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COMBINING ABILITY ANALYSIS OF YIELD AND FIBER QUALITY TRAITS UNDER NORMAL AND WATER DEFICIT CONDITION IN *GOSSYPIM HIRSUTUM* L.

W. S. Chattha[1*], A. Shakeel[2], T. A. Malik[2], M. F. Saleem[3], H. M. Akram[4], M. Yaseen[5] and M. Naeem[6]

[1]Department of Plant Breeding and Genetics, UCA & ES, Islamia University of Bahawalpur Pakistan; [2]Department of Plant Breeding and Genetics, [3]Department of Agronomy, [5]Department of Mathematics and Statistics, [6]Endowment Fund Secretariat, University of Agriculture Faisalabad-Pakistan; [4]Agronomic Research Institute, Agricultural Research Institute, Faisalabad-Pakistan.
[*]Corresponding author's email: Waqas1518@gmail.com

ABSTRACT

Present investigation was conducted to study the genetic basis of seed cotton yield and fiber quality traits in cotton under normal and water deficit condition. 30F$_1$ crosses along with 13 parents were planted under two stress levels i.e. normal and water-deficit conditions in field. The best general combiners under normal condition were FH-153, FH-159 and FH-207, while FH-207, FH-322 and NS-131 were the best general combiner for seed cotton yield, under water-deficit conditions. For fibre quality traits, VH-291 & NS-131 and S-15 & FH-207 were best general combiners under normal irrigation and water deficit condition, respectively. Variance due to specific combining ability was greater for the traits indicating the dominant role of non-additive genes under normal and water-deficit condition. The best specific combiner for fiber quality traits were FH-159 × KZ-191 and VH-291 × NS-131 under normal irrigation while under water deficit condition the best specific combiners were FH-207 × AA-703 and VH-291 × NS-131. Under normal condition the crosses FH-153 × NS-131, FH-159 × KZ-191, IR-6 × KZ-191, S-15 × NS-131 and VH-289 × AA-703 were the best specific combiner for seed cotton yield and the crosses FH-207 × KZ-191, MNH-886 × AA-703 and S-15 × NS-131 showed high specific combining ability effects for seed cotton yield under water-deficit condition. These crosses might be used in variety development program for water deficit areas of Pakistan. Non additive variation for all the traits suggests possibility of using this material for hybrid development in cotton.

Keywords: Combining ability, Line × tester analysis and seed cotton yield.

INTRODUCTION

Cotton crop is a major source of fibre in the world as well as in Pakistan. Pakistan ranks 4th among cotton producing countries of the world (Anonymous, 2018). But, in current situation, cotton productivity is fluctuating substantively due to abiotic and biotic stresses. Among the abiotic stresses, water deficit stress is considered as the most significant factor that limits the seed cotton yield (Haq *et al.*, 2017). Response of plants to water-deficit condition depends upon intensity and time-span of the stress (Cattivelli *et al.*, 2008). Onset of water-deficit stress, photosynthetic activity and growth of the plant is hindered, while flower and fruit shedding is increased. These phenomenon resulted in noticeable reduction in cotton yield (Alisha and Ahmadikhah, 2009). If water deficiency occurs during fiber elongation and post fiber elongation stages of the cotton, this resulted in decrease in fiber length and micronaire value, respectively (Malik *et al*., 2006).

An understanding of plant response to drought stress is required for the development of drought tolerance cultivars. In this respect, an efficient selection plan conferring drought tolerant traits must be accompanied. The breeding value of traits is increased if that are controlled by additive component which indicate the response of a breeding population toward selection (Iqbal *et al.*, 2010).

Drought tolerance in plants is a genetically controlled mechanism that is associated with many physiological and agronomic features of plants (Singh and Singh, 2004). Cotton plant possessed good attributes for tolerance against drought, since it has properly developed root system and has a capability to withstand against the temporary wilting of plant. But plant yield is seriously affected, when water deficiency occurs during the reproductive stage of the plant (Selote and Chopra, 2004). Rapidly changing climatic conditions exerted unfavourable effects on the adaptability of crop varieties that were developed by plant breeders during last few years for a specific agro ecological zone. Unpredictable distribution of rainfall around the globe has become more uncertain for crop plants. It is need of the time not only to identify the genotypes with unique characters from existing germplasm but also to develop new varieties which can cope against drought, by initiating new breeding programs.

