elongation and fiber uniformity. Raza *et al.* (2013) studied gene action and results revealed that there were additive gene action for lint percentage, fibre length, strength and fineness. The findings of Channa *et al.* (2006) revealed that both type of gene actions (additive and non-additive) were important for lint percentage. The result of Patel *et al.* (2007) shows the gene action of non-additive in nature for uniformity ratio having higher value of SCA than GCA. The variances due to SCA were more than GCA variances for various fibre quality parameters which indicates the preponderance of non-additive nature of gene action (Simon *et al*., 2013). Shaukat *et al*. (2013) studied the gene action and results presented higher additive gene effect in the hybrid population (first generation) due to higher GCA variances for fibre strength and fineness whereas lint percentage and fibre elongation presented higher SCA variances, pointing towards the gene action of non-additive in nature controlling the various traits. Non-additive gene action for fibre strength and fibre uniformity percentage was also reported by Ali *et al*. (2009). Samreen *et al.* (2008) studied the combining ability effects in upland cotton genotypes by using analysis related to line × tester and results revealed that GCA and SCA variances for all the traits were significant. However, the higher GCA variance than SCA variance revealed gene action of additive in nature. The results of Munawar and Malik (2013) revealed that there were significant differences of SCA and GCA for various fibre parameters. Patel *et al.* (2007) found that certain cross combinations show high SCA and it is not necessary that the parents have to good GCA effects.

In altered climatic condition, the present research was carried out to examine the genetic variation in cotton genotypes and to study the genetics of various fibre quality traits under water-deficit stress in upland cotton.

MATERIALS AND METHODS

For the development of genetic materials, to conduct genetic investigations, 10 drought tolerant and 5 drought sensitive genotypes were sown in pots in the glasshouse during the winter season 2013-14 to produce F_1 hybrids. When the parents started flowering, these were hybridized by keeping drought tolerant genotypes as females (lines) and drought sensitive genotypes as males (testers) following the line × tester mating design (Kempthorne, 1957). In the evening suitable buds of the lines were emasculated and covered with glyssine bags in order to prevent the pollen contamination. The sufficient amounts of pollens were collected from the tester plants in petri dish and these pollens were dusted on the stigma of emasculated buds in the following morning. Numerous pollinations were made to obtain sufficient amount of crossed seeds. Some buds from both male and female parents were also bagged to develop selfed seed. At maturity, the seed cotton from each crossed bolls were collected by hand picking and ginned with the help of single roller electric gin.

In order to investigate the genetics of drought tolerance for various fibre quality traits in cotton, 50 F_1 hybrids along with fifteen parents (ten lines and five testers) were planted under two moisture regimes i.e. normal and drought stress during May 2014. This experiment was conducted using normal irrigation (To) and giving stress at 50% reduced irrigation (T1). The irrigation water of 23 acre inches and 12 acre inches was given under normal and drought condition respectively while 11.50 acre inches received in the form of rain. Climatic conditions prevailing during present experimentation (April-November) in the year 2014 were given in Fig. 1 (Source: Agromet Bulletin, Agriculture Meteorology Cell, Department of Crop Physiology, UAF, Pakistan). This experiment was carried out in split plot under RCBD arrangement repeated thrice. The water levels were kept in main plot whereas genotypes in subplot. Seeds of each of the 65 entries per replication and treatment were planted in single row plot having ten plants each. There were 75 cm and 30 cm distance between row to row and plant to plant respectively. There were 100cm distance between normal and stress plot while 90 cm between different replications of a plot. All recommended agronomic measures from sowing to harvesting were adopted. The 5 guarded plants per replication and treatment for each genotype were tagged for the pickings. The mature bolls were picked by three picks and seed cotton for all the plants in three replications was collected in paper bags separately.

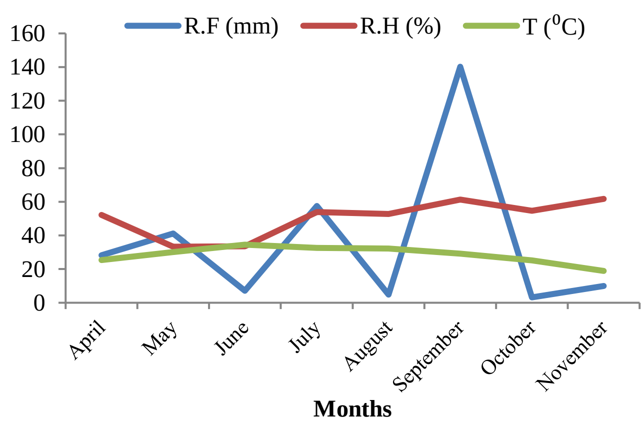

Figure 1. Rainfall, relative Humidity and average temperature from April to November during 2014.

