Gene action study for yield and yield stability related traits in *Gossypium hirsutum*: An overview

[1]Muhammad Sajjad, [1]Saif-ul-Malook, [2]Awaas Murtaza, [1] Ikram Bashir, [3]Muhammad Khalid Shabaz, [3]Muazim Ali and Muhammad Sarfraz

[1.] Department of Plant Breeding and genetics, University of Agriculture Faisalabad, Pakistan
[2.] Department of Pathology, University of Agriculture Faisalabad, Pakistan
[3.] Department of Agronomy, Bahauddin Zakariya University, Multan, Pakistan
[4.] Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
Corresponding Author Email: Saifulmalookpbg@gmail.com

Abstruct: Cotton (*Gossypium hirsutum* L.) is the most important fiber as well as cash crop of the world. Pakistan ranks third among consumers and fourth among producers of the cotton worldwide. There is immense need to increase cotton yield and contribution through various breeding practices to fulfill the demand of national and international market. Improvement in fibre yield and quality is much important to meet the demands and supplies of cotton fibre. Present review will help the reader to understand the gene action in terms of general combining ability and specific combining ability of the genotypes for the development of high yielding cotton varieties and hybrids.

[Sajjad M, Saif-ul-Malook, Murtaza A, Bashir I, Shahbaz MK, Ali M and Sarfarz M. **Gene action study for yield and yield stability related traits in** *Gossypium hirsutum*: **An overview.** *Life Sci J* 2015;12(5s):1-11]. (ISSN:1097-8135). http://www.lifesciencesite.com. 1

Keywords: Gene action, Combing ability, fiber, breeding, yield, diploid

Introduction

Cotton crop is known as silver fiber for Pakistan and produces world's most important fiber. Cotton explicates 7% of value addition in the agriculture, shares 1.5% of GDP and 69% share in foreign exchange earnings (Pak. Economic Survey, 2012-13). It is second most valuable oil seed crop as it feeds almost 300 oil expellers; this further enhances its importance. Cotton is mainly grown for fiber and it also has great contribution in edible oil industry, it produces 78% edible oil of Pakistan. Pakistan is the 4th major producer and 3rd major consumer. During 2011-12 the cultivated area of cotton was 2835 thousand hectares and total production was 13595 thousand bales. During 2012-13 the area of cotton under cultivation is 2879 thousand hectares with total production of 13026 thousand bales so, we are lacking behind among the cotton producing countries of the region (Pak. Economic Survey, 2012-13). It is a cash crop and plays a crucial role to boost up the economy of Pakistan. The textile industry of Pakistan is based upon the cotton production because it is a main source of raw material of fiber; in addition it feeds almost 443 textile mills, almost 943 ginning factories, 300 oil expellers, 8.45 million spindles and almost 5 million labour is directly or indirectly engaged with the cotton industry of Pakistan. Cotton provides basic byproducts like lint, oil, seed hull, meal and linters. As the lint is a major product of cotton but the byproducts are also very important most importantly seed oil which is being to fulfill the needs of cooking oil. Cotton seed hulls are also very useful, which are rich source of proteins and amino acids and are used as a cattle feed they are also being used to cover the soil known as mulching. Short fibers and linter clinging to the seed after ginning, these are removed from the seeds and are used as a great source of cellulose for synthetic fibers, batting for cushions and explosives.

Cotton is a delicate crop and lots of resources are wasted on its protection against pests, diseases and proper nourishment (Puspito *et al*., 2015). The effect of abiotic stresses on crop plants caused a reduction in crop yield and quality (Mohammad et al., 2015; Abbas et al., 2014; Mustafa et al., 2014). Cotton is also much affected due to environmental stresses. Cotton is an often cross pollinated crop and hold indeterminate type of growth habit. Cotton is a soft, fluffy, staple fiber that grows around the seeds as a boll. Cotton is intrinsic to tropical and subtropical areas of the India, America and Africa. Relatives of cultivated types of cotton; the wild types are commonly woody perennials and mostly vary from shrubs to small trees while the four domesticated species are annual herbaceous plants. In some places of world, cotton is grown as a ratoon crop. The genus of cotton i.e. *Gossypium* is very diverse and contains 50 species which have basic chromosome number (x) 13. Among all of the 50 species of cotton, two tetraploid and two diploid species have fiber which is known as "spin-able" fiber usually called as lint. These domesticated species include, (diploid, 2n= 2^{X}= 26) *Gossypium arborium L.* and *Gossypium herbaceum L.* which contributes only about 10 % out of total production of cotton. whereas (tetraploid, 2n= 4x= 52) *Gossypium barbadance L.* and *Gossypium hirsutum L. Gossypium hirsutum L.* is the most widely cultivated kind of cotton and accounts for about 90 % of the total production of cotton in the world.

It resides a distinctive position in the global trade because it is a very important agricultural and industrial crop. The demand of cotton is increasing at a rapid pace, more than the world's population growth rate, so we have to increase the yield per unit area. The use of poor quality seed is one of the primary reasons for lowering the yield per acre in Pakistan. It is essential to develop new high yielding cultivars to improve production level (Jatoi *et al*., 2011; Akhtar *et al*., 2014). Conventional breeding methods are being used to increase the production of the cotton crop in the current years (Schwartz and Smith, 2008). Fiber quality of a peculiar cotton genotype is a combination of different characters like, fiber strength, fiber fineness, staple length and uniformity with uttermost importance (Poehlman and Sleper, 1995; Ali *et al*. 2008). Studies showed that additive and non-additive genes control the variation in seed cotton yield and its related components (Ashokkumar *et al*., 2010*)*. The general combining (GCA) governs the additive gene action and specific combining ability (SCA) governs the non-additive type of gene action. (Sprague and Tatum, 1942; Griffing, 1956). Thus the SCA is important for hybrid crop exploitation while the GCA is practicable for hybridization and selection programs (Jatoi *et al*., 2011). Line × tester analysis could be used to find information about combining ability and provide the information about parents and their F_1 crosses which is useful for breeding program (Shakeel *et al*., 2012; A;li et al., 2013; Ali et al 2014ab; Ahsan et al., 2013).

Gene action study

Khan *et al.* (1992) studied six cultivars of cotton to estimate the gene action controlling yield of seed cotton and its components. They found additive type of gene action for number of bolls/plant, whereas over-dominance type in case of boll weight and yield of seed cotton. The epistatic effects were absent in the inheritance of these characters. Ahmad *et al*. (2001) studied gene action controlling the inheritance of seed cotton yield and some other related traits in cotton. They found additive type of gene action with partial dominance for number of bolls, number of seeds, boll weight and seed cotton yield. They found that epistatic effects were absent in the inheritance of these traits. Haq and Azhar (2004) studied the genetic mechanism to control seed cotton yield and its components in cotton *(Gossypium hirsutum* L). It was concluded that variety Carolina 173 proved to be the best general combiner for plant height and seed cotton yield, whereas N1AB 98 for number of bolls per plant and seed cotton yield and Cross combination NIAB 98 × Carolina 173 were proved best for number of bolls and seed cotton yield, Arizona 6218 × Carolina 173 for boll weight. For lint percentage NIAB 98 × Arizona 6218 proved to be the best for varietal combination.

