The Journal of Animal & Plant Sciences, 26(1): 2016, Page: 156-162
ISSN: 1018-7081

COMBINING ABILITY ANALYSIS AND HETEROTIC STUDIES FOR WITHIN-BOLL YIELD COMPONENTS AND FIBRE QUALITY IN COTTON

I. Ali[1], A. Shakeel[1], A. Saeed[1], W. Nazeer[2,3], Z. U. Zia[3], S. Ahmad[3], K. Mahmood[3]and W. Malik[4]

[1]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad.
[2]Department of Plant Breeding and Genetics, Muhammad Nawaz Shareef University of Agriculture, Multan.
[3]Cotton Research Station, Multan.
[4]Department of Plant Breeding and Genetics, Faculty of Agricultural Science and Technology, BahauddinZakariya University, Multan.
Corresponding author's email: imtiaz.malghani@gmail.com

ABSTRACT

Combining ability and heterosis for within-boll yield components and fibre quality traits were carried out using line × tester mating system in upland cotton at the University of Agriculture, Faisalabad, Pakistan.Variance due to specific combining ability was greater than general combining ability for all the traits depicting the importance of non-additive genetic effects.The line BH-89 was found to be good general combiner for lint mass per boll, seed volume per 100 seeds, surface area per seed and lint percentage. NIAB-999 was good general combiner for fibre fineness. The third line which was actually the F_1 of the first two lines performed better regardingseed number per boll, seed mass per bolland fibre strength.Among testers, NIAB-78 exhibited higher GCA effects for seed number per boll, lint mass per boll and fibre fineness while CIM-1100 proved to be good general combiner for seed volume per 100-seeds, surface area per seed and lint percentage. NIAB-999 × VH-144 exhibited the highest SCA effects regarding seeds per boll and seed mass per boll while the cross NIAB-999 × CIM-70 was considered desirable for seed volume per 100-seeds and surface area per seed. Maximum heterosis over better parent for lint mass per boll and lint percentage was observed for the cross BH-89 × NIAB-78 while for seed volume per 100-seeds and surface area per seed, NIAB-999 × CIM-240 was the best.

Key words: Genetics, cotton, within-boll yield components, fibre quality.

INTRODUCTION

Cotton is an important cash crop which is mainly grown for its fibre in more than 65 countries of the world. *Gossypiumhirsutum* L., a domesticated tetraploid species, among the cultivated species of cotton accounts for more than 80% of the global cotton production (Shakeel *et al*., 2008). Pakistan is the 4th major cotton producing and 5th major cotton consuming country worldwide, however cotton productivity on per hectare basis is low i.e. 769 kg ha^{-1} (Pakistan Economic Survey 2012-13) as compared to Australia (1669 kg ha^{-1}), China (1275 kg ha^{-1}) and other leading cotton producing countries (USDA, FAO. 2013).

Tremendous efforts have been made by plant breeders to increase cotton productivity but focus remained on direct selection for number of bolls on unit land area and boll size for decades. Boll weight depends upon many within-boll yield contributing traits e.g. number, weight and volume of seeds, lint mass per boll and per seed, fibre length and number of fibres per unit seed surface area etc. A little selection has been made for these basic traits mainly because of the difficulty of their measurement (Ali *et al*., 2015).

Within-boll yield components are the most basic determinants of seed cotton and/or lint yield in cotton (Worley *et al.*, 1974). The number of bolls on unit land area played primary, lint mass produced by individual seed as secondary and seed number per boll as tertiary roll in total contribution to lint yield (Worley *et al.*, 1974). Culp and Harrell (1975) reported that increased lint yield resulted by increasing seed number per boll, which increased the seed surface area for greater lint production. Green and Culp (1990) determined significant general combining ability (GCA) for fibre length, uniformity, strength, yield and lint percentage which suggested early generation selection to improve these traits. Good (GCA) effects for upper half mean length, micronaire value, maturity and strength of fibre while negative GCA variances were observed for the most basic boll related yield components in the same genetic material (Coyle and Smith, 1997). Negative correlation of fibre length and strength with seed surface area, number of spinnable fibres per unit seed surface area, seed number per boll, lint percentage and other boll related traits was found (Smith and Coyle 1997).

Plant density modifications might have strong influence on within-boll yield components (Bednarz *et al*., 2006). They documented that plant density exhibited direct relation with total seed surface area per unit of land area but inverse relation with lint mass per boll, individual seed mass and seed number per boll.Bednarz*et al*. (2007) determined within-boll lint and seed parameters and fibre quality characters. They observed that the genotypes which had less seed size, produced more seed surface area but low lint mass and fibre number and vice versa. Seed size was the determinant of lint weight and number of fibres on unit seed surface area (Bednarz *et al*., 2007).

Higher estimates of SCA than GCA depicted the predominance of non-additive gene action for all traits except for fibre length, fibre strength and seed number per boll, which were additively controlled (Basal *et al*., 2009). Lint properties were negatively correlated with the most basic within-boll lint yield components (Basal *et al*., 2009). Tang and Xiao (2013) revealed that both additive and dominance effects were found to be significant for all traits except seed mass per seed for which only dominant component was significant. Lint mass per seed, seed mass per seed and boll bur weight were primarily controlled by additive type of gene action. Lint mass per boll and seed number per boll exhibited dominance genetic effects (Tang and Xiao, 2013).

