Pak. J. Bot., 43(3): 1713-1718, 2011.

GENETIC POTENTIAL AND HERITABILITY STUDIES FOR SOME POLYGENIC TRAITS IN COTTON (*GOSSYPIUM HIRSUTUM* L.)

MUSHTAQ AHMAD[1*], NAQIB ULLAH KHAN[1], FIDA MOHAMMAD[1], SHERAZ AHMED KHAN[1], IQBAL MUNIR[2], ZARINA BIBI[3] AND SALMA SHAHEEN[3]

[1]*Department of Plant Breeding and Genetics, Khyber Pakhtunkhwa Agricultural University, Peshawar, Pakistan.*
[2]*Institute of Biotechnology and Genetic Engineering, Khyber Pakhtunkhwa Agricultural University, Peshawar, Pakistan*
[3]*Department of Soil and Environmental Sciences, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan.*

Abstract

The research work comprising genetic potential and heritability in a 6 × 6 F_1 diallel cross of upland cotton was conducted during 2008 and 2009 at Khyber Pakhtunkhwa Agricultural University, Peshawar, Pakistan. The parental cultivars used in the diallel crosses were CIM-473, CIM-496, CIM-499, CIM-506, CIM-554 and CIM-707. Genotypes manifested significant variations for plant height, monopodia plant^{-1}, sympodia plant^{-1}, bolls sympodia^{-1}, bolls plant^{-1} and seed cotton yield plant^{-1}. On average, the F_1 hybrids manifested significant increase over parents for plant height (11.5%), sympodia plant^{-1} (6.34%), bolls sympodia^{-1} (4.83%), bolls plant^{-1} (9.95%) and seed cotton yield plant^{-1} (26.07%). Broad sense heritability was high with expected response to selection being for plant height (0.81 & 17.85 cm), monopodia plant^{-1} (0.95 & 0.49), sympodia plant^{-1} (0.92 & 4.00), bolls sympodia^{-1} (0.90 & 0.74), bolls plant^{-1} (0.90 & 9.45) and seed cotton yield plant^{-1} (0.76 and 38.84 g), respectively. Seed cotton yield exhibited significant positive correlation with all traits except monopodia plant^{-1}. Parental cultivars CIM-506 and CIM-554 performed better in their specific cross combinations and revealed reasonable mean performance. The F_1 hybrids CIM-506 × CIM-554, CIM-473 × CIM-554, CIM-554 × CIM-506 and CIM-554 × CIM-707 manifested best genetic potential for majority of the traits. Results also revealed that the above four F_1 hybrids have the potential to be used for hybrid cotton production and can also be studied in segregating generations for further improvement and stability in their genetic potential for seed cotton yield and its components.

Introduction

Worldwide cotton (*Gossypium hirsutum* L.) is a major fiber crop and sixth largest source of vegetable oil in the world (Alishah *et al*., 2008). Cotton contributing about 2% to GDP and 8.2% of value added in Agriculture and has leading role of around 70% share in edible oil industry of Pakistan (Khan, 2003). In this context, awareness among growers, millers and exporters is must for improving and maintaining cotton standards to compete in the international market (Khan *et al*., 2009b & 2009c). Our yields are still very low and stagnant for the last several years as compared to other cotton growing countries. Factors responsible for the stagnant cotton production includes excessive rains at sowing time, high temperature and its fluctuations at the flowering stage, late wheat harvesting resulting a decline of area planted to cotton, incidence of cotton leaf curl virus (CLCuV) and lack of CLCuV resistant varieties, pest attack and improper production technology in the major cotton growing areas.

Heritability and genetic potential studies of different cultivars in form of their expression for different morpho-yield traits are earnestly needed for selection of parental lines for breeding programme (Ahmad, 2010; Khan *et al*., 2010; Batool *et al*., 2010; Batool, 2011). The yield is highly complex character and is directly influenced by the different morpho-yield traits. A thorough knowledge about the nature and genetic potential of different genotypes, inheritance pattern of different traits and extent of relationship and correlation of yield with various agronomic characters is crucial for breeder to tackle the problem and increase the yield successfully (Ahmad *et al*., 2008; Makhdoom *et al*., 2010; Makhdoom, 2011).