Nadeem and Azhar (2004) studied the type of gene action controlling plant height, number of bolls per plant, boll weight, seed cotton yield and lint percentage in *Gossypium hirsutum* L. The Vr/Wr graphs showed that additive type of gene action was important for controlling these characters. The regression lines for plant height (b=0.99±0.23), number of bolls (b=1.14±0.10), boll weight (b=0.97±0.19), seed cotton yield (b= 1.00±0.01) and lint percentage (b=l. I0±0.05) showed the absence of epistatic component in the inheritance of these characters. They concluded that GFS had maximum number of dominant genes for plant height, seed cotton yield and lint percentage while Tashkant-7 contained maximum number of recessive genes for plant height and boll weight, whilst for seed cotton yield and lint percentage. The estimates of narrow-sense heritability for all the characters were high. They concluded that both pedigree and recurrent selection method may be useful in seed cotton yield and its components improvement. Ali and Khan (2007) carried out an experiment having full diallel design involving five parents to examine various agronomic traits like plant height, number of bolls per plant, seed cotton yield, noumber of monopodial branches, number of sympodial branches. The data were recorded for these traits showed that, for the inheritance of these traits additive type of gene action had a major role while partial dominance was accompanying for the manipulation thus selection breeding was highly recommended for the improvement of these traits. Abbas *et al*. (2008) studied five cotton *(Gossypium hirsutum* L.) varieties namely CIM-443, Cris-420, NIAB Krishma, Coker-207 and RH-112 to check genetic effects involved in the inheritance of various plant traits. They found that narrow sense heritability estimates were higher for all the characters except staple length and lint percentage. Presence of additive gene effects and high narrow sense heritability indicated that selection breeding will be progressive for genetic improvement for yield. Larik *et al*. (2008) concluded that dominant components (H_1, H_2) and additive components (D) were highly significant for plant height, bolls/plant and boll weight and dominant components were greater than additive components. Dominant components were non-significant for seed cotton yield and dominant components were greater than additive components. The average degree of dominance was greater than unity. Further they concluded that the dominant genes were less frequent than recessive genes in the parents by positive non-significant F-value. Fl_2/H_2 value indicated that there were at least three groups of genes controlling seed cotton yield per plant.

Combining Ability

Soomro *et al.* (1995) studied the combining ability effects by using line × tester analysis for yield and its components in upland cotton. They found that GCA and SCA effects were significant for number of bolls per plant and seed cotton yield per plant which means that GCA was due to additive genes and SCA was due to dominant genes. Further they found that BH-36, CYTO-129 and CIM-240 exhibited significant GCA for no. of bolls per plant md CYTO-129 andS-12 for seed cotton yield. The CYTO-129 was the best general combiner for number of bolls and seed cotton yield per plant and the crosses Cris-52 × S-12, Cyto-129 × Cim-240 and NIAB-78 × NH-26 were high in specific combining ability effects for number of bolls per plant and seed cotton yield per plant. Islam *et al.* (2001) concluded that Additive type of gene action was predominant for boll weight and ginning out-turn and the 4F were higher yield and to be better general combiner for yield. Cheatham *et al.* (2003) carried out an experiment to examine the combining ability effects and pattern of inheritance in American cotton for fiber traits and the characters related to yield. The performance of F_2 generation was greater than the parents for boll weight, long fibers and lint % age. The calculation of genetic variance was done for these characters and it was declared that the best general combiner for lint yield were paymaster-1560, Fibermax-832 and Stonevile-474. On the other hand, fibermax-975 and pay master-1560 both showed remarkable GCA effects for lint percentage and boll size. Genotype Fibermax-975 and B-1388 gave best GCA effect for fiber elongation, lint yield and boll size respectively to get gene pool for fiber quality and quantity improvement. It was also suggested that wild accessions and these cultivars can cross with U.S. cultivar. Mert *et al.* (2003) studied the general combining ability and specific combining ability of parents and hybrids to develop high yielding cotton cultivars by using five lines and seven testers in line into tester analysis. They found significant results for general and specific combining ability effects for lint yield, lint percentage, 100 seed weight and number of bolls per plants. The lines PAUM-403 for number of bolls per plant; UKUROVA-1518, PAUM-400, PAUM-401, PAUM-405 for lint percentage; Sure grow 125, PAUM-400 for hundred seed weight were the best general combiner and Sure grow 501 x PAUM-400 hybrid for bolls per plant was the best specific combiner.

Ahmad *et al.* (2005) studied the combining ability of yield and its components in eight cotton varieties. They concluded that specific combining ability variance was more important and greater in magnitude for the traits of plant height, monopodial tranches per plant, sympodial branches per plant, number of bolls per plant and seed cotton yield per plant. Further they found involvement of non-additive type of gene action for these parameters and Cim-1100 is the best general combiner to be exploited in breeding programmed to improve yield in cotton. Basal and Azhar *et al.* (2007) studied general and specific combining ability effects for some traits of *G.hirsuitum.* They found significant effect for the expression of days to flowering, earliness index and seed cotton yield, while position of first sympodial branch for GCA effect was non-significant. Reciprocal effects were significant for seed cotton yield and earliness index. Further they observed that SCA variance was greater for position of first earliness index and sympodial branch. The proportion of GCA and SCA variance for days to flowering, days to squaring and seed cotton yield were in similar extent. The CIM-435 proved to be the best general combiner for days to flowering, days to squaring and position of first sympodial branch and MNH-3570 was best general combiner for days to flowering, earliness index and seed cotton yield. MNH-3570 × MS-95 was the best combination for days to flowering, position of first sympodial branch and earliness index, MNH-3570 × BAR 2/1 for days to squaring, and BAR 12/1 × MS-95 for seed cotton yield. Rauf *et al.* (2006) investigated combining abilities in upland cotton for seed cotton yield and its relevant traits. It was found that both non-additive and additive gene effects were playing their role for most of the quality traits inheritance. The ACALA 1517-C, NIAB-999 and CIM-473 gave highly significant GCA effects among the parents whereas the hybrid CIM-473 × NIAB-999 gave best SCA effects for majority of traits. To improve the quantity and quality of cotton these hybrids and their parents might be used for selection. Ahuja and Dhayal (2006) studied SCA and GCA of the parents for the best quality cultivars and improving yields. Excluding fiber elongation for all the traits SCA and GCA effects were found significant. Including fiber traits seed cotton yield showed non-additive gene action. Among the parents CNFI-36 for seed cotton yield and CCFI-526612 for boll weight were acquired with excellent combining ability while, parent CCH-526612 showed the great performance as best general combiner for fiber elongation, fiber strength and fiber length. Genotype found as good general combiner for micronaire value and fiber strength was AKH-9618. The high yielding hybrids found among the crosses were RS-2283 × SGNR-2, H-1242 × PIL-8 and CISV-24 × LH-1995.