The picking was done when the dew was evaporated. The seed cotton yield was weighed on electronic balance. By using the fibro graph HVI-900, the various fibre characteristics i.e. fibre length (mm), fibre strength (g/tex), fibre fineness (ug/inch) and fibre uniformity (%) were measured. The recorded data were subjected to simple analysis of variance (Steel *et al*., 1997). The characters showing significant differences were analyzed for general and specific combining ability following line × tester analysis by Kempthorne (1957).

RESULTS

The analysis of variance following line × tester analysis for each fibre quality trait was conducted separately under both normal and stress condition. Mean squares were differed significantly among the traits (Table 1).

Fiber length: Positive general combining ability (GCA) is desirable for fibre length. GCA effects for fibre length under normal condition revealed that VH-295 exhibited the maximum significant and positive effects (0.54) and considered as a good general combiner for the trait under discussion followed by IUB-212 and FH-113 with GCA effect of 0.44 and 0.38, respectively. Whereas the line such as NIAB-111 exhibited significant and negative GCA estimate (-0.76) indicating its poor ability to combine with testers. Among testers (male parents) IR-3 represent significant and positive GCA (0.44) that depict its good combining ability with lines followed by CIM-443 which also showed significant positive GCA effects (0.30). On the other hand, S-

Table 1. Mean square values of line × tester analysis for various traits under normal and drought condition.

SOV	DF	Normal condition				Drought Condition			
		FL	FS	FF	FU	FL	FS	FF	FU
Rep.	2	5.40**	11.95**	1.66**	6.12**	19.73**	3.08	0.79**	3.83**
Gen.	64	3.25**	21.65**	0.73**	10.89**	7.75**	20.84**	0.69**	12.64**
Parents	14	4.22**	17.84**	0.96**	13.29**	17.19**	11.71**	0.51**	13.02**
Crosses	49	2.80**	22.56**	0.67**	10.29**	4.83**	22.64**	0.75**	12.49**
P. vs Crosses	1	11.61**	30.13**	0.41**	6.54**	19.01**	60.29**	0.49**	14.56**
Lines	9	3.53**	28.65**	0.40**	2.62**	7.78**	29.01**	0.41**	3.40**
Testers	4	3.96**	39.94**	0.21**	82.98**	1.36	57.12**	0.71**	104.10**
L x T	36	2.49**	19.11**	0.79**	4.14**	4.48**	17.22**	0.84**	4.59**
Error	128	0.13	0.21	0.05	0.39	2.18	0.66	0.04	0.25

Significant = *, highly significant = **, df = degree of freedom, Rep = replications, Gen = genotypes, FL = Fiber length and FS = fibre strength, FF = fibre fineness, FU = Fiber uniformity

Table 2. Estimation of genetic components of variation under normal and drought condition.

Traits	Normal condition		Drought condition	
	∂ GCA	∂ SCA	∂ GCA	∂ SCA
FL	0.004	0.786	0.005	0.767
FS	0.046	6.298	0.072	5.520
FF	-0.002	0.249	-0.001	0.267
FU	0.081	1.249	0.105	1.445

∂ GCA = Estimate of GCA variance, ∂ SCA = Estimate of SCA variance, FL = Fiber length and FS = fibre strength, FF = fibre fineness, FU = Fiber uniformity

Table 3. Estimation of general combining ability effects for various fiber quality traits under normal and drought condition.