Keeping in view the key role of within-boll yield traits in the final seed cotton yield and fibre quality, the current study was carried out to analyze some local genotypes with respect to involved genetic mechanism, combining ability effects and heterotic potential of parental genotypes and their crosses for within-boll yield components and fibre quality traits.

MATERIALS AND METHODS

The research work was conducted at the University of Agriculture, Faisalabad. Three lines,NIAB-999, BH-89 and their F_1 (NIAB-999 × BH-89)were crossed to ten testers namely CIM-70, Russian, CIM-496, CIM-1100, Reshmi-90, FH-634, S-12, NIAB-78, CIM-240 and VH-144.Genotypes used as lines and testers originated from different breeding stations, methodology of evolution and possessed distinguishing characters with respect to plant morphology, seed cotton yield and fiber quality traits. The resulting line × tester progeny along with the parents were grown in field in three replicates using randomized complete block design. All the standard practices were followed during the entire crop duration. At maturity total bolls were counted, picked and weighed from each of the five tagged plants in each plot. A sample of five bolls was drawn from each of the five tagged plants from various locations i.e. basal, middle and top portion, pooled for each plot and ginned to measure within-boll yield components by ontogenetic yield model of Worley *et al*. (1976) and reported also by Coyle and Smith (1997). These were as follows:

Seed number per boll (S/B) = (Number of seeds in the sample/number of bolls).

Seed mass per boll (SM/B) =(Seed weight of the sample/number of bolls).

Lint mass per boll (LM/B)= (lint weight of the sample/number of bolls).

Seed volume per 100 seeds = Measured by alcohol displacement method.

Surface area per seed (SA/S) =Seed volume was converted to SA/S by Hodson's (1920) table.

Alcohol displacement method: Seed volume was determined by alcohol displacement method. Alcohol is used due to low specific gravity and the seed dries out rapidly. For this purpose 50 ml ethanol was taken in a graduated cylinder and a seed sample of 100 seeds was added to it. Total volume of ethanol and seeds was read directly from cylinder. Volume of 100 seeds was calculated by subtracting the volume of ethanol from total volume and expressed in cm^3.

A ginned sample (10g) of each genotype from each replicate was used to measure the fibre quality parameters on HVI in fibre technology lab, University of Agriculture, Faisalabad. The data of various within-boll yield components and fibre quality traits were subjected to line × tester analysis as suggested by Kempthorne (1957) to estimate the general combining ability effects of parents and specific combining ability effects of crosses and their respective variances for various traits. Performance of crosses as compared to their respective better parents was also calculated to estimate the heterotic potential of studied genotypes regarding within-boll yield components and fibre quality traits.

RESULTS AND DISCUSSION

Line × tester analysis revealed highly significant differences ($p \geq 0.01$) among the genotypes (Table 1). A great deal of variability with respect to within-boll yield components was previously reported by Imran *et al.* (2012) and Tang and Xiao (2013). Expression of considerable variability may be attributed to the broad genetic base of the genotypes used to develop the progeny (Ali *et al.*, 2015). Some contrasting results were documented by Rahman *et al.* (2005) who reported low genetic variability for seed physical trait. The contrary situation may be attributed to differences in the genetic back ground of genotypes under study. Male and female parents were originated at different breeding institutes and method of evolution which resulted in valuable diversity for within-boll yield components for selection. Line × tester interaction was also found to be significant for all the characters. Both GCA and SCA variances were significant for almost all the traits except for seed number per boll, fibre length and fibre strength for which the GCA variances were negative. Coyle and Smith (1997) also reported negative GCA variances for basic within-boll yield components. Importance of additive as well as non-additive genetic components in the inheritance of various within-boll traits is evident in earlier studies documented by Neelima *et al.* (2004), Kiani *et al.* (2007), Pareetha and Raveendren (2008) and Pole *et al.* (2008).The variance due to SCA was higher than variance due to GCA for all the traits indicating the prevalence of non-additive genetic effects in the inheritance of these traits. These results are in line with Tang and Xiao (2013) and Ali *et al.* (2015). Dominance variance (D) was found to be much higher than the additive (A) one. Major role of the genes behaving dominantly in the inheritance of various traits related to seed cotton yield per boll was previously supported by Basal and Turgut (2005), Rahman *et al.* (2005), Basal *et al.*(2009)and Imran *et al.* (2012). Presence of dominant component of genetic variation as a key factor strongly favors the heterosis breeding (Ahuja and Dhayal, 2007) or late generation selection (Imran *et al.*, 2012) for improvement of these characters.

The female parent, BH-89 exhibited the highest GCA effects for the traits like lint mass per boll, seed volume per 100-seeds, surface area per seed and lint percentage which indicated that this line, being good general combiner, can be used as donor parent for desirable genes regarding the mentioned traits (Khan *et al*., 2009). While for seed number per boll, seed mass per boll and fibre strength, the third line (NIAB-999 × BH-89) was found to be good general combiner. None of the female parents revealed significant GCA effects for fibre length while NIAB-999 showed the most desirable GCA effects fibre fineness as for fineness lower value is preferred (Table 2). Among male parents NIAB-78 showed the highest GCA effects for seed number per boll, lint mass per boll and fibre fineness. The other tester CIM-1100 presented higher estimates of GCA effects for seed volume per 100-seeds, surface area per seed and lint percentage followed by Reshmi-90 for the earlier two characters.Reshmi-90 showed higher estimates of GCA effects for seed mass per boll and fibre strength also. The above mentioned male and female parents could be used in breeding programs for the improvement in respective traits.