Kiani *et al.* (2007) worked to discover the combining ability of American cotton for different plant traits. The best general combiner found for plant height and seed cotton yield was Siokra 324, which was shown by the degree of variance. For different quantitative characters importance of additive and non-additive gene action was revealed by the degree of variances among SCA and GCA. Non additive gene effects were shown by the number of sympodial branches. It was also studied that for boll weight FH-925 and for seed cotton yield hybrids, Nazily-84 × Siokra-324, Tabladila × mehr superiority percentage. CIM-499 was the highest GCA scoring parent for seed cotton yield.

Mendez-natera *et al.* (2007) conducted an experiment to study the best parent and better parent for seed cotton yield, some agronomic traits and fiber characters in 15 hybrids of cotton. They found that there were no significant differences for better parent in seed index but found significant difference for days to blooming, set flowers, boll set, fruitful branches, and boll weight. For fiber properties, significant difference was found for fiber percentage, fiber length, fiber fineness and fiber strength. Further they found significant heterosis over best parent only for Set Flower and fruitful branches. Significant heterosis over best parent was not found for fiber properties. They concluded that Hb was mostly negative for fiber quality and the hybrid L3 × LA with the biggest Hb for SCYH and with the smallest value for the fiber strength (711b/inch2). Those hybrid combinations that represent a positive heterobeltosis for SCYH and fiber quality will be selected. Zeng *et al.* (2007) evaluated two hundred and sixty lines of the SP population with five commercial cultivars. They found significant genotypic variation for all characters of seed cotton yield and fiber quality. Further they found highly significant interaction between genotype and location for fiber strength and yield parameters. The large variation among the SP lines were found for nectary size, pubescence, plant height, leaf area and leaf length, Span length contributed more variation to fiber strength than span length in the SP population. They found that lint yield was negatively correlated with fiber content. They concluded that the SP population proved to be useful germplasm for genetic improvement of lint yield and fiber quality traits.

Breeding for qualitative traits

Ali *et al.* (2008) studied five cotton varieties to check genetics of fiber length, strength, fineness, fiber uniformity and fiber elongation. They found significant differences among all traits. Adequacy tests showed that data of all the traits were partially adequate for genetic interpretation. Further they found that additive component was significant in all the traits and was in low magnitude than dominant components for fiber strength and fiber uniformity. Dominant genes were more than recessive genes in the parents for all the traits except for fiber fineness. The h_2 value was non-significant for all the traits except fiber strength. Moderately high narrow sense heritability was exhibited by fiber fineness, fiber uniformity and fiber elongation. They found additive gene action for fiber fineness and fiber elongation while; fiber strength and fiber uniformity were controlled by over dominance effects.

Asif *et al.* (2008) screened out nineteen cotton *(Gossypium hirsutum*) genotypes for fiber length, fiber strength and fiber fineness. They found that fiber length ranged from 23 to 3 D mm with mean value of 27.6 mm and fiber fineness was variable with mean value of 4.75. They found highly significant negative correlation between fiber length and fiber fineness md highly significant positive correlation between fiber length and fiber strength. Fiber fineness was negatively correlated with fiber strength. They concluded that two contrasting cotton genotypes viz., FH-631S and FH-883 can be selected for further genome mapping studies. Ashokkumar and Ravikesavan (2008) studied the transferring of genes responsible for seed oil content and the inheritance of seed protein, seed oil, seed cotton yield and fiber quality characters in twenty eight hybrids involving four varieties as females/lines and the seven as males/testers in Line × Tester fashion. They found that all the characters under study (i.e., seed oil, seed cotton yield, seed protein, 2.5% span length, uniformity ratio, bundle strength, micronaire and fiber elongation percentage) were controlled by non-additive gene action. The best general combiners among the parents were MCU 5 for seed protein and rundle strength 776 and Surabhi for seed oil, SVPR 2 for uniformity ratio and elongation percentage and MCU 12 and F 1861 for seed cotton yield and micronaire. Among hybrid 4CU 12 × TCH 1644 for seed protein and 2.5% span length, Surabhi × TCH 1646 and 5rrabhi × F 1861 for seed oil and MCU 12 × SOCC 11 and Surabhi × TCH 1641 for seed cotton yield and Surabhi × TCH 1644 for uniformity ratio and elongation percentage proved to be good specific-combiner. They concluded that the result of present study indicated the possibility of developing high yielding hybrids in combination with high seed oil content and better fiber quality traits.

Iqbal *et al.* (2008) worked on heterosis to increase cotton (*G. hirsutum* L.) yield. Their main objective of study was to evaluate the potential of F_2 hybrids. They use five parents (CIM-496, FH-901, MNH-554, FH-945, LRA5166, 10 F_1 & 10 F_2). They determined differences among genotypes. They found that CIM-496 3521 kg ha^{-1} was highest yielding parent followed by MNH-554 with 3268 kg ha^{-1} while FH-901 with 2391 kg ha^{-1} was minimum yielded among the parents. With cross combinations MNH-554 × LRA-5166, MNH-786 × VH-144 and CIM-499 ×

LRA-5166 revealed minimum inbreeding depression for seed cotton yield, fiber traits and yield components than expected inbreeding depression. They found significant GCA and SCA effect for all traits while the GCA effects were higher than SCA effects for all traits which showed additive gene action is prevailing with dominant gene action for expression of these traits. Further they found that variety FH-901 was the best general combiner for the yield and yield components. They concluded that F_2 can be used for availing the heterosis and the cost of seed production will also be reduced. Neelima and Reddy (2008) evaluated quantitative and qualitative traits in 54 genotypes comprising of 4 lines and 10 testers in upland cotton through Line × tester mating design. It was revealed that moderate heritability along with moderate genetic advance was present for yield components, boll weight, seed index, number of bolls per plant, seed cotton yield and number of sympodia indicating the action of additive and non-additive genes in the inheritance of these characters. Panhwar *et al*. (2008) calculated combining ability estimation through line × tester analysis comprising on five lines and three testers of American cotton. Among parents CIM-707 was best general combiner and FH-1000 was good general combiner. They found out significant GCA and SCA variances for most of the characters which showed additive as well as non-additive gene action controlling the yield related traits. General combining ability estimates suggest that if most of the traits; seed cotton yield, number of bolls per plant and boll weight etc. are to be improved through hybridization and selection then importance should be given to the parents.