Keeping in view the current climatic change scenario the present study was planned to find out the genetic variation present in cotton genotypes against water-deficit condition and to examine the genetics of agronomic and fiber quality traits for water deficit tolerance in upland cotton.

MATERIALS AND METHODS

Three sensitive and ten tolerant parents were planted in earthen pots under greenhouse condition during November, 2014. When the genotypes reached at flowering stage, they were crossed in line × tester fashion (10 × 3). For crossing, unopened flowers, known as buds, were selected in the evening for emasculation. The petals of the selected buds were removed by giving a circumcision around the floral bud near the base. The stamens were removed gently with the help of forceps and stigma was covered with soda straw tubes plugged with cotton lint from upper opened end. Flowers to be used as male parents were also covered with glassine bags in the evening. In the following morning, the emasculated flowers were pollinated by transferring pollen grains from the desired male parent and recovered by the respective soda straw tubes. Intensive crossing attempts were made to develop a reasonable quantity of F_0 seed. Some of the buds were also covered with glassine bags to produce selfed seed. At maturity the selfed and crossed bolls were picked, ginned and seed was stored in small paper bags.

In order to investigate the genetics of water-deficit tolerance, 30F_1 hybrids along with 13 parents were planted under two moisture levels i.e. control and water-deficit stress during March, 2015. The experiment was layed out in split plot arrangement under randomized complete block design. Moisture levels were kept in main plot and F_1 crosses along with their parents in subplot. In each replication there was one row for each genotype. Row to row and plant to plant distance were 75 cm and 30 cm, respectively. There were ten plants in a row. The distance between stress and non-stress plot was 100 cm while between different replications of a plot were 90 cm. All recommended production practices and plant protection measures were practised. The water deficit stress was imposed to water deficit plot by skipping irrigation water. The total irrigation water applied to well water and water-deficit condition was 22 acre inches and 12 acre inches respectively while precipitation received was 15.34 inches in the form of rain. Water deficit stress was observed by phenotypic appearance of the crop.

The mature bolls were picked at three different picks and seed cotton was collected in paper bags separately for all the plants in all three replications. Picking was done after evaporation of dew. The harvest was weighed on electronic balance. The fiber characteristics like staple length (mm), fiber fineness (ug/inch) and fiber strength (g/tex) were also measured using the fibro graph HVI-900.

Statistical Analysis: Line × tester analysis as suggested by Kempthorne (1957) provides information about the estimates of combining ability of parents and crosses which is pre-requisite for genotypes to be used as parents in hybrid development program.

The data on various traits were subjected to the analysis of variance as per design used and tested the significance of

General combining ability (GCA) effects for lines and testers were calculated as

GCA effects of lines: gi = {(xi.. / tr) – (x…/ltr)}

GCA effects of testers: gt = {(x.j./lr) – (x…/ltr)}

Where;

l = No. of lines (female parents).

t = No. of testers (male parents).

r = No. of replications.

xi.. = Total of the F_1 resulting from crossing the ith line with all the testers.

x.j. = Total of all the crosses of jth testers with all the lines.

x… = Total of all the crosses.

Specific combining ability (GCA) effects for crosses were calculated as

Sij = {(xij./r) – (xi../tr) – (x.j./lr) + (x…/ltr)

Where;

Xij. = Total of F_1 resulting from crossing ith lines with jth testers.

Standard error were calculated as

$$\text{S.E. (GCA for lines)} = \sqrt{\text{M.S.E}/r \times t}$$

$$\text{S.E. (GCA for testers)} = \sqrt{\text{M.S.E}/r \times l}$$

$$\text{S.E. (SCA)} = \sqrt{\text{M.S.E}/r}$$

RESULTS

Detailed analysis of variance following line × tester analysis for each trait was performed under normal and water-deficit condition separately and mean squares are given in Table 1. Under normal condition all the traits were differed significantly except fiber fineness for testers and staple length for lines while under water deficit condition staple length for testers. General and specific combining ability effects under normal irrigation and water-deficit stress were calculated in accordance with the model and procedure as outlined in materials and methods. Results of general combining ability effects are presented in Tables 3. While, effects due to specific combining ability for seed cotton yield, staple length, fiber fineness and fiber strength are presented in Table 4. Genetic components of variation under normal and water-deficit condition are presented in Table 2.