Although both the parents, NIAB-999 and VH-144 were poor general combiner for seed number per boll and seed mass per boll yet their combination produced valuable hybrids based on SCA effects regarding the two characters (Table 3). Same the situation was observed with the cross NIAB-999 × CIM-70 for seed volume per 100-seeds and surface area per seed, NIAB-999 × S-12 for lint percentage, NIAB-999 × FH-634 for fibre length etc. These results predict that for producing valuable hybrids for specific character/s it is not necessary that any one or both the parents should possess higher GCA value. Some contrasting situations may also arise which may be attributed to inter-genic interactions. Similar results were also shown by Patel *et al.* (1997) and Imran *et al.* (2012). The three way crosses (NIAB-999 × BH-89) × CIM-1100, (NIAB-999 × BH-89) × VH-144 and (NIAB-999 ×BH-89) × Reshmi-90 presented the highest SCA effects for lint mass per boll, fibre strength and fibre fineness respectively. This predicted that the three way crosses may be utilized with the objective to improve fibre quality parameters.

Contribution of line × tester interaction, to the total variability, was higher as compared to lines or testers individual contribution for all the characters except for lint percentage where the contribution of testers was higher (Fig. 1). Similarly if we compare contribution of lines and testers, the testers contributed more for all the traits except fibre fineness where the condition was reversed. Relatively higher contribution through interaction also supported the prevalent role of non-additive type of gene action and/or epistasis (Samreen *et al.*, 2008).

For improvement in traits under non-additive genetic control, heterosis breeding is considered the more rewarding option (Imran *et al*., 2012; Ali *et al*., 2015). Results pertaining to heterosis as compared to better parent revealed that the highest heterotic potential (16.14%) for seed number per boll was expressed by the cross BH-89 × CIM-496 while maximum heterosis for seed mass per boll was exhibited by NIAB-999 × CIM-70 (Table 4). This contradiction arose due to the reason that although the earlier hybrid produced more seeds per boll but the size of individual seed might be less than that of later hybrid. Increased seeds per boll are considered desirable as to increase in surface area for greater lint production within the boll (Culp and Harrell, 1975; Harrell and Culp, 1976; Ali *et al.*, 2015). BH-89 × NIAB-78 showed maximum increase in lint mass per boll and lint percentage over the better parent. Increase in lint mass per boll resulted in higher lint percentage which resulted due to increase in number of seeds of medium size (Ali *et al.*, 2015). Desirability for increased seed number per boll and seed mass per boll was also focused by Rahman *et al*. (2007) while studying various seed related traits under high temperature regimes. The highest heterosis for seed volume per 100-seeds and surface area per seed was exhibited by NIAB-999 × CIM-240 which also seemed logical as seeds of higher volume resulted in greater surface area per seed. Iqbal and Nadeem (2003), Khan *et al*. (2009) and many other researchers reported heterosis for seed cotton yield and its component traits.

For fibre quality parameters a low range of heterosis was seen. Maximum increase over better parent was displayed by BH-89 × VH-144 for fibre length (5.12%), BH-89 × CIM-70 and BH-89 × CIM-1100for fibre fineness (-8.97%) and (NIAB-999 × BH-89) × VH-144 for fibre strength (11.36%).Mendez-Natera*et al.*(2007) also reported a low range of heterosis over the better parent for fibre quality traits like fibre length (-10.38% to 4.85%), fibre strength (-10.47% to -5.45%) and fibre fineness (7.32% to -12.64%).Wu *et al.* (2004), Khan *et al.* (2010) and Shakeel *et al.* (2014) also reported varying degree of heterosis over better parent regarding fibre quality traits.

Table 1. Analysis of variance for various within-boll yield components and fibre traits in cotton.

SOV	d.f.	Seed number/ boll	Seed mass/ Boll (g)	Lint mass/ Boll (g)	Seed volume/ 100 seeds (cm^3)	Seed surface area (cm^2)	Lint percentage (%)	Fibre length (mm)	Fibre strength (g/tex)	Fibre fineness (µg/inch)
Reps	2	1.425	0.008	0.011	0.011	0.0001	0.208	0.507	0.073	0.208
Genotypes	42	23.095**	0.108**	0.146**	1.277**	0.013**	0.925**	18.476**	0.376**	0.925**
Parents (P)	12	6.754**	0.058**	0.228**	1.303**	0.014**	0.917**	8.616**	0.256**	0.917**
Crosses(C)	29	30.635**	0.113**	0.111**	1.261**	0.013**	0.897**	22.214**	0.399**	0.897**
P vs C	1	0.566**	0.561**	0.181**	1.445**	0.015**	1.817**	28.413**	1.147**	1.817**
Lines (L)	2	50.111**	0.299**	0.174**	0.411**	0.004**	1.949**	73.920**	1.323**	1.949**
Testers (T)	9	26.260**	0.126**	0.157**	1.544**	0.016**	1.491**	5.616**	0.334**	1.491**
L×T	18	30.658**	0.086**	0.082**	1.214**	0.013**	0.484**	24.767**	0.329**	0.484**
Error	84	1.392	0.006	0.004	0.009	0.0001	0.05	0.616	0.025	0.05
σ^2GCA		-0.0004	0.0005	0.0006	0.0009	0.0001	0.2115	-0.0008	-0.0477	0.0013
σ^2SCA		9.8257	0.0266	0.0257	0.4020	0.0042	2.0231	0.3321	8.0488	0.1004
σ^2GCA/σ^2SCA		-0.00004	0.0188	0.0234	0.0022	0.0238	0.1045	-0.0024	-0.0059	0.0129
σ^2A		-0.0009	0.0010	0.0011	0.0018	0.0001	0.4229	-0.0016	-0.0955	0.0026
σ^2D		9.8257	0.0266	0.0257	0.4020	0.0042	2.0231	0.3321	8.0488	0.1004