Samreen *et al*. (2008) estimated combining ability of the parents through line × tester analysis. They studied traits; number of bolls per plant, boll weight, ginning out turn percentage, seed index and seed cotton yield by using five lines, three testers and their 15 F_1 hybrids. GCA is due to additive gene action while SCA is due to dominant and epistatic gene action. Greater magnitude of GCA from lines and testers than the SCA was found which expresses the prevalence of additive genes in the expression of above described traits. CIM-505 manifested best general combiner among lines and NB-999 manifested best general combiner among testers, for near about all traits. CIM-497 × BH-147 and CIM-506 × NB-999 was best specific combiner among F_1 hybrids so, can be used for hybrid development. Abro *et al*. (2009) studied combining ability of parents and F_1 hybrids for the selection of superior recombinants. The genotype sadori proved to be best general combiner for plant height, bolls per plant and yield. From the F_1 hybrids the sadori × CIM-448 showed higher specific combining ability (SCA) effects for boll number per plant.

Ali *et al.* (2009) studied five cotton cultivars to check the inheritance of different polygenic traits. They found significant differences for all the traits. Adequacy tests shows mat data of all the characters were fully adequate for genetic analysis except bolls per plant, fiber strength and fiber fineness. Additive genetic component (D) was significant for plant height, staple length and fiber strength. More dominant genes were revealed in the parents for sympodia per plant, lint percentage and seed cotton yield. The H2/4H1 value shows unequal distribution of dominant genes in the parents for all the characters. The traits such as plant height, sympodia, staple length and fiber strength shows high narrow sense heritability due to additive gene action, while, monopodia, number of bolls per plant, lint percentage and seed cotton exhibit low heritability. The genetic analysis shows that plant height, staple length and fiber strength could be improved through pedigree, sib family and progeny selection, whereas heterosis would be necessary to attain the genetic advancement in monopodia per plant, number of bolls per plant, lint percentage and seed cotton yield.

Deosarkar *et al.* (2009) conducted the experiment to study the general and specific combining ability for seed cotton yield, no. of bolls per plant, lint % age, plant height, fiber fineness and fiber length by using diallel analysis including seven diverse parents. Twenty one (21) hybrids were developed by using seven parents for investigation of these purposes. For further research two checks NHH-44 and PHH-316 and these hybrids were planted. The analysis of variance for combining ability showed that variances due to SCA and GCA effects were found highly important for all features observed. The variance due to SCA was greater than GCA for fiber length, fiber fineness, and number of bolls per plant. This exposed the presence of non-additive gene action. The parents KH-923 and PH-44-1-2 exhibited good combining ability effect for all traits. The hybrids PH-44-1-2 × KH-120 and KH-923 × KH-113 expressed significant SCA effects. Hussain *et al*. (2009) carried out generation mean analysis to check genetic mechanisms controlling inheritance of morphological and yield-contributing characters in cotton. They found that fitting the adequacy of five parameter models exhibited its adequacy for leaf area, number of bolls, seed cotton yield and petiole length, whereas inadequacy of this model for boll weight, which showed that there is involvement of gene interaction controlling the boll weight expression. They found over-dominance for leaf area, number of bolls per plant, boll weight and petiole length but partial dominance for seed cotton yield. Narrow sense heritability estimates ranging from 0.62 to 1.24 were observed for leaf area, boll weight and seed cotton yield while, the moderate estimate of heritability was revealed for number of bolls per plant. On the basis of high heritability and positive associations measured among traits they concluded that there is possibility of improving seed cotton yield through direct selection and conventional breeding techniques.

Kaliyaperumal *et al.* (2009) used line × tester mating design to investigate the combining ability effects in American cotton for high production and enhance quality cultivars. According to experiments significant ($P \leq 0.05$) GCA & SCA effects for all characters. It was reported that for boll weight, seed cotton yield, no. of bolls per plant parent MCU-12 has been found best general combiner. Whereas F-1861 was also found as best combiner by attaining positive characters like no. of bolls & cotton yield. High GCA effects observed by Surabhi for no. of sympodia and TCH-1641 for ginning out turn. Parents F-1861 and F-776 were observed best combiners for fiber quality values. The experiment has been conducted in high yielding and good quality hybrids with significant GCA effect for fiber quality characters and seed cotton yield per plant. Karademir *et al*. (2009) carried out a study with the purpose of evaluating parental lines and their crosses for general combining ability and specific combining ability and then their selection for a breeding programme. They crossed 7 lines/females and 3 testers/males of upland cotton through line × tester mating system. The variances of general and specific combining ability were highly significant for about all the yield and fiber related traits. Additive and non-additive genes were responsible and influencing all these traits. It was detected that fiber length, fiber elongation, fiber strength and fineness were highly influenced by additive gene action but fiber yield, seed cotton yield and fiber uniformity were highly influenced by the non-additive gene action.

Khan *et al*. (2009) studied F_1 and F_2 hybrids by crossing six upland cotton cultivars e.g. CIM-109, CIM-1100, CIM-240, FH-682, CRIS-9 and BH-36 to estimate nature of gene action, heritability and genetic gain in the hybrids. They found that mean values of genotypes differed significantly for all the fiber quality parameters. They found adequate additive-dominance model for fiber length, fiber fineness, and uniformity ratio, whereas found martially adequate for fiber strength. Further they found that additive component was significant for all the traits. Dominance components were also significant for all the traits in 5 generation except the fiber fineness, while were non-significant for all the traits in F_2 generation. Partial additive gene action was observed in F_1, whereas in F_2 all the traits were controlled by additive gene action. Broad & narrow sense heritabilities were moderate to high. On the basis of transgressive segregation they concluded that, heritability with suitable genetic gain, selections made in F_2 population. CIM-1100 surpassed the standard cultivar i.e. ClM-446 for fiber quality traits in Segregating generations.