	Normal condition				Drought condition			
Parents	FL	FS	FF	FU	FL	FS	FF	FU
VH-144	0.34**	0.03	0.29**	0.03	0.47	0.10	0.25**	0.01
IUB-212	0.44**	-1.83**	-0.25**	-0.01	0.62	-1.79**	-0.21**	-0.03
MNH-886	-0.52**	-0.33**	0.05	0.05	-0.37	0.21	0.06	-0.37**
VH-295	0.54**	-2.42**	0.09	-0.47**	0.79*	-2.25**	0.22**	-0.79**
IR-3701	-0.17	1.08**	0.07	0.48**	-0.10	0.88**	0.07	0.98**
AA-802	0.37**	0.11	-0.05	-0.73**	0.39	0.06	-0.02	0.05
NIAB-111	-0.76**	0.37**	-0.12*	0.66**	-0.62	0.48*	-0.26**	0.23
NS-121	-0.59**	1.77**	0.06	-0.30	-1.39**	2.41**	-0.02	0.29*
FH-113	0.38**	1.77**	-0.22**	0.23	0.75	1.02**	0.02	0.04
FH-142	-0.04	-0.55**	0.08	0.06	-0.53	-1.12**	-0.11*	-0.42**
S.E	0.09	0.12	0.05	0.16	0.38	0.21	0.05	0.13
IR-3	0.44**	1.12**	0.11**	-2.85**	0.17	1.84**	0.21**	-2.91**
CIM-443	0.30**	0.44**	0.05	1.34**	0.23	0.66	0.08*	2.13**
FH-1000	-0.06	-1.93**	-0.07	0.56**	0.04	-1.89	-0.05	0.56**
MNH-147	-0.24**	-0.01	0.00	0.02	-0.21	-0.42	-0.03	-0.43**
S-12	-0.44**	0.37**	-0.09*	0.93**	-0.23	-0.19	-0.21**	0.65**
S.E	0.07	0.08	0.04	0.11	0.27	0.15	0.04	0.09

Significant = *, highly significant = **FL = Fiber length and FS = fibre strength, FF = fibre fineness, FU = Fiber uniformity

12 was considered as bad combiner because it revealed the maximum negative GCA (-0.44). Under drought condition the maximum significant positive GCA were exhibited by the line VH-295 (0.79) and designated as good general combiner for this trait. The maximum value of negative GCA was displayed by NS-121 followed by NIAB-111 with a value of -1.39 and -0.62, respectively and hence showing poor combining ability for this trait. Regarding testers (male parents), all these presented non-significant GCA estimates for this trait (Table 3).

Under normal condition, the results of specific combining ability revealed that out of 50 combinations, 18 combinations exhibited significant and positive estimates, 17 showed significant and negative SCA effects whereas the remaining combinations displayed non-significant results for fibre length. NS-121 × IR-3 and FH-142 × FH-1000 were the most favorable combinations due to high SCA effects (1.44 and 1.30, respectively) followed by IUB-212 × S-12 (1.11). While FH-142 × MNH-147 exhibited the maximum significant negative SCA estimate (-1.95) followed by NS-121 × S-12 (-1.53) which showed that these were undesirable combinations for the improvement of trait. Under drought condition, the highest significant and positive SCA effects was presented by the combinations NS-121 × FH-1000 and NS-121 × MNH-147 of equal value (2.07) followed by FH-142 × S-12 (1.79) depicting the best combinations whereas the combinations FH-142 × CIM-443 and FH-142 × MNH-147 were considered as poor with negative SCA value (-2.31 and -1.74, respectively) for the trait (Table 4)

Fiber strength: The analysis regarding combining ability for fibre strength in normal condition showed that maximum positive significant GCA estimates were exhibited by the lines NS-121 and FH-113 of equal value (1.77) showing their good combining ability for this trait followed by IR-3701 (1.08) and NIAB-111 (0.37) (Table 3). While the genotype VH-295 showed maximum negative GCA effects (-2.42). Among the testers (male parents) maximum GCA estimates were presented by the tester IR-3 followed by CIM-443 (1.12 and 0.44, respectively) while highest significant and negative GCA effects were exhibited by FH-1000 (-1.93) which depicts its bad combining ability with the lines under discussion.

In drought condition, NS-121 demonstrated the maximum positive GCA effects for fibre strength (Table 3) followed by FH-113 (1.84 and 0.66, respectively) while FH-1000 showed maximum negative GCA estimate (-1.89). Highest GCA estimates, among male parents (testers), was exhibited by IR-3 followed by CIM-443 (1.84 and 0.66, respectively) while the maximum significant negative GCA estimates (-1.89) were shown by FH-1000 that was indicated as a poor combiner.