Table 2. General combining ability effects of lines and testers for various within-boll yield components and fibre quality traits in cotton.

	Seed number/ boll	Seed mass/boll	Lint mass/boll	Seed volume/100 seeds	Seed surface area	Lint percentage	Fibre length	Fibre strength	Fibre fineness
Lines									
NIAB-999	−1.38**	−0.11**	−0.00^{NS}	−0.08**	−0.01**	−0.01^{NS}	0.02^{NS}	−1.71**	−0.21**
BH-89	0.20^{NS}	0.02^{NS}	0.08**	0.13**	0.01**	1.15**	−0.09^{NS}	0.34*	−0.00^{NS}
NIAB-999 × BH-89	1.18**	0.09**	−0.07**	−0.06**	−0.01**	−1.14**	0.08^{NS}	1.37**	0.21**
S.E. Lines	0.198	0.014	0.012	0.016	0.002	0.193	0.119	0.144	0.03
Testers									
CIM-70	1.28**	0.12**	−0.18**	−0.12**	−0.01**	−3.92**	−0.46*	−0.26^{NS}	0.12*
Russian	1.36**	0.04^{NS}	−0.05*	−0.37**	−0.04**	−0.37^{NS}	0.16^{NS}	−0.15^{NS}	−0.23**
CIM-496	1.17**	0.04^{NS}	0.07**	0.22**	0.02**	−0.84*	0.02^{NS}	−1.10**	−0.02^{NS}
CIM-1100	−1.33**	0.03^{NS}	0.11**	0.72**	0.07**	2.71**	0.22^{NS}	0.31^{NS}	0.01^{NS}
Reshmi-90	1.34**	0.19**	0.02^{NS}	0.44**	0.05**	−1.06**	−0.09^{NS}	1.09**	0.21**
FH-634	−1.87**	−0.08**	−0.21**	0.16**	0.02**	−0.33^{NS}	−0.42^{NS}	0.56*	0.37**
S-12	−3.35**	−0.18**	0.00^{NS}	0.04^{NS}	0.00^{NS}	2.51**	−0.54*	−0.90**	−0.04^{NS}
NIAB-78	1.73**	0.04^{NS}	0.18**	−0.25**	−0.03**	−1.36**	−0.12^{NS}	0.90**	−0.23**
CIM-240	−0.04^{NS}	−0.04^{NS}	0.14**	−0.12**	−0.01**	1.30**	0.52*	−0.93**	−0.18**
VH-144	−0.30^{NS}	−0.16**	−0.10**	−0.72**	−0.07**	1.36**	0.72**	0.48^{NS}	−0.02^{NS}
S.E. Testers	0.362	0.026	0.022	0.029	0.003	0.353	0.218	0.263	0.056

Table 3. Specific combining ability effects of crosses for various within-boll yield components and fibre quality traits in cotton

Cross	Seed number/ boll	Seed mass/ boll	Lint mass/ boll	Seed volume/100 seeds	Surface area/ seed	Lint percentage	Fibre length	Fibre strength	Fibre fineness
NIAB-999 × CIM-70	1.87**	0.17**	0.14**	0.83**	0.09**	1.37*	−0.22^{NS}	1.93**	0.14^{NS}
NIAB-999 × Russian	−5.17**	−0.15**	−0.12**	0.48**	0.05**	0.79^{NS}	0.30^{NS}	2.36**	0.12^{NS}
NIAB-999 × CIM-496	1.32*	−0.06^{NS}	0.25**	−0.08^{NS}	−0.01^{NS}	0.72^{NS}	0.04^{NS}	−1.03*	−0.16^{NS}
NIAB-999 × CIM-1100	−3.16**	−0.21**	−0.29**	0.09^{NS}	0.01^{NS}	−1.33*	−0.93*	−4.31**	0.05^{NS}
NIAB-999 × Reshmi-90	0.88^{NS}	0.05^{NS}	−0.09*	−0.33**	−0.03**	−1.39*	−0.55^{NS}	2.95**	0.25**