Patel and Kumar (2009) determined that both non-additive and additive variances were present for inheritance of various characters like plant height, boll number per plant, cotton yield, GOT, fiber strength, and sympodial branches. Except for fiber length, variances for GCA were higher than SCA, which shows that these characters under the control of additive gene effects. Combinations like BC-682 × GISV-197, G.Cot-10 × LRA 5166, SD-3 × GISV197, SD-3 × B55-53 and G. CotlO × BC-682 had higher performance while GISV-197 was proven best parent for fiber strength, plant height and boll number. Crosses showed great degree of SCA effects. Rashid *et al.* (2009) studied the genetic potential of 15 cotton genotypes by analyzing phenotypic correlation, genotypic and path co-efficient analysis. They found highly significant association between number of bolls per plant and boll weight with seed cotton yield. Further they found Positive direct effect of fiber fineness and fiber strength on seed cotton yield, which shows that direct selection through these traits, may lead to an increase in yield. Heritability estimates of seed yield, fiber fineness and fiber strength shows the presence of strong to very strong genetic expression. They concluded that heritability and correlation both help to determine the selection criteria for the improvement of yield and fiber quality traits whereas path co-efficient analysis helps to determine the direct effect of traits and their indirect effects on other traits.

Ashokkumar *et al.* (2010) studied general and specific combining ability of parents to develop the better quality and high yielding genotypes. Four lines and seven testers along with their 28 F_1 hybrids were sown through line × tester mating system, for about all the traits significant general and specific combining ability revealed through this line × tester analysis. F-776 and F-1861 were among parents which were good combiner for fiber traits. The better performing and high yielding hybrids with significant SCA for yield and fiber traits were derived which could be further used. Hussain *et al.* (2010) worked on five upland cotton cultivars to check inheritance pattern and combining ability of parents for different fiber quality parameters i.e., staple length, fiber strength, uniformity and fineness. They found highly significant differences among the genotypes for all the traits under study. Genetic analysis also revealed highly significant effects due to general and specific combining ability for all the fiber quality characters. The magnitude of dominance variance was greater than that of additive effects for all the traits which revealed non-additive gene action for controlling these traits. They concluded that fIM-707 showed best general combining ability for staple length and fiber strength, LA-I^{T} 801 for fiber uniformity and FH-1000 for fiber fineness. The best specific combining ability was exhibited by the cross CIM-707 × DPL-2775 for staple length, CIM-707 × TH- 83 for fiber uniformity, CIM-707 × LA-17801 for fiber strength and FH-1000 × DPL-2775 for fiber fineness. They found correlation analysis as positive association between fiber strength and staple length while negative relationship between fiber fineness and staple length.

Salahuddin *et al*. (2010) by using six parents and nine crosses (fifteen genotypes) of *G.hirsuitum* L. found that bolls per plant, sympodial branches, boll weight and lint index were correlated positively with yield and its components. Further he concluded that bolls per plant and boll weight were correlated with seed cotton yield. Saravanan *et al.* (2010) conducted various crosses through line × tester approach. Three cultivars were used as males while, four other jasid resistance cultivars were used as females to carry out the experiment. The aim of the experiment was to observe twelve different traits including fiber and yield traits too. The data showed that in almost all of the traits studied the type of gene action controlling the inheritance is non-additive type of gene action for some of the traits some good combiners were selected by means of SCA estimates. The superior hybrids found for the traits high seed cotton yield, jasid resistance and high fiber quality. Singh *et al.* (2010) studied the combining ability effects and patterns of inheritance. Different plant traits were investigated by using 8 genotypes namely F-1861, VCH-F RS-810, 25-K, 23ES, CSH-7106, 3-HS and B58-1290 of cotton. The analysis of variance showed presence of significant general and specific combining ability effects for all fiber traits except for fiber strength and lint index. The genotypes 3HS and RS-810 showed good combining ability effects for boll weight and cotton yield. Parental line CS-117106 proved better general combiner for boll weight whereas B58-1290 and CH-F were also proven as good general combiners for cotton yield. For seed cotton yield, some crosses like 23-ES × 23-K and KF-1861 × VCH-F showed significant specific combining ability effects. Whereas, hybrids like CSH-7106 × 23-Kx and 3HS × VCH-F RS-810 showed significant amount of SCA effect for fiber strength. Therefore these hybrids crosses must go through selection for varietal improvement or could be used in cotton hybrid development.

Ali *et al*. (2011) found out that over-dominant type of gene action influenced monopodial branches and sympodial branches per plant, plant height, boll number and boll weight. The line CP-15/2 showed maximum dominant genes for monopodial branches and sympodial branches per plant, plant height, boll number and boll weight while CIM-497 possessing maximum recessive genes for monopodials and plant height. Ishaq and Khan (2011) studied the genetic inheritance of some plant traits in cotton (*G. hirsutum* L.). The characters under study were: plant height, number of sympodial branches, number of monopodial branches, and number of bolls per plant and boll weight. Five varieties viz. AC-134, CIM-473, MS-39, 124-F and LA85-52-2 were crossed to make F_1 hybrids. They found additive type of gene action with partial dominance was involved in the inheritance of all these traits. Jatoi *et al.* (2011) conducted a study to identify the parents with high general and specific combining ability using line × tester analysis, for better agro-economic traits in American cotton. They used 5 lines/females and 3 testers/males. For boll per plant, sympodial branches per plant lint percentage and yield the general and specific combining ability mean squares were highly significant but GCA and SCA mean squares for boll weight was non-significant. The variances of general combining ability (GCA) were higher than the variances of specific combining ability (SCA) this shows the more importance of additive gene action against than that of non-additive gene action.

Patil *et al.* (2011) studied the nature and magnitude of gene action through Line × Tester analysis by using 3 lines and 10 testers for seed cotton yield and fiber quality traits. They found that the magnitude of *GCA* and *SCA* variances showed that pre-dominance of additive as well as non-additive gene action was important for inheritance of seed cotton yield and its quality traits. The parents BC 68-2, GSHV-112 and 76 IH-20 were proved to be good general combiners for seed cotton yield and its quality traits. The hybrids G. CotT20 × 6 IH-20, GSHV 155 × GSHV 112 and GSHV 155 × LRA 5166 had significant SCA effects for seed cotton yield and its quality trait. They concluded that the good combiner genotypes could be used in crossing program and the crosses having significant SCA effects should tested over the location and years before commercially exploitation. Thomson and Luckett (2011) studied combining ability for number of bolls, fiber quality traits and yield of seed cotton in the cultivated species of cotton. In experiment nine parents were used, which had Africa and North America origin. Each hybrid set was sown along with their own parents. Variation due to general combining ability was significant while due to specific combining ability was significant and extensive for all traits. General combining ability effects revealed to be closely related with parental performance which may be used in choosing desirable parents in breeding program. In isolation of superior parents, some African varieties were proved of inferior quality while American varieties showed good GCA effect.