Under normal condition, it is evident from the results that the combination MNH-886 × FH-1000 exhibited the maximum SCA estimates (4.09) considered as the desirable combination followed by VH-144 × MNH-147 and AA-802 × MNH-147 (3.75 and 3.47, respectively) whereas highest negative SCA effect was exhibited by FH-113 × FH-1000 (-4.51) followed by IUB-212 × MNH-147 (-4.17) and VH-144 × S-12 (-3.50). Under drought condition, the maximum value of positive effects (3.82) was presented by the cross AA-802 × MNH-147 followed by MNH-886 × FH-1000 (3.00) which indicates good combinations for this improvement, while maximum negative SCA value (-4.29) was estimated for the cross IR-3701 × MNH-147 followed by MNH-886 × S-12 (-3.69) (Table 4).

Fiber fineness: General combining ability (GCA) effects for fibre fineness under normal and drought condition are given in Table 3. For this trait, the genotypes which have low micronaire value that are being considered desirable because of higher fibre fineness, so the parents and crosses showing lower GCA and SCA estimate. Regarding this trait, under the normal condition significant and negative GCA effects (-0.25) were exhibited by the line IUB-212, which depicts that this is best general combiner. Whereas the line VH-144 was marked as poor general combiner due to significant and positive GCA effects (0.29). Among testers (male parents), S-12 showed significant lower GCA estimates (-0.09) that was good combiner within the lines whereas IR-3 displayed the highest significant positive GCA effects (0.11) which regarded as poor combiner for this trait.

Under drought condition, NIAB-111 showed significant lower GCA effects (-0.26) which depicted that; this was best combiner for this trait. VH-144 was marked as poor combiner because of maximum GCA estimate (0.25). Among the testers (male parents), S-12 gained highest negative GCA effects (-0.21), while IR-3 was considered as poor general combiner having higher GCA effect (0.21).

Highly significant low SCA estimates (-0.88) were exhibited by the combination FH-113 × IR-3 and these were considered as the most favorable combination for improving fibre fineness under normal condition. While significantly high SCA estimates (0.89) were shown by the cross IUB-212 × FH-1000 which indicates that this was unfavorable combination for this trait. Under drought condition, highly significant low SCA estimates (-0.78) were displayed for the cross VH-144 × CIM-443 followed by AA-802 × IR-3 (-0.72) and FH-113 × IR-3 (-0.64) considered as favorable combinations for this trait (Tab.1.4). While significant and maximum SCA estimates (0.94) were shown for AA-802 × CIM-443 which was indicated as undesirable combination considering the trait (Table 4).

Fiber uniformity: Estimation of GCA effects for fibre uniformity in normal condition revealed that NIAB-111 exhibited the maximum significant positive effect (0.66) followed by IR-3701 (0.48) which was indicated as good general combiners for the trait under discussion (Table 3). Whereas the line AA-802, displayed significant and negative GCA estimates (-0.73) followed by VH-295 (-0.47) which indicated as poor combiners. Among the testers (male parents), CIM-443 exhibited significant and positive GCA estimates (1.34) which indicated as good combining ability with lines followed by S-12 which also showed significant positive GCA estimates (0.93). IR-3 was poor combiner because it exhibited maximum negative GCA effects (-2.85). General combining ability effects for this trait under drought condition showed that maximum significant positive GCA

Table 4. Specific combining ability effects of crosses for various fiber quality traits under normal (N) and drought (D) condition.