NIAB-999 × FH-634	−2.48**	−0.17**	−0.09*	0.05^{NS}	0.00^{NS}	0.14^{NS}	0.81*	−2.49**	−0.08^{NS}
NIAB-999 × S-12	1.61*	0.12**	−0.09*	−1.03**	−0.11**	2.63**	−0.17^{NS}	1.20**	0.23*
NIAB-999 × NIAB-78	2.69**	−0.00^{NS}	0.06^{NS}	−0.48**	−0.05**	−2.46**	0.37^{NS}	−1.80**	0.02^{NS}
NIAB-999 × CIM-240	−1.32*	0.01^{NS}	0.19**	0.80**	0.08**	0.78^{NS}	0.64^{NS}	2.67**	−0.39**
NIAB-999 × VH-144	3.78**	0.25**	0.05^{NS}	−0.33**	−0.03**	−1.25*	−0.29^{NS}	−1.48**	−0.19*
BH-89 × CIM-70	1.12^{NS}	−0.07^{NS}	−0.10*	−1.01**	−0.10**	−0.39^{NS}	−0.27^{NS}	0.18^{NS}	−0.43**
BH-89 × Russian	1.54*	0.05^{NS}	0.08*	−0.23**	−0.02**	1.10^{NS}	−0.53^{NS}	1.90**	0.21*
BH-89 × CIM-496	1.81**	0.19**	−0.13**	0.28**	0.03**	−1.70**	−0.62^{NS}	1.01*	0.14^{NS}
BH-89 × CIM-1100	−0.45^{NS}	−0.03^{NS}	−0.00^{NS}	0.04^{NS}	0.00^{NS}	0.68^{NS}	0.32^{NS}	0.57^{NS}	−0.32**
BH-89 × Reshmi-90	2.84**	0.17**	0.14**	−0.15**	−0.01**	0.85^{NS}	0.23^{NS}	0.86^{NS}	0.18^{NS}
BH-89 × FH-634	0.62^{NS}	0.07^{NS}	0.11**	0.33**	0.03**	−0.05^{NS}	0.55^{NS}	0.49^{NS}	−0.29**
BH-89 × S-12	−1.71**	−0.12**	0.13**	0.72**	0.07**	−2.06**	−0.13^{NS}	−1.05*	0.16^{NS}
BH-89 × NIAB-78	−3.33**	−0.10*	0.02^{NS}	0.58**	0.06**	1.72**	−0.42^{NS}	0.41^{NS}	0.28**
BH-89 × CIM-240	−1.32*	0.04^{NS}	−0.14**	−0.08^{NS}	−0.01^{NS}	−0.88^{NS}	0.42^{NS}	−1.85**	−0.03^{NS}
BH-89 × VH-144	−1.13^{NS}	−0.18**	−0.11**	−0.48**	−0.05**	0.73^{NS}	0.45^{NS}	−2.53**	0.10^{NS}
(NIAB-999 × BH-89) × CIM-70	−2.99**	−0.10*	−0.04^{NS}	0.18**	0.02**	−0.97^{NS}	0.49^{NS}	−2.12**	0.29**
(NIAB-999 × BH-89) × Russian	3.63**	0.10*	0.04^{NS}	−0.24**	−0.02**	−1.89**	0.23^{NS}	−4.26**	−0.33**
(NIAB-999 × BH-89) × CIM-496	−3.13**	−0.13**	−0.11**	−0.20**	−0.02**	0.98^{NS}	0.58^{NS}	0.02^{NS}	0.02^{NS}
(NIAB-999 × BH-89) × CIM-1100	3.61**	0.24**	0.30**	−0.13**	−0.01**	0.66^{NS}	0.61^{NS}	3.74**	0.27**
(NIAB-999 × BH-89) × Reshmi-90	−3.72**	−0.22**	−0.04^{NS}	0.48**	0.05**	0.54^{NS}	0.32^{NS}	−3.80**	−0.43**
(NIAB-999 × BH-89) × FH-634	1.86**	0.11*	−0.02^{NS}	−0.38**	−0.04**	−0.10^{NS}	−1.36**	2.00**	0.37**
(NIAB-999 × BH-89) × S-12	0.10^{NS}	0.00^{NS}	−0.04^{NS}	0.31**	0.03**	−0.57^{NS}	0.30^{NS}	−0.15^{NS}	−0.39**
(NIAB-999 × BH-89) × NIAB-78	0.64^{NS}	0.11*	−0.09*	−0.10*	−0.01*	0.74^{NS}	0.04^{NS}	1.38**	−0.30**
(NIAB-999 × BH-89) × CIM-240	2.64**	−0.05^{NS}	−0.05^{NS}	−0.72**	−0.07**	0.10^{NS}	−1.06**	−0.82^{NS}	0.42**
(NIAB-999 × BH-89) × VH-144	−2.65**	−0.07^{NS}	0.06^{NS}	0.81**	0.08**	0.51^{NS}	−0.16^{NS}	4.01**	0.09^{NS}
S.E.	0.627	0.046	0.038	0.05	0.005	0.612	0.377	0.455	0.096

Table 4. Heterotic manifestation for within-boll yield components and fibre quality traits in cotton