Positive general combining ability effects are more important for seed cotton yield, which is the main objective for any breeding program. A significant positive general combining ability estimate were found in FH-153(9.65), FH-159 (9.27), FH-207 (7.51) and FH-322

(5.87) while under water deficit condition the lines, FH-153 (1.64), FH-159 (2.08), S-15 (0.79), S-15 (0.79), VH-289 (0.45), FH-207 (3.16) and FH-322 (5.71) showed significant positive general combining ability estimates. Among testers KZ-191 (2.17) and NS-131 (3.72) showed positive significant estimates under normal and water deficit conditions respectively (Table 3). Parents showing positive and non-significant general combining effects are undesirable for seed cotton yield. Similarly, parents showing significant or non-significant but negative general combining ability estimates are also not favorable. While studying combinations under normal irrigation condition the crosses like FH-153 × NS-131 (12.22), FH-159 × KZ-191 (6.13) and FH-322 × NS-131 (7.66) and IR-6 × KZ-191 (8.44), S-15 × NS-131 (5.94) and VH-289 × AA-703 (6.65) showed positive and significant SCA effects for seed cotton yield while the crosses S-15 x NS-131 (13.69), MNH-886 × AA-703 (10.32), FH-322 × NS-131 (7.89), FH-207 × KZ-191 (6.34) FH-329 × AA-703 (6.19), FH-153 × KZ-191 (4.59) , FH-159 × KZ-191 (3.94), , VH-291 × AA-703 (5.31), FH-159 × NS-131 (2.87), S-15 × AA-703 (3.69) and IR-6 × KZ-191 (3.45) showed significant positive estimates under water deficit stress condition. Positive, negative and significant negative specific combining ability estimates were found in the remaining crosses which were undesirable for seed cotton yield (Table 4).

For staple length, positive general combining ability effects are desirable. Among female parents, FH-153 (0.36) and VH-291 (0.46) while among male parents NS-131 (0.42) showed positive significant desirable estimates under normal irrigation condition. While under water deficit condition male parent FH-207 (0.69) showed significant positive estimates (Table 3). The results regarding specific combining ability effects showed that under normal irrigation condition the hybrids, FH-159 × KZ-191 (0.35), FH-329 × AA-703 (0.56) and VH-291 × NS-131 (0.73) showed positive and significant SCA effects under normal irrigation condition for staple and under water deficit conditions the crosses FH-207 × AA-703 (1.07) VH-291 × NS-131 (0.75) and S-15 × KZ-191 (0.61) showed significant positive estimates. Though some of the crosses showed positive and negative estimates in both conditions but were non-significant and undesirable in case of proline contents (Table 4).

Among female parents, the FH-159 (0.09), FH-207 (0.12), FH-329 (0.09), MNH-886 (0.13) and VH-291 (0.06) showed positive significant desirable estimates under normal irrigation condition for fiber fineness and none of the male parent showed significant results. While under water deficit condition the female parents FH-159 (0.15), FH-322 (0.12), VH-291 (0.22), S-15 (0.11) and VH-289 (0.07) showed significant positive estimate and among male parents KZ-191 (0.08) and AA-703 (0.06) showed positive significant desirable estimates (Table 3). For Specific combining ability effects under normal irrigation condition the hybrids FH-159 × KZ-191 (0.27), FH-207 × AA-703 (0.18) FH-322 × NS-131 (0.14), FH-329 × AA-703 (0.23), MNH-886 × NS-131 (0.2), IR-6 × NS-131 (0.12), VH-291 × NS-131 (0.15), S-15 × KZ-191 (0.2), VH-289 × KZ-191 (0.21) showed positive and significant SCA effects for fiber fineness and under water deficit condition the crosses FH-159 × KZ-191 (0.06), FH-153 × NS-131 (0.22), FH-159 × KZ-191 (0.21), FH-159 × AA-703 (0.25) FH-207 × KZ-191 (0.26), FH-322 × AA-703 (0.24), FH-329 × AA-703 (0.39), MNH-886 × AA-703 (0.37), IR-6 × KZ-191 (0.14), VH-291 × NS-131 (0.38), S-15 × KZ-191 (0.28) showed VH-289 × NS-131 (0.21) showed significant positive estimates. However, some of the crosses showed positive and negative estimates in both conditions but were non-significant and undesirable in case of fiber fineness (Table 4).