Cotton stability and adaptability have been studied and observed varied values for different morphological and yield related traits (Suinaga *et al*., 2006; Taohua & Haipeng, 2006; Khan *et al*., 2007; Meena *et al*., 2007). Genetic variability and positive correlation were observed for yield traits in *G. hirsutum* (Khan *et al*., 1999; Iqbal *et al*., 2003; Wang *et al*., 2004; Khan *et al*., 2010; Makhdoom *et al*., 2010, Makhdoom, 2011). Overall performance of a genotype may vary due to changes in environment and the higher the heritability, the simpler the selection process and greater the response to selection (Larik *et al.*, 1997 & 2000; Soomro *et al*., 2008). Substantial genetic variances and high heritability estimates implied that characters could be improved through selection from segregating populations (Baloch, 2004; Khan *et al*., 2000; Khan *et al*., 2009b; Batool *et al*., 2010; Batool, 2011). Heritability estimates were generally found to be high in intraspecific crosses of *G. hirsutum* comparative to *G. barbadense* crosses except for days to flowering and lint % (Esmail, 2007).

The success of cotton breeding programme is primarily based on the choice and use of promising parental lines for hybridization, followed by selection for favorable gene combinations. Consequently, in plant breeding, the identification and use of genotypes with better genetic potential is a continuous pre-requisite for synthesis of physiologically efficient and genetically superior genotypes showing promise for increased production on per unit area under a given set of environments. The economic significance of hybrid cotton cultivation, and the importance of selected hybrids which have lower inbreeding depression and superior performance than well-adapted cultivars mandated a research project to evaluate the manifestation of genetic potential and heritability in a 6 × 6 F_1 diallel cross for different morpho-yield traits in upland cotton.

Materials and Methods

Breeding material and experimental procedure: The research work comprising genetic potential in 6 × 6 F_1 diallel hybrids and their parents and heritability in different traits of *Gossypium hirsutum* L., during 2008-2009 at Khyber Pakhtunkhwa Agricultural University, Peshawar-Pakistan. Six diverse genotypes (CIM-473, CIM-496, CIM-499, CIM-506, CIM-554 and CIM-707) of upland cotton varying in pedigree, year of release, and morph-yield traits, were hand sown during May, 2008 and were crossed in a complete diallel fashion. During May, 2009, the parents and 30 F_1s were also hand sown in a randomized complete block (RCB) design. Parents and F_1s were planted in a single row measuring six meter with four replications. The row and plant spacings were 75 and 30 cm, respectively. Thinning was performed after 15 to 20 days when the plant height reached up to 15 to 20 cm to ensure single plant per hill. Recommended cultural practices were carried out and the crop was grown under uniform field conditions to minimize environmental variations to the maximum possible extent. Picking was made during the month of November on individual plant basis.

*E-mail: mushi_dir@yahoo.com

Traits measurement and statistical analyses: Data was recorded on individual plant basis on plant height, monopodia plant^{-1}, sympodia plant^{-1}, bolls sympodia^{-1}, bolls plant^{-1} and seed cotton yield plant^{-1}. All the data were subjected to analysis of variance (ANOVA) technique according to Steel & Torrie (1980) to test the null hypothesis of no differences between various F_1 populations and their parental line means. The least significant difference (LSD) test was also used for means separation and comparison after significance. Heritability (broad sense) was calculated according to Singh & Chaudhary (1985). The simple correlation coefficient (r) of seed cotton yield with other yield components was also worked out according to Kwon & Torrie (1964).

Results and Discussion

According to analysis of variance (Table 1), the mean values of 30 F_1 diallel hybrids and their six parental cultivars manifested highly significant differences for plant height, monopodia per plant, sympodia per plant, bolls per sympodia, bolls per plant and seed cotton yield per plant. Results revealed that there are significant variations in the genotypes for majority of the traits and have room for further improvement also. The trait-wise results are given as under.