Cross	Seed number/ boll	Seed mass/ boll	Lint mass/ boll	Seed volume/ 100 seeds	Seed surface area	Lint percentage	Fibre length	Fibre strength	Fibre fineness
NIAB-999 × CIM-70	7.46*	31.38**	−35.87**	12.39**	12.33**	−9.45**	−7.56**	−8.46**	11.68**
NIAB-999 × Russian	−24.98**	−3.57^{NS}	−43.28**	9.66**	9.63**	−2.20^{NS}	−3.48*	−6.70**	3.65^{NS}
NIAB-999 × CIM-496	8.46*	6.10^{NS}	−16.58**	−6.56**	−6.60**	−3.50^{NS}	−4.92**	−20.99**	2.19^{NS}
NIAB-999 × CIM-1100	−17.63**	−12.35**	−44.08**	10.71**	10.78**	0.16^{NS}	−7.68**	−30.21**	7.30*
NIAB-999 × Reshmi-90	−0.62^{NS}	24.29**	−38.01**	9.66**	9.63**	−9.20**	−7.89**	−0.66^{NS}	16.06**
NIAB-999 × FH-634	−19.18**	−22.12**	−50.50**	1.77^{NS}	1.78^{NS}	−3.66^{NS}	−3.72*	−20.33**	12.41**
NIAB-999 × S-12	−12.11**	−2.26^{NS}	−38.93**	−13.39**	−13.41**	9.36**	−7.68**	−12.97**	10.22**
NIAB-999 × NIAB-78	6.96*	−5.78^{NS}	−20.37**	−16.18**	−16.13**	−12.54**	−4.20*	−16.92**	1.46^{NS}
NIAB-999 × CIM-240	−10.49**	−3.98^{NS}	−15.78**	17.87**	17.88**	1.87^{NS}	−0.96^{NS}	−8.24**	-6.57*
NIAB-999 × VH-144	5.64^{NS}	7.69^{NS}	−36.61**	−7.25**	−7.25**	−2.93^{NS}	−3.60*	−17.25**	1.46^{NS}
BH-89 × CIM-70	10.42**	2.25^{NS}	−29.61**	−23.74**	−23.72**	7.68**	−6.71**	−6.03**	-8.97**
BH-89 × Russian	2.15^{NS}	3.93^{NS}	−9.83**	−17.51**	−17.49**	3.75^{NS}	−0.77^{NS}	6.91**	-3.21^{NS}
BH-89 × CIM-496	16.14**	11.80**	−21.27**	−4.67**	−4.62**	2.96^{NS}	−6.11**	2.68^{NS}	-0.64^{NS}
BH-89 × CIM-1100	−1.75^{NS}	−0.19^{NS}	−1.25^{NS}	−1.56^{NS}	−1.53^{NS}	9.69**	−1.23^{NS}	−8.32**	-8.97**
BH-89 × Reshmi-90	11.54**	19.66**	6.82^{NS}	−7.00**	−6.99**	9.54**	−5.50**	5.61*	4.49^{NS}
BH-89 × FH-634	−2.32^{NS}	−1.86^{NS}	−15.44**	−4.67**	−4.62**	5.94*	−1.62^{NS}	1.62^{NS}	-1.28^{NS}
BH-89 × S-12	−18.21**	−17.79**	38.33**	−1.56^{NS}	−1.53^{NS}	7.57**	−1.92^{NS}	−4.15^{NS}	-0.64^{NS}
BH-89 × NIAB-78	−8.26*	−4.48^{NS}	42.46**	−6.61**	−6.61**	12.69**	−5.17**	−1.78^{NS}	-1.92^{NS}
BH-89 × CIM-240	−4.90^{NS}	−0.75^{NS}	9.26*	−12.84**	−12.83**	1.06^{NS}	−1.69^{NS}	−15.63**	-7.05**
BH-89 × VH-144	−5.99^{NS}	−20.04**	2.32^{NS}	−24.51**	−24.48**	9.17**	5.12**	−4.51^{NS}	-1.28^{NS}
(NIAB-999 × BH-89) × CIM-70	−4.66NS	19.62**	−36.54**	3.67**	3.60**	−9.68**	−3.76*	−11.36**	29.77**
(NIAB-999 × BH-89) × Russian	12.20**	25.00**	−23.28**	−5.50**	−5.54**	−9.42**	−2.43NS	−18.08**	7.63*
(NIAB-999 × BH-89) × CIM-496	−5.56NS	11.94**	−29.88**	−7.79**	−7.80**	3.85NS	−1.70NS	−7.06**	20.61**
(NIAB-999 × BH-89) × CIM-1100	9.11**	26.49**	9.29*	8.04**	8.02**	3.97NS	−0.85NS	4.95*	26.72**
(NIAB-999 × BH-89) × Reshmi-90	−7.61*	16.20**	−17.93**	15.60**	15.57**	2.06NS	−4.54**	−12.46**	15.27**

(NIAB-999 × BH-89) × FH-634	1.19NS	4.46NS	−35.57**	−3.54**	−3.52**	−0.17NS	−10.32**	4.96*	37.40**
(NIAB-999 × BH-89) × S-12	−10.01**	2.46NS	−10.23*	4.91**	4.95**	5.48*	−4.73**	−6.95**	10.69**
(NIAB-999 × BH-89) × NIAB-78	8.73**	11.57**	0.27NS	−11.20**	−11.20**	1.79NS	−4.13*	4.08NS	8.40**
(NIAB-999 × BH-89) × CIM-240	10.19**	4.57NS	−0.41NS	−8.72**	−8.69**	−2.13NS	−6.39**	−9.26**	25.95**
(NIAB-999 × BH-89) × VH-144	−8.97**	0.62NS	−10.93*	4.13**	4.05**	2.80NS	−1.82NS	11.36**	22.14**