For fiber strength, positive general combining ability effects are desirable. Among lines MNH-886 (0.28), VH-291 (0.65) and S-15 (0.51) showed positive significant desirable estimates under normal irrigation condition and among male parents NS-131 (0.7) showed positive significant desirable estimates (Table 3). Under water deficit condition among female parents, S-15 (0.59) only showed significant positive estimate and among male parents only NS-131 (0.52) showed positive significant desirable estimates. Specific combining ability effects under normal irrigation condition showed that hybrids, FH-159 × KZ-191 (0.68), FH-207 × AA-703 (1.45) FH-322 × KZ-191 (1.55), MNH-886 × KZ-191 (1.65), VH-291 × KZ-191 (1.18), S-15 × NS-131 (3.43), VH-289 × AA-703 (0.8) showed positive and significant SCA effects for fiber strength and for water deficit conditions crosses, FH-207 × AA-703 (1.95) FH-329 × KZ-191 (1.15), MNH-886 × KZ-191 (1.8), S-15 × NS-131 (2.79) showed significant positive estimates. While the remaining crosses showed positive and negative estimates in both conditions but were non-significant and undesirable in case of fiber strength (Table 4).

Genetic components computed for various traits measured under normal and water-deficit condition are given in the Table 2. The variance due to specific combining ability is greater for seed cotton yield, staple length fiber strength and fiber fineness under both conditions indicating the dominant role of non-additive genes action.

Table 1. Mean square values of line × tester analysis for various traits under normal irrigation and water-deficit condition.

SOV	DF	Normal Irrigation				Water-deficit Condition			
		SCY	FF	SL	FS	SCY	FF	SL	FS
Rep.	2	447.26**	0.87**	5.54**	122.43**	48.09**	1.79**	11.18**	50.13**
Gen.	42	366.24**	0.12**	2.08**	4.70**	456.23**	0.25**	2.14**	4.43**
Cross	29	363.01**	0.13**	0.83**	5.54**	179.30**	0.27**	0.81**	4.45**
Line	9	781.63**	0.14**	1.03	1.18**	222.70**	0.20**	0.98*	1.89*
Tester	2	207.91**	0.01	2.36**	12.15**	343.07**	0.44**	0.02	7.46**
L × T	18	170.94**	0.13**	0.56**	6.99**	139.4**	0.28**	0.81*	5.40**
Parent	12	298.72**	0.12**	2.04**	2.84**	820.99**	0.23**	1.61**	4.04**
Cross vs Par	1	1270.24**	0.07**	39.**	2.52**	4109.79**	0.13**	47.39*	8.34**

df = degree of freedom, Rep = replications, Gen = genotypes, SCY = seed cotton yield, FF = fiber fineness, SL = staple length and FS = fiber strength

Table 2. Estimation of genetic components of variation under normal and water-deficit condition.

Traits	Normal Irrigation		Water-deficit condition	
	∂ GCA	**∂ SCA**	**∂ GCA**	**∂ SCA**
SCY	3.5913	51.0387	0.7459	44.5273
FF	-0.0001	0.0423	-0.0003	0.0934
SL	0.0051	0.1566	0	0.1782
FS	-0.027	2.2792	-0.0178	1.5443

∂ GCA = Estimate of GCA variance, **∂ SCA** = Estimate of SCA variance, SCY = seed cotton yield, FF = fiber fineness, SL = staple length and FS = fiber strength

Table 3. Estimation of general combining ability effects for various traits under normal irrigation and water deficit condition.