Cross	Fiber length		Fiber strength		Fiber fineness		Fiber uniformity	
	SCA(N)	SCA(D)	SCA(N)	SCA(D)	SCA(N)	SCA(D)	SCA(N)	SCA(D)
VH-144 × IR-3	-0.27	-0.51	-1.35**	-0.68	0.31*	0.42**	-0.88*	-1.56**
VH-144 × CIM-443	-0.28	0.59	-1.68**	-1.35**	-0.62**	-0.78**	-1.19**	-0.20
VH-144 × FH-1000	0.32	-1.68	2.79**	2.25**	-0.34**	-0.34**	1.86**	1.93**
VH-144 × MNH-147	0.94**	1.67	3.75**	2.96**	0.33**	0.12	-0.10*	-0.10
VH-144 × S-12	-0.71**	-0.07	-3.50**	-3.19**	0.32*	0.59**	0.31*	-0.07
IUB-212 × IR-3	-0.67**	-0.48	0.60*	0.56	-0.53**	-0.31**	-1.03**	-0.03
IUB-212 × CIM-443	0.26	0.74	0.22	-0.12	-0.11	-0.15	-0.71	-0.13
IUB-212 × FH-1000	0.12	-0.18	1.03**	0.92	0.89**	0.80**	1.57**	0.95**
IUB-212 × MNH-147	-0.83**	-1.35	-4.17**	-3.40**	-0.13	-0.23*	0.04	-0.63*
IUB-212 × S-12	1.11**	1.27	2.32**	2.04**	-0.13	-0.12	0.14	-0.17
MNH-886 × IR-3	-0.58*	-0.87	-0.93**	-1.23**	0.56**	0.65**	0.00	-0.69*
MNH-886 × CIM-443	-0.11	-0.22	-1.57**	1.35**	-0.31*	-0.51**	-0.34	0.36
MNH-886 × FH-1000	-0.90**	-0.81	4.09**	3.00**	-0.10	-0.30**	-1.58**	-1.17**
MNH-886 × MNH-147	1.05**	1.45	0.87**	0.56	0.05	0.40**	0.86*	0.18
MNH-886 × S-12	0.54*	0.45	-2.46**	-3.69**	-0.19	-0.23*	1.05**	1.32**
VH-295 × IR-3	-0.63**	-0.28	2.93**	2.77**	-0.18	0.01	0.68	0.81**
VH-295 × CIM-443	0.21	0.00	1.06**	1.46**	0.68**	0.76**	1.47**	2.06**
VH-295 × FH-1000	0.86**	0.92	-0.71*	-0.72	0.06	-0.13	-0.23	-1.32**
VH-295 × MNH-147	-0.64**	-0.99	-1.74**	-2.12**	-0.25*	-0.25*	-2.59**	-2.27**
VH-295 × S-12	0.20	0.34	-1.54**	-1.39**	-0.31*	-0.39**	0.66	0.73*
IR-3701 × IR-3	1.02**	1.78*	0.18	1.18*	-0.16	-0.53**	0.95*	0.02
IR-3701 × CIM-443	0.34	0.38	0.59*	-0.75	0.62**	0.62**	-0.65**	-0.99**
IR-3701 × FH-1000	-0.81**	-0.82	0.30	0.99*	-0.15	-0.20	-0.12	0.50*
IR-3701 × MNH-147	0.45*	-0.31	-3.31**	-4.29**	-0.28*	0.07	0.16	0.13
IR-3701 × S-12	-0.99**	-1.03	2.24**	2.87**	-0.03	0.04	-0.34	0.34
AA-802 × IR-3	0.51*	1.01	0.20	-1.03*	-0.14	-0.72**	0.74*	0.93**
AA-802 × CIM-443	-0.77**	-1.28	-1.24**	-0.97*	0.82**	0.94**	0.74*	-0.12
AA-802 × FH-1000	-0.01	-0.02	-3.45**	-2.27**	0.11	0.46**	-2.19**	-1.34**
AA-802 × MNH-147	1.09**	1.42	3.47**	3.82**	-0.04	-0.21	-0.47	-1.01**
AA-802 × S-12	-0.82**	-1.13	1.03**	0.44	-0.75**	-0.49**	1.18**	1.54**
NIAB-111 × IR-3	-0.36	0.48	-0.51	0.18	0.48**	0.26*	0.19	-0.28
NIAB-111 × CIM-443	0.53*	0.55	-2.18**	-2.65**	-0.56**	-0.46**	0.33	0.03
NIAB-111 × FH-1000	-1.18**	-0.42	3.23**	2.89**	-0.35**	-0.16*	0.12	0.26
NIAB-111 × MNH-147	0.21	-0.34	-3.06**	-2.64**	0.46**	0.28*	0.64	1.53**
NIAB-111 × S-12	0.80**	-0.27	2.52**	2.23**	-0.02	0.08**	-1.28**	-1.54**
NS-121 × IR-3	1.44**	-1.45	-0.78*	-0.62	0.25*	0.38**	-0.75*	0.69*
NS-121 × CIM-443	-0.51*	0.63	1.21**	0.39	-0.80**	-0.52**	-0.34	-0.86*
NS-121 × FH-1000	0.92**	2.07*	-0.27	-1.16*	0.47**	0.61**	0.95**	0.52
NS-121 × MNH-147	0.92**	2.07*	-0.27	-1.16*	0.47**	0.61**	0.95**	0.52
NS-121 × S-12	-1.53**	-1.29	-0.54*	0.24	0.48**	-0.14	1.40**	1.28**
FH-113 × IR-3	-0.48*	-0.06	0.40	-1.41**	-0.88**	-0.64**	-0.19	-0.12
FH-113 × CIM-443	0.65**	0.93	1.45**	1.86**	0.58**	0.57**	0.68	0.20
FH-113 × FH-1000	-0.63**	-0.95	-4.51**	-3.46**	-0.28*	-0.38**	-0.24	-0.16
FH-113 × MNH-147	0.00	0.14	1.19**	1.21*	-0.24	-0.30**	1.42**	1.91**
FH-113 × S-12	0.46*	-0.05	1.47**	1.80**	0.81	0.75**	-1.68**	-1.83**
FH-142 × IR-3	0.01	0.39	-0.74**	0.27	0.30*	0.49**	0.29	0.22
FH-142 × CIM-443	-0.31	-2.31**	2.15**	0.78	-0.31*	-0.48**	0.00	-0.34
FH-142 × FH-1000	1.30**	1.88*	-2.50**	-2.46**	-0.32*	-0.36**	-0.15	-0.16
FH-142 × MNH-147	-1.95**	-1.74*	2.66**	2.76**	0.52**	0.43**	1.29**	1.87**
FH-142 × S-12	0.95**	1.79*	-1.56**	-1.35**	-0.19	-0.09	-1.43**	-1.60**
S.E	0.21	0.85	0.27	0.47	0.12	0.11	0.36	0.29