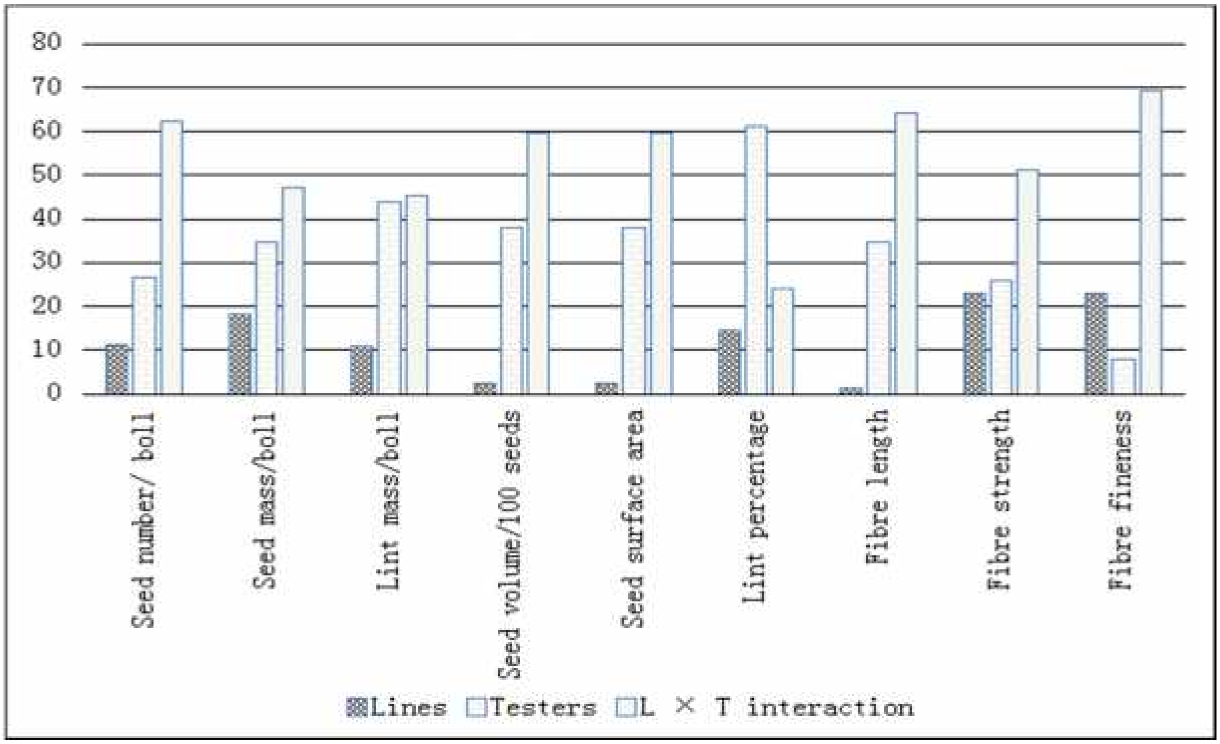

Figure 1. Proportional contribution of lines, testers and L × T interaction in total variability for various within-boll yield components and fibre quality in cotton

Conclusions: Within-boll yield components played a basic role in determination of seed cotton yield and fibre quality. All the parameters studied in present work showed the predominance of non-additive genetic control. Heterosis breeding could be rewarding when attempting to improve the within-boll yield components and fibre quality. Increase in seed mass per boll was the key factor for greater seed cotton yield but this increase should be in number rather than the size of the seed. Increase in seed number (of medium size) per boll will increase surface area per seed for greater lint production. On the other hand increase in seed mass per boll owing to the larger and bolder seeds will lower the lint mass per boll and ultimately lint percentage.

REFERENCES

Ahuja, S. L., and L. S. Dhayal (2007). Combining ability estimates for yield and fiber quality traits in 4 × 13 line × tester crosses of *Gossypiumhirsutum*. Euphytica 153: 87-98.

Ali, I., A. Shakeel, A. Ali, and B. Sadia (2015). Genetic basis of variation for within-boll yield components in cotton. Turk J. Agr. For. 39 (doi:10.3906/tar-1409-117).

Anonymous (2012-13). Economic Survey of Pakistan. Ministry of Food and Agriculture, Division (Economic Wing) Government of Pakistan, Islamabad.

Basal, H. and I. Turgut (2005). Genetic analysis of yield components and fibre strength in upland cotton (*Gossypiumhirsutum* L.). Asian J. Pl. Sci. 4: 293-298.

Basal, H., A. Unay, O. Canavar, and I. Yavas (2009). Combining ability for fibre quality parameters and within-boll yield components in intraspecific and interspecific cotton populations. Spanish J. Agr. Res. 7(2): 364-374.

Bednarz, C.W., R.L. Nichols, and S.M. Brown (2006).Plant density modifications of cotton within-boll yield components. Crop Sci. 46(5): 2076-2080.

Bednarz, C.W., R.L. Nichols, and S.M. Brown (2007). Within-boll yield components of high yielding cotton cultivars. Crop Sci. 47(5): 2108-2112.

Coyle, G. G., and C. W. Smith (1997). Combining ability for within-boll yield components in cotton, *Gossypiumhirsutum* L. Crop Sci. 37(4): 1118-1122.