	Normal irrigation				Water-deficit Condition			
Genotype	**SCY**	**FF**	**SL**	**FS**	**SCY**	**FF**	**SL**	**FS**
FH-153	9.65**	-0.22**	0.36**	0.02	1.64*	-0.17**	0.01	0.09
FH-159	9.27**	0.09**	-0.09	-0.25	2.08*	0.15**	-0.29	0.06
FH-207	7.51**	0.12**	-0.17	-0.32*	3.16**	-0.12**	0.69**	-0.41
FH-322	5.87**	-0.09**	-0.11	-0.21	5.71**	0.12**	0.03	-0.95**
FH-329	2.42	0.09**	-0.04	-0.12	-1.73*	-0.08**	-0.03	0.02
MNH-886	3.89**	0.13**	-0.53**	0.28*	-7.83**	-0.07**	-0.5**	0.24
IR-6	-7.08**	-0.15**	-0.41**	-0.42**	-7.4**	-0.2**	-0.25	-0.37
VH-291	-17.94**	0.06*	0.46**	0.65**	-1.47	0.22**	0.04	0.36
S-15	-10.44**	-0.09**	0.42**	0.51**	7.09**	0.11**	0.3	0.59*
VH-289	-3.16*	0.05	0.11	-0.14	-1.25	0.07**	-0.02	0.37
S.E	1.38	0.029	0.099	0.13	0.76	0.016	0.174	0.293
KZ-191	2.17**	0.02	-0.03	-0.55**	-0.82	0.08**	0.01	-0.47**
AA-703	-2.93**	0	-0.27**	-0.15*	-2.9**	0.06*	-0.03	-0.04
NS-131	0.76	-0.02	0.29**	0.7**	3.72**	-0.14**	0.02	0.52**
S.E	0.75	0.016	0.054	0.07	0.42	0.009	0.095	0.16

SCY = seed cotton yield, FF = fiber fineness, SL = staple length and FS = fiber strength

DISCUSSION

Like most major agricultural crops, cotton production and productivity is negatively influenced by water-deficit stress. The research work with respect to the possibilities of overcoming stresses or limitations imposed by environmental factor is limited. It is important at this juncture to see and understand how best the stress effect can be minimized by adopting different strategies and to elucidate the impact of such strategies in enhancing productivity potential of cotton under water limited conditions. Among different approaches to overcome the impacts of water deficit stress on crop plants, the assessment of natural genetic variation against drought stress is much helpful.

Table 4. Specific combining ability effects of crosses for seed cotton yield under normal irrigation (N) and water-deficit (D) condition.