Gupta and Singh (2012) carried out an experiment to study combining ability effects in American cotton. For all the traits studied the variance was significant for both GCA and SCA. Variances for both SCA and GCA were found highly significant. The degree of combining ability of GCA was more than six times greater than SCA effects. For fiber fineness, fiber length, seed index and lint index the strain A-102 was found best general combiner. Among all the parents very high association was recorded for specific combining ability due to genetic diversity. Khan and Qasim (2012) conceded out research project with 5 parental genotypes and their 20 crosses. Data for monopodial branches, sympodial branches, bolls per plant, boll weight, plant height and seed cotton yield were recorded. Studied genotypic differences for above characters by subjecting the data to the analysis of variances. When the traits were tested for the genetic analysis to the additive dominance model, overdominance type of gene action for monopodial branches was observed. But additive type of gene action was involved with partial dominance in the inheritance of all other traits.

Shakeel *et al*. (2012) described the agronomic and quality traits such as number of bolls per plant, lint percentage, seed cotton yield, fiber fineness and fiber length using these genotypes FH-945, MNH-93, MNH-129, CIM-496, CIM-446 and NIAB-78. It was revealed that CIM-496 showed significant and non-additive effects on yield related parameters while CIM-446 × NIAB-78 was poor combiner for yield and quality related components. Presence of non-addive genes in genetic makeup seems to be complex revealed by the inheritance pattern of dominance gene effects. Tabasum *et al*. (2012) reported the inheritance pattern among the various genotypes for seed cotton yield and other quantitative traits. It was assessed that fuzzy seed weight and non-fuzzy seed weight revealed the low genetic variation among genotypes while other agronomic traits exposed the medium variability. It was reported that seed cotton yield and cotyledonary leaf area exhibited moderate to high heritability.

Iqbal *et al*. (2013) performed genetic analysis for plant height, number of bolls per plant, average boll weight, yield per plant, ginning out turn to evaluate the genetic effects on superior genotypes SLH-41, F-281, COKER-3113, LA-85-52-1 and H-88-8-J.69-J.70. It was observed that ginning out turn percentage and average boll weight were controlled by the dominant gene effect with additive response while other traits number of bolls per plant, plant height and yield per plant represented partial dominance with additive effect of genes. Shaukat *et al*. (2013) identified and evaluated the superior cultivars and hybrids to study the combining ability in American cotton. Highly significant analysis of variance was shown by the genotypes for all traits. Studies showed that in F_1 generation specific combining ability (SCA), general combining ability (GCA), mean squares and reciprocal effects were highly significant. High proportion of additive type of genes was shown by the fiber related traits in F_1 like fiber length, fiber fineness, fiber strength. GCA variances were high as compared to SCA variances. GR-156 was proved to be best combiner for fiber length and lint percentage. For fiber fineness FH-207 was proved to be the best combiner. So, these genotypes can be used for the further and future breeding programme. Swamy *et al*. (2013) evaluated the genetic variability and gene action of 16 superior genotypes comprising 6 lines and 10 testers of upland cotton using line × tester analysis for yield and quality parameters. It was assessed that additive and non-additive genes have prominent effect on yield and quality. It was reported that genotypes having high GCA and SCA could be used in breeding program and should be evaluated in different climatic conditions of the country.

Kumar *et al*. (2014) they conducted a study to investigate the combining ability effects. They used 42 genotypes and found that all the characters were influenced and controlled by additive type of gene action but sympodial number of branches and bundle strength were controlled by non-additive type of gene action. MCU-13 was considered best general (GCA) combiner because it showed higher values for single plant yield, sympodial number of branches, seed index and lint index. F_1 Hybrid TCH-1705 × MCU-13 showed higher specific (SCA) combiner as they showed higher values for sympodial number of branches, boll numbers per plant and yield. Latif *et al*. (2014) studied inheritance, general combining ability and specific combining ability for different plant traits of upland cotton (*Gossypium hirsutum* L.). Mean values of all genotypes were significantly different from each other for all the traits under study. The inheritance was controlled by additive type of gene action for all the traits under study, so non-additive type of gene action (epistasis or dominant) was not found in any character under study. All the traits were governed by additive gene with partial dominance, but seed cotton yield was governed by additive genes with over- dominance. The parent MS-84 was revealed as best general combiner for the traits e.g. number of monopodial branches per plant, plant height, number of bolls per plant. For best specific combining ability MS-84 × NIAB-Krishma was best general combiner for the traits number of monopodial branches per plant, plant height, number of sympodial branches per plant.

Conclusions

Cotton is an important fibre crop, the quality and fibre production should be improved to fulfill the demands. Cotton breeders select genotypes for improvement through various breeding methods and breeding techniques. Gene action is one of the most important criteria of selection in cotton. Additive, genetic advance, heritability, dominance, GCA, SCA, heterosis and hertobeltiosis are some of the important statistical approaches to improve yield and quality of cotton fibre.