Culp, T. W., and D. C. Harrell (1975). Influence of lint percentage, boll size and seed size on lint yield of upland cotton with high fibre strength. Crop Sci. 15(6): 741-746.

Green, C., and T. Culp (1990). Simultaneous improvement of yield, fibre quality and yarn strength in upland cotton. Crop Sci. 30(1): 66-69.

Hodson, E. A. (1920). Lint frequency in cotton with a method for determination. pp. 3-11. Ark. Agric. Exp. Sta. Bul. No. 168.

Imran, M., A. Shakeel, F. M. Azhar, J. Farooq, M. F. Saleem, A. Saeed, W. Nazeer, M. Riaz, M. Naeem and A. Javaid (2012). Combining ability analysis for within-boll yield components in upland cotton (*Gossypiumhirsutum* L.). Genet. Mol. Res. 11(3): 2790-2800.

Iqbal, M. Z., and M. A. Nadeem (2003).Generation mean analysis for seed cotton yield and number of sympodial branches per plant in cotton (*Gossypiumhirsutum* L.). Asian J. Plant Sci. 2(4): 395-399.

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

Khan, M. A., M. Iqbal, and M. Jamil (2010). Finding heterosis for fiber traits in intervarietal crosses of cotton, *Gossypiumhirsutum* L. Front.Agri. China. 4(2): 185-187.

Khan, N. U., G. Hassan, M. B. Kumbhar, K. B. Marwat, M. A. Khan, A. Parveen, and M. Saeed (2009). Combining ability analysis to identify suitable parents for heterosis in seed cotton yield, its components and lint% in upland cotton. Indust. Crops and Prod. 29(1): 108-115.

Kiani, G., G. A. Nematzadeh, S. K. Kazemitabar and O. Alishah (2007). Combining ability in cotton cultivars for agronomic traits. Int. J. Agri. Bio. 9: 521-522.

Mendez-Natera, J. R., A. Rondon, J. Hernandez, and J. F. Merazo-Pinto (2007). Genetic studies in upland cotton (*Gossypiumhirsutum* L.) I. Heterotic effects. Pakistan J. Bot. 39(2): 385-395.

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

Patel, U. G., J. Patel, P. Patel, K. Vadodaria, and C. Sutaria (1997). Combining ability analysis for seed cotton yield and mean fibre length in upland cotton (*G. hirsutum* L.).The Ind. J. Genet. Plant Breed. 57(3): 315-318.

Pole, S., S. Kamble, I. Madrap, and D. Sarang (2008). Diallel analysis for combining ability for seed cotton yield and its components in upland cotton (*Gossypiumhirsutum* L.). J. Cotton Res. Develop. 22(1): 19-22.

Preetha, S., and T. Raveendran (2008). Combining ability and heterosis for yield and fibre quality traits in line × tester crosses of upland cotton (*Gossypiumhirsutum* L.). Int. J. Plant Breed. Genet. 2(2).64-74.

Rahman, H., S. A. Malik, and M. Saleem (2005). Inheritance of seed physical traits in upland cotton under different temperature regimes. Spanish J. Agr. Res. 3(2): 225-231.

Rahman, H., S. A. Malik, M. Saleem, and F. Hussain (2007). Evaluation of seed physical traits in relation to heat tolerance in upland cotton. Pakistan J. Bot. 39(2): 475-483.

Samreen, K., M.J. Baloch, Z.A. Soomro, M.B. Kumbhar, N.U. Khan, N. Kumboh, W. A. Jatoi, and N. F. Veesar (2008). Estimating combining ability through line × tester analysis in upland cotton. Sarhad J. Agr. 24(4): 581-586.

Shakeel, A., F. M. Azhar, and I.A. Khan (2008). Assessment of earliness in *Gossypiumhirsutum* L. Pakistan J. Agri. Sci. 45(1): 80-87.

Shakeel, A., H. Mehmood, M. M. Sheraz, A. Saeed, M. F. Saleem and G. Nabi (2014). Evaluation of new F_1 hybrids using hybrid vigor analysis in upland cotton for seed cotton yield and fibre quality traits. J. Agri. Res. 52(4): 471-480.

Smith, C. W., and G. G. Coyle (1997). Association of fibre quality parameters and within-boll yield components in upland cotton. Crop Sci. 37(6): 1775-1779.

Tang, F., and W. Xiao (2013). Genetic effects and heterosis of within-boll yield components in upland cotton (*Gossypiumhirsutum* L.). Euphytica 194(1): 41-51.

United States Department of Agriculture. Foreign Agriculture Service. World Agricultural Production. Circular series WAP 12-13. December, 2013.

Worley, S., T.W. Culp, and D.C. Harrell (1974). The relative contributions of yield components to lint yield of upland cotton, *Gossypiumhirsutum* L. Euphytica 23(2): 399-403.

Worley, S., H. H. Ramey, D.C. Harrell, T.W. Culp (1976). Ontogenic model of cotton yield. Crop Sci. 16: 30-34.

Wu, Y. T., J. M. Yin, W. Z. Guo, X. F. Zhu, and T. Z. Zhang (2004). Heterosis performance of yield and fiber quality in F_1 and F_2 hybrids in upland cotton. Plant Breed. 123(3): 285-89.