Trait	Seed cotton yield		Staple length		Fiber fineness		Fiber strength	
CROSS	**SCA (N)**	**SCA (D)**	**SCA (N)**	**SCA (D)**	**SCA (N)**	**SCA (D)**	**SCA (N)**	**SCA (D)**
FH-153 x KZ-191	-1.81	4.59**	0.26	0.22	0	0.06*	0.21	0.36
FH-153 x AA-703	-10.41**	-3.1*	0.34	0.16	0.06	-0.28**	-0.38	-0.55
FH-153 x NS-131	12.22**	-1.49	-0.6**	-0.39	-0.06	0.22**	0.17	0.19
FH-159 x KZ-191	6.13*	3.94**	0.35*	0.25	0.27**	0.21**	0.68**	0.82
FH-159 x AA-703	-1.46	-1.07	-0.07	-0.07	-0.04	0.25**	0.18	-0.28
FH-159 x NS-131	-4.67	-2.87*	-0.27	-0.18	-0.23**	-0.46**	-0.87**	-0.54
FH-207 x KZ-191	-4.34	6.34**	-0.33	-0.65*	-0.04	0.26**	-1.55**	-1.15*
FH-207 x AA-703	-0.14	-5.48**	0.17	1.07**	0.18**	-0.27**	1.45**	1.95**
FH-207 x NS-131	4.49	0.87	0.16	-0.42	-0.14**	0.01	0.1	-0.81
FH-322 x KZ-191	1.36	-3.12*	-0.4*	0.15	0.06	0.01	1.55**	-0.67
FH-322 x AA-703	-9.01**	-4.77**	0.17	-0.22	-0.2**	0.24**	-1.45**	0.07
FH-322 x NS-131	7.66**	7.89**	0.23	0.07	0.14**	-0.25**	-0.1	0.6
FH-329 x KZ-191	2.92	-0.71	-0.07	0.48	-0.29**	-0.32**	0.15	1.15*
FH-329 x AA-703	-0.42	6.19**	0.56**	-0.28	0.23**	0.39**	-0.25	-0.61
FH-329 x NS-131	-2.5	-5.48**	-0.49**	-0.21	0.06	-0.07*	0.1	-0.54
MNH-886 x KZ-191	-4.19	-5.93**	0.15	0.11	-0.26**	-0.28**	1.65**	1.8**
MNH-886 x AA-703	4.26	10.32**	0.16	0.06	0.06	0.37**	0.35	-0.32
MNH-886 x NS-131	-0.07	-4.39**	-0.3	-0.17	0.2**	-0.09**	-2**	-1.49**
IR-6 x KZ-191	8.44**	3.45*	-0.16	-0.28	-0.17**	0.14**	-0.35	0.55
IR-6 x AA-703	4.14	-3.43*	-0.03	0.01	0.06	-0.19**	0.15	-0.28
IR-6 x NS-131	-12.58**	-0.02	0.19	0.27	0.12*	0.05	0.2	-0.28
VH-291 x KZ-191	-0.3	-0.44	-0.14	-0.54	-0.09	-0.2**	1.18**	0.45
VH-291 x AA-703	4.29	5.31**	-0.59**	-0.21	-0.06	-0.18**	0.28	0.26
VH-291 x NS-131	-3.99	-4.87**	0.73**	0.75*	0.15**	0.38**	-1.47**	-0.71
S-15 x KZ-191	-8.04**	-10**	0.3	0.61*	0.2**	0.28**	-2.29**	-1.8**
S-15 x AA-703	2.09	3.69**	-0.59**	-0.8**	-0.16**	-0.29**	-1.15**	-1
S-15 x NS-131	5.94*	13.69**	0.28	0.19	-0.04	0.01	3.43**	2.79**
VH-289 x KZ-191	-0.15	1.88	0.05	-0.36	0.32**	-0.15**	-1.23**	-1.53**
VH-289 x AA-703	6.65**	-0.28	-0.11	0.27	-0.12*	-0.06*	0.8**	0.74
VH-289 x NS-131	-6.5**	-1.59	0.06	0.09	-0.2**	0.21**	0.42	0.78
S.E	**2.39**	**1.32**	**0.17**	**0.302**	**0.052**	**0.028**	**0.225**	**0.507**

Variance due to specific combining ability was greater for seed cotton yield, staple length, fiber fineness and fiber strength indicating the dominant role of non-additive genes under normal and water-deficit condition. Lukonge *et al.* (2008) reported additive variation for fiber length and fineness. Under normal condition, the best general combiners were FH-153, FH-159, FH-207, FH-322 and KZ-191, while S-15, VH-289, VH-291 and AA-703 were poor general combiners for seed cotton yield. The VH-291 and NS-131 were best combiner and IR-6 and AA-703 were the poor combiner. Under normal condition while under water deficit condition the FH-207, FH-322 and NS-131 were the best general combiners for fiber traits. Considering the fiber traits the best general combiners were S-15 and NS-131. For fiber traits the best specific combiner were FH-159 x KZ-191 and VH-291 x NS-131 under normal irrigation while under water deficit condition the best specific combiner were FH-207 x AA-703 and VH-291 x NS-131. Comparisons of combinations showed that FH-322 × NS-131 was best for seed cotton yield under water deficit condition and this involved both FH-322 and NS-131 with good general combiner depicting the phenomena of good × good. The MNH-886 and AA-703 were poor general combiners but it combined each other in a cross combination MNH-886 × AA-703 that showed best specific combining ability for seed cotton yield. A plenty of cases have been reported involving good × good, good × poor and poor × poor parents resulting in hybrids without standing performance for the trait of interest (Imran *et al*., 2015). Variation in performance of parents and hybrids could be justified on the basis of differences in genetic make-up and environmental conditions prevailing during the study (Pettersen *et al.,* 2006). The crosses FH-207 x KZ-191, MNH-886 x AA-703 and S-15 x NS-131 performed better for seed cotton yield under drought condition with high specific combining ability effects. Theses crosses can be used in variety development program for water deficit areas of Pakistan. Variance due to specific combining ability was greater for seed cotton yield, staple length, fiber fineness and fiber strength indicating the dominant role of non-additive genes under normal and water-deficit condition. Silva and Alves (1983) studied gene action in cotton (*G. hirsutum* L.) and reported that for number of bolls per plant, seed cotton yield and boll weight non-additive gene action was predominant, while dominance affected bolls per plant to a minor extent.Variation in performance of parents and hybrids could be justified on the basis of differences in genetic make-up and environmental conditions prevailing during the study (Pettersen *et al.,* 2006). Significant of non-additive gene action for all the traits revealed the possibility of using such plant material for the development of hybrids (Singh and Singh, 1999). India and China has attained self-sufficiently in cotton production through successful adoption of hybrid cotton (Gao *et al.,* 2016). But at present cotton hybrid development research is at early stage of development in Pakistan.