References

1. Abbas, A., M.A. Ali and T.M. Khan. 2008. Studies on gene effects of seed cotton yield and its attributes in five american cotton cultivars. J. Agric. Soc. Sci. 4: 147-152.
2. Abbas, HG, A Mahmood, Ali Q, Saif-ul-Malook, Muhammad Waseem and Nazar, Hussain Khan. Genetic variability for yield, its components and quality traits in upland cotton *(Gossypium hirsutum* L.*). Nat Sci* 2014;12(11):31-35.
3. Abro, S., M.M. Kandhro, S. Laghari, M.A. Arain and Z.A. Deho. 2009. Combining ability ability and heterosis for yield contributing traits in upland cotton (*Gossypium hirsutum* L.). Pak. J. Bot. 41: 1769-1774.
4. Ahmad, I., A. Ali, M. Zubair and I.A. Khan. 2001. Mode of gene action controlling seed cotton yield and various components in (*Gossypium hirsutum* L.). Pak. J. Agric. Sci. 38: 19-21.
5. Ahmad, R.D., A.J. Malik, G. Hassan and M. Subhan. 2005. Estimation of combining ability for seed cotton yield and its components in inter-varietal crosses of cotton (*Gossypium hirsutum* L.) Gomal Univ. J. Res. 21: 1-6.
6. Ahsan, M., A. Farooq, I. Khaliq, Q. Ali, M. Aslam and M. Kashif. 2013. Inheritance of various yield contributing traits in maize (*Zea mays* L.) at low moisture condition. African J. Agri. Res. 8(4): 413-420.
7. Ahuja, S. and S. Dhayal. 2007. Combining ability estimates for yield and fibre quality traits in 4 × 13 line × tester crosses of *Gossypium hirsutum*. Euph.153: 87-98.
8. Akhtar, S., Shahid, A. A., Rao, A. Q., Bajwa, K. S., Muzaffar, A., Latif, A., & Husnain, T. (2014). Genetic effects of Calotropis procera CpTIP1 gene on fiber quality in cotton (Gossypium hirsutum). *Advancements in Life Sciences*,*1*(4), 223-230.
9. Ali, B., M.S. Iqbal, M.K.N. Shah, G. Shabbir and N.M. Cheema. 2011. Genetic analysis for various traits in *Gossypium hirsutum* L. Pak. J. Agric. Biol. 10: 217-220.
10. Ali, M.A., A. Abbas, M. Younas, T. M. Khan and H.M. Hassan. 2009. Genetic basis of some quantitative traits in upland cotton (*Gossypium hirsutm* L.). Plant Omics. J. 2: 91-97.
11. Ali, M.A., and I.A. Khan. 2007. Assessment of genetic variation and inheritance mode of some metric traits in cotton (*Gossypium hirsutum* L.). 2007. J. Agric. Soc. Sci. 3: 112-116.
12. Ali, M.A., I.A. Khan, S.I. Awan, S. Ali and S. Niaz. 2008. Genetics of fiber quality traits in cotton (*Gossypium hirsutum* L.). Aust. J. Crop Sci. 2: 10-17.
13. Ali Q, Ahsan M, Ali F, Aslam M, Khan NH, Munzoor M, Mustafa HSB, Muhammad S. 2013. Heritability, heterosis and heterobeltiosis studies for morphological traits of maize (Zea mays L.) seedlings. Adv. life sci., 1(1): 52-63.
14. Ali, Q., Ali, A., Tariq, M., Sarwar, B., Ahmad, M., Awaan, M. F., ... & Husnain, T. (2014). Gene Action for Various Grain and Fodder Quality Traits in Zea Mays. *Journal of Food and Nutrition Research*, *2*(10), 704-717.
15. Ali Q, Ali A, Ahsan M, Ali S, Khan NH, Muhammad S, Abbas HG, Nasir IA, Husnain T. 2014a. Line × Tester analysis for morpho-physiological traits of Zea mays L. seedlings. Adv. life sci., 1(4): 242-253.
16. Ashokkumar, K. and R. Ravikesavan . 2008. Genetic studies of combining ability estimates for seed oil, seed protein and fibre quality traits in upland cotton (*G. hirsutum* L.). Res. J. Agric. Biol. Sci. 4: 798-802.
17. Ashokkumar, K., R. Ravikesavan and K.S.J. Prince. 2010. Combining ability estimates for yield and fibre quality traits in line × tester crosses of upland cotton (*Gossypium hirsutum*). Int. J. Biol. 2: 179-189.
18. Asif, M., J.I. Mirza and Y. Zafar. 2008. Genetic analysis for fiber quality traits of some cotton genotypes. Pak. J. Bot. 40: 1209-1215.
19. Azhar, F.M., A. Hussain and A. Shakeel. 2007. Combining ability of plant characters related to earliness in (*Gossypium hirsutum* L.). J. Agric. Soc. Sci. 30: 342-349.
20. Cheatham, C.L., J. Wu, J.N. Jenkins, C.E. Watson J.C. Mccarty. 2003. Genetic variances and combining ability of crosses of American cultivars, Australian cultivars, and wild cottons. J. Cotton Sci. 7: 16-22.
21. Deosarkar, D.B., D.S. Jadhav and S.G. Patil. 2009. Combining ability studies for yield and quality traits in cotton (*Gossypium hirsutum* L.). J. Cotton Res. Dev. 23: 183-187.

22. Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. Aust. J. Biol. Sci. 9: 463-493.
23. Gupta, S.P. and T.H. Singh. 2012. Combining ability in F1 and advanced generations of a diallel cross in upland cotton *(Gossypiun hirsutum* L.). Indian J. Genet. Plant Breed. 46: 345-347.
24. Haq, I. and F.M. Azhar. 2004. Genetic basis of varietal differences for seed cotton yield and its components in *hirsutum* spp. Int. J. Agric. Biol. 6: 76-83.
25. Hussain, A., F.M. Azhar, M.A. Ali, S. Ahmad and K. Mahmood. 2010. Genetic studies of fiber quality characters in upland cotton. J. Anim. Plant Sci. 20: 234-238.
26. Hussain, M., F.M. Azhar and A.A. Khan. 2009. Genetics of inheritance and correlations of some morphological and yield contributing traits in upland cotton. Pak. J. Bot. 41: 2975-2986.
27. Iqbal, M., K. Hayat, M. Atiq and N.I. Khan. 2008. Evaluation and prospect of F_2 genotypes of cotton (*Gossypium hirsutum*) for yield and yield components. Int. J. Agri. Biol. 10: 442-446.
28. Iqbal, M., M. Naeem, M. Rizwan, W. Nazeer, M.Q. Shahid, U. Aziz, T. Aslam and M. Ijaz. 2013. Studies of genetic variation for yield related traits in upland cotton. American-Eurasian J. Agric. and Environ. Sci. 13: 611-618.
29. Ishaq, M.A. and T.M. Khan. 2011. Estimation of variation in some economic plant traits of upland cotton (*G. hirsutum* L.). The Pak. Cottons, 37: 15-20.
30. Islam, Z., H.A. Sadaqat and F.A. Khan. 2001. Combining ability of some hirsute cotton types for economic traits. Int. J. Agri. Biol. 3: 411-412.
31. Jatoi, W.A. M.J. Baloch, N.F. Veesar and S.A. Panhwar. 2011. Combining ability estimates from line × tester analysis for yield and yield components in upland cotton genotypes. J. Agric. Res. 49: 165-172.
32. Kaliyaperumal, A., R. Ravikesavan, I.V. Satange and L.D. Meshram. 2009. Combining abilities and inheritance of yield components in influential upland cotton varieties. Int. J. Plant Sci. 2: 37-45.
33. Karademir, C., E. Karademeir, R. Ekinci and O. Gencer. 2009. Combining ability estimate and hetrosis for yield and fiber quality of cotton in line × tester design. Not. Bot. Hort. Agrobot. Cluj. 37: 228-229.
34. Khan, N.U., K.B. Marwat, G. Hassan, M.B. Kumbhar, Farhatullah, Z.A. Soomro, N. Khan, A. Parveen and Umm-e-aiman. 2009. Study of fiber quality traits in upland cotton using additive-dominance model. Pak. J. Bot. 41: 1271-1283.
35. Khan, T. M., I.A. Khan, M. A. Khan, N. Murtaza and A.M. Khan. 1992. Genetic analysis of upland cotton under Faisalabad conditions. I. yield of seed cotton and its components. Pak. J. Agri. Sci. 29: 89-93.
36. Khan, T.M. and M.U. Qasim. 2012. Genetic studies of yield traits in cotton (*Gossypium hirsutum* L.). J. Agric. Res. 50: 21-28
37. Kiani, G., G.A. Nematzadeh, S.K. Kazemitabar and O.A. Shah. 2007. Combining ability in cotton cultivar for agronomic traits. Int. J. Agric. Biol. 9: 521-522.
38. Larik, S. Z.A.. A.S.,M.B. Kumbhar and M.L. Rajput. 2008. Genetic analysis of yield and yield components in *Gossypium hirsutum* L. Pak. J. Agric. Res. 21: 1-4.
39. Latif, A., T. Ahmad, S. Hayat, G. Sarwar, M.Z. Ehsan, M. Raza, M. Sarwer and I.A. Khan. 2014. Genetics of yield and some yield contributing traits in upland cotton (*G. hirsutum* L.). J. plant breed. Crop Sci. 6: 57-63.
40. Mendez-natera, J.R., A. Rondon, J. Hemandez and J.F. Merazo-pinto. 2007. Genetic studies in upland cotton (*Gossypium hirsutum* L.) i. heterotic effects. Pak. J. Bot. 39: 385- 395.
41. Mert, M., O. Gencer. Y. Akiscan and K. Boyaci. 2003. Determination of superior parents and hybrid combinations in respect to lint yield and yield components in cotton (*Gossypium hirsutum* L.). Turk . J. Agric. 27: 337-343.
42. Mohamed, B. B., Sarwar, M. B., Hassan, S., Rashid, B., Aftab, B., & Husnain, T. (2015). Tolerance of Roselle (Hibiscus Sabdariffa L.) Genotypes to Drought Stress at Vegetative Stage. *Advancements in Life Sciences*, *2*(2), 74-82.
43. Mustafa, G, Ehsanullah, Saif-ul-Malook, M Sarfaraz, MK Shahbaz U Chopra and Q, Ali. A review of production for various Bt and non Bt cotton varieties in Pakistan. *Nat Sci* 2014;12(11):81-91.
44. Nadeem, K. and F.M. Azhar. 2004. Genetic analysis of seed cotton yield and its components in *Gossypium hirsutum* L. Int. J. Agri. Biol. 6: 865-868.
45. Neelima, S., and V.C. Reddy. 2008. Genetic parameters of yield and fiber quality traits in American cotton (*Gossypium hirsutum* L.). Indian J. Agric. Res. 42: 67-70
46. Pakistan Economic Survey. 2012-13. Govt. of Pakistan, Ministry of Finance, Economic Advisor's Wing, Islamabad.
47. Panhwar, S.A., M.J. Baloch, W.A. Jatoi, N.F. Veesar and M.S. Majeedano. 2008. Combining