Significant = *, highly significant = **

estimates were shown by the line IR-3701 (0.98) that marked as a best general combiner (Table 3). The maximum value of negative GCA estimates was exhibited by VH-295 followed by FH-142 with a value of -0.79 and -0.42, respectively and were considered as bad combiner for this trait. Among testers (male parents), CIM-443 displayed significant and positive GCA estimates (2.13) followed by S-12 (0.65). The genotype, IR-3 displayed maximum significant negative GCA estimate (-2.91) followed by MNH-147 (-0.43) which was indicator of poor combining ability.

SCA effects of various cross combinations for fiber uniformity in normal and drought condition are given in Table 4. The result revealed that 15 crosses out of 50 crosses exhibited significant and positive estimates, 23 crosses displayed significant and negative SCA effect while the remaining crosses presented non-significant results. VH-144 × FH-1000 was considered as best combination due to maximum SCA estimates (1.86) followed by IUB-212 × FH-1000 (1.57). While VH-295 × MNH-147 exhibited the maximum significant negative SCA estimates (-2.59) followed by AA-802 × FH-1000 (-2.19) depicted as poor combinations for the trait. Under drought condition, the highest positive SCA estimates was shown by the combination VH-295 × CIM-443 (2.06) followed by VH-144 × FH-1000 (1.93) showing good combinations while the VH-295 × MNH-147 and FH-113 × S-12 were considered as poor combiners with significant negative SCA estimate (-2.27 and -1.83, respectively) for the trait.

***Genetic components*:** Genetic components for various fibre quality traits under normal and drought stress are presented in Table 2. The variances due to specific combining ability (SCA) were greater for all the fibre quality traits (fibre length, fibre strength, fibre fineness and fibre uniformity) under both normal and drought conditions which indicate the dominant role of non-additive genes action.

DISCUSSION

Cotton productivity is negatively influenced by drought stress like most major agricultural crops. The limited studies are reported for overcoming these types of abiotic stresses which are usually imposed by environmental factor. At the age of technological excellency, it is very important to understand how the stress effect is reduced by implementing different approaches and strategies to improve the productivity level of cotton under water deficit conditions. Among various methods to overcome the drought effect on crop plants, assessing genetic variation under water deficit is very helpful.