Conclusions: The crosses FH-207 x KZ-191, MNH-886 x AA-703 and S-15 x NS-131 can be used in variety development program for drought hit areas of Pakistan as theses crosses showed high specific combining ability effects for seed cotton yield under water-deficit condition. Furthermore, non-additive variation for all the traits suggests possibility of using this material for hybrid development or variety development in upland cotton

REFERENCES

Alishah O. and A. Ahmadikhah. (2009). The effects of drought stress on improved cotton varieties in Golesatn Province of Iran. Int. J. Plant Prod. 3: 17-26.

Cattivelli, L., F. Rizza, F.W. Badeck, E. Mazzucotelli, A.M. Mastrangelo, E. Francia, C. Mare, A. Tondelli and A.M. Stanca. (2008). Drought tolerance improvement in crop plants: An integrative view from breeding to genomics. Field Crops Res. 105: 1–14.

Gao, Q., J. Hu, R. Li, L. Pang, Z. Xing, L. Xu and G. Wu. (2016). Preparation and characterization of super hydrophobic organic-inorganic hybrid cotton fabrics via γ-radiation-induced graft polymerization. Carbohydr. Polym. 149: 308-316.

Haq, A.U., N.U. Khan, H. Raza, S. Gul, S. Akbar, S.U. Khan, S. Muhammad, M. Ali, H. Khan and S.M. Khan. (2017). Genetic attributes of F_3 populations and their parental lines in upland cotton. The J. Anim. Plant Sci. 27(2): 655-666.

Imran, M., S.A. Saif-ul-Malook. M.A. Nawaz, M.K. Ahabaz, M. Asif and Q. Ali. (2015). Combining ability analysis for yield related traits in sunflower (*Helianthus annuus* L.). Am. Eurasian J. Agric. Environ. Sci. 15(3): 424-436.

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.

Kempthorne, O. (1957). An introduction to genetics statistics. John Wiley and Sons; London.

Lukonge, E.P., M.T. Labuschagne and L. Herselman. (2008). Combining ability for yield and fiber characteristics in Tanzanian cotton germplasm. Euphytica. 161(3): 383-389.

Malik, T.A. and S. Malik. (2006). Genetic linkage studies of drought tolerant and agronomic traits in cotton. Pakistan J. Bot. 38 (5): 1613-1619.

Pettersen, R., L. Mortensen, R. Moe and H. Gislerod. (2006). Air humidity control essential for rose production under continuous lighting. Acta Hort. 711: 323–331.

Selote, D.S. and R. Khanna-Chopra. 2004. Drought-induced spikelet sterility is associated with an inefficient antioxidant defence in rice panicles. Physiol. Plant. 121(3): 462-471.

Silva, F.P.D.A. and J.F. Alves. (1983). Estimation of epistatic, additive and dominance variation in cotton (*G. hirsutum* L.) race latifolium Hutch. Rev. Brasileria Genet. 6: 491–503.

Singh, S. B. and D. Singh. 2004. Genetic analysis of morph-physiological parameters in cotton (*Gossypium hirsutum* L.). Indian J. Genet. & Pl. Br. 61(1): 57-60.

Singh, P. and S. Singh. (1999). Heterosis breeding in cotton. Kalyani Publishers; New Delhi. Anonymous (2018). Pakistan Economic Survey (2017-18). Pakistan Bureau of Statistics. Ministry of Finance, Government of Pakistan.