ability estimates from line × tester mating design in upland cotton. Proc. Pak. Acad. Sci. 45: 69-74.
48. Patel, A.D., and V. Kumar. 2009. Diallel analysis for combining ability for seed cotton yield and its component traits in upland cotton. J. Cotton Res. Dev. 23: 222-225.
49. Patil, S. A., M.R. Naik and A.B. Patil. 2011. Line x tester analysis for seed cotton yield and fibre quality traits in *(Gossypiun hirsutum* L.). Plant Archives. 1: 525-528.
50. Poehlman, J.M. and D.A. Sleper. 1995. Breeding Field Crops. Lowa State Univ. Press.
51. Rashid, A., W. Malik, A.A. Khan, N. Murtaza, A. Qayyum and E. Noor. 2009. Genetic evaluation of fiber yield and yield components in fifteen cotton (*Gossypium hirsutum*) genotypes. Int. J. Agric. Biol. 11: 581-585.
52. Puspito AN, Rao AQ, Hafeez MN, Iqbal MS, Bajwa KS, Ali Q, Rashid B, Abbas MA, Latif A, Shahid AA, Nasir IA and Husnain T (2015). Transformation and evaluation of Cry1Ac+Cry2A and GT Gene in Gossypium hirsutum L. *Front. Plant Sci.* **6**:708. doi:10.3389/fpls.2015.00708.
53. Rauf, S., H. Munir, S.M.A. Basra, and E. Abdullojon. 2006. Combining ability analysis in upland cotton (*Gossypium hirsutum* L.). Int. J. Agric. Biol. 3: 341-343.
54. Salahuddin, S., S. Abro, M.M. Kandhro, L. Salahuddin and S. Laghari. 2010. Correlation and path coefficient analysis of yield components of upland cotton (*Gossypium hirsutum* L.). World Appl. Sci. J. 8: 71-75.
55. Samreen, K., M.J. Baloch, Z.A. Somroo, 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 (*Gossypium hirsutum* L.). Sarhad J. Agric. 24: 581-586.
56. Schwartz, B.M. and C.W. Smith. 2008. Genetic gain in yield potential of upland cotton under varying plant densities. Crop Sci.48: 601-605.
57. Shakeel, A., S. Ahmad, M. Naeem, M.H.N. Tahir, M.F. Saleem, S. Freed, W. Nazeer. 2012. Evaluation of *Gossypium hirsutum* L. Genotypes for combining ability studies of yield and quality traits. Iğdır Univ. J. Inst. Sci. and Tech. 2: 67-74.
58. Shaukat, S., T.M. Khan, A. Shakeel and S. Ijaz. 2013. Estimation of best parents andsuperior cross combinations for yield and fiber quality related traits in upland cotton (*Gossypium hirsutum* L.). Sci. Tech. Dev. 32: 281-284.
59. Singh, S., V.V. Singh and A.D. Chaudary. 2010. Combining ability estimates for oil content, yield components and fiber quality traits in cotton (*G. hirsutum*) using an 8x8 diallel mating design. Trop. subtrop. Agro. ecosyst. 12: 161-166.
60. Soomro, Z.A., M.S. Kalwar, M.I. Memon and M.D. Keerio. 1995. Genetic analysis of yield and yield components in intraspecific crosses of (*Gossypium hirsutum* L.). Pak. J. Bot. 2: 431-434.
61. Sprague, G.F. and L.A. Tatum. 1942. General vs. Specific combining ability in single crosses of corn. J. Am. Soc. Agron. 34: 923-932.
62. Swamy, M.L., M. Gopinath, K.G.K. Murthy. 2013. Line × tester analysis for yield and yield attributes in upland cotton (*Gossypium hirsutum* L.) Helix. 5: 378-382.
63. Tabasum, A., I. Aziz, M.J. Asghar and M.Z. Iqbal. 2012. Inheritance of seed cotton yield and related traits in cotton (*Gossypium hirsutum* L.). Pak. J. Bot. 44: 2027-2031.
64. Thomson, N.J., and D.J. Luckett. 2011. Heterosis and combining ability effects on cotton. Int. J. Crop Sci. 2: 37-45.
65. Zeng, L., W.R. Meredith, D.L. Boykin and E. Taliercio. 2007. Evaluation of an exotic germplasm population derived from multiple crosses among *Gossypium* tetraploid species. J. Cotton Sci. 11: 118-127.

10/11/2015