Ten drought tolerant and five sensitive genotypes were crossed in glasshouse following line × tester for the development of $50F_0$. For studying the genetics of drought tolerance in upland cotton, $50F_1$ crosses and 15 parents were field planted under two different moisture regime i.e. normal and drought condition. Data were analyzed for fibre length (mm) and fibre strength (g/tex), fibre fineness (µg/inch) and fibre uniformity (%). Data recorded were analyzed by line × tester analysis for studying general and specific combining ability effects. The combining ability analysis is an important tool which helps for the assessment of genotypes potential to combine with each (Olfati *et al*., 2012). Line × tester analysis (Kempthorne, 1957) portioned additive and non-additive variation. The significant results of combining ability effects indicating sufficient amount of variability among the genotypes under normal and drought condition and showed genotypes potential to combine with other ones and produce appropriate results. The parents used in the present study have diverse genetic nature and they were collected from different institutes. Their evolutionary methodology showed significant differences with respect to various fibre quality traits. The hybrids thus produced by these parents depicted a range of desirable and undesirable results.

Variance due to specific combining ability was greater for fibre length, fibre strength, fibre fineness and fibre uniformity showing the dominance of non-additive genes under normal and drought stress. The studies of Shakeel *et al*. (2001) and Neelima *et al*. (2004) seemed to come to an agreement with the present investigation, whilst Karademir *et al.* (2007) and Lukonge *et al.* (2008) found additive type of variation for fibre length and fibre fineness. Under normal condition, the best general combiner were IUB-212, FH-113, IR-3, CIM-443, S-12 and poor were VH-295, MNH-147, FH-1000 and NS-121 while under drought condition, S-12 and IUB-212 were good general combiners whereas MNH-147, IR-3, VH-295 and FH-142 were poor general combiners for most of fibre quality traits. For most of fibre quality traits the best specific combiner were VH-144 × CIM-443 and AA-802 × S-12 under normal condition while under drought condition the best specific combiner were VH-144 × CIM-443 and VH-295 × IR-3. Patel *et al*. (2007) described that some of the cross combinations which showed higher SCA value, it is not necessary that parents have good general combining ability. Comparisons of combinations denoted that VH-295 × IR-3 was good for fibre strength under drought condition and this involved VH-295 with poor general combiner and IR-3 with good general combiner depicting the phenomena of poor × good. The FH-113 and IR-3 were good general combiners but it combined each other in a cross combination FH-113 × IR-3 that showed poor specific combining ability for fibre strength. Certain cases which involved good × good, poor × poor and good × poor parents resulting in hybrids without good performance have been reported for the desired trait (Imran *et al*., 2012; Karademir *et al*., 2007). The variability in the performance of parents and their cross combinations depends on the variances in genetic make-up and the environment which prevailed during the study (Petterson *et al.*, 2006). The crosses between VH-144 × FH-1000, VH-295 × IR-3 and VH-295 × CIM-443 performed better for most of fibre quality traits under drought condition with high specific combining ability effects. Theses crosses can be used in variety development program for drought prone areas of Pakistan. Variance due to specific combining ability was greater for fibre length, fibre strength, fibre fineness and fibre uniformity showing the dominance of non-additive genes under both normal and drought stress. The findings of Shakeel *et al*. 2001 and Neelima *et al*. (2004) are accordingly to the present research, whilst Karademir *et al*. (2007) and Lukonge *et al.* (2008) found additive type of variation for fibre length and fibre fineness. Differences between performance of parents and their cross combinations are demonstrated based on variances in genetic make-up and environmental situations which prevailed during the course of study (Petterson *et al.*, 2006). In the present study, preponderance of non-additive type of gene action for all studied traits indicated the suitability of using this plant material for developing cotton hybrids (Singh and Singh, 1999). Through effective implementation of hybrid cotton, India and China has achieved self-reliant status in the production of cotton (Gao *et al.*, 2016; Nachimuthu *et al.*, 2017). But at present status in Pakistan, research related to hybrid cotton development is at initial stage of development.

Conclusion**:** It is concluded that the crosses VH-144 × FH-1000, VH-295 × IR-3 and VH-295 × CIM-443 can be used in variety development program for drought hit areas of Pakistan as theses crosses showed high specific combining ability effects for fibre traits under drought condition. Furthermore, for all the traits non-additive variation suggests possibility of using this material for hybrid development or variety development in upland cotton.

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