Plant height: Plant height varied from 75.84 to 119.8 cm among the parental cultivars, while 81.69 to 143.90 cm in their F_1 hybrids (Fig. 1). The highest plant height (143.90 cm) was observed in cross CIM-473 × CIM-554; however, it was found statistically at par with 10 other F_1 hybrids ranged from 107.00 to 136.80 cm. CIM-499 revealed minimum plant height (75.84 cm) and was found at par also with three parents and 15 F_1 hybrids ranged from 81.69 to 99.65 cm. Broad sense (bs) heritability and expected response to selection values for said trait were 0.81 and 17.85 cm, respectively (Table 2). The correlation of plant height was positively significant (r = 0.563) with seed cotton yield per plant (Table 3).

Plant height is one of the important traits and has vital role in managing the seed cotton yield. Taller parents and hybrids showed medium to high number of bolls plant^{-1}. Results revealed that plant height has some association with bolls plant^{-1}. It was also noticed that bolls plant^{-1} does not entirely depend on plant height, but plant height contribution cannot be ignored. In mean performance of F_1 hybrids, 11.5% increase over parents was observed. High broad sense heritability with expected response to selection also authenticated that the genetic variance play vital role in inheritance of the said trait. Khan *et al*., (2009a & 2010) observed that genetic variances were greater than the environmental variances for majority of the traits with high heritability and genetic gain. Plant height was significantly positive correlated with seed cotton yield. Mustafa *et al*., (2007) noticed that plant height, bolls per plant and ginning outturn were the most important components in determining lint yield. Mostly breeders are interested in short stature cotton plants for easy picking and to skip the lodging threat. However, plant height was found positively correlated with seed cotton yield, if lodging didn't occur (Khan *et al*., 2003). Plant height was positively correlated with seed cotton yield and bolls per plant in upland cotton genotypes (Arshad *et al*., 1993). Tyagi (1994) also observed positive correlation between plant height and seed cotton yield and their studies further revealed that characters such as plant height contributed 70% of total variability for seed cotton yield.

Monopodia plant^{-1}: Monopodia per plant varied from 0.38 to 1.03 among the parental genotypes while 0.22 to 1.59 in their F_1 hybrids (Fig. 2). The lowest monopodia per plant were recorded in CIM-496 × CIM-499 (0.22), which was also found statistically equal with two parental cultivars and 11 F_1 hybrids ranged from 0.31 to 0.67. The hybrid CIM-506 × CIM-499 showed maximum monopodia (1.59) and was found at par with seven other F_1 genotypes ranged from 1.18 to 1.40. Monopodia per plant were mostly found negatively correlated with seed cotton yield; therefore the breeders are interested in less or no monopodia. Heritability (bs) and expected response to selection values for the monopodia were 0.95 and 0.49, respectively (Table 2) and the correlation with seed cotton yield per plant was negative (Table 3). Greater genetic variability with desirable significant decrease in monopodia was also observed in F_1 diallel hybrids as compared to their parental cultivars (Khan *et al*., 1991, 2000; Ahmad *et al*., 2008).

Monopodia, the vegetative branches were found negatively correlated with yield. Results revealed that if the number of monopodia increased the plants become bushy which ultimately decrease the flowering and boll bearing and eventually the seed cotton yield also decreased. However, Tariq *et al*., (1992) derived positive correlation of seed cotton yield with six yield components including monopodia per plant in *G. hirsutum*. Mandloi *et al*., (1996) concluded genotype × environmental interaction and observed significant differences for monopodia. Murthy (1999) worked out genotypic correlation and concluded that monopodia have positive correlation with bolls per plant. Plant height, monopodia and bolls per plant were observed to be significantly correlated with seed cotton yield (Hussain *et al*., 2000). However, it is mentioned in most of the literature that monopodia, GOT and staple length had negative association with yield. The contradictions of findings with literature might be due different breeding material used under varied environments.

Sympodia plant^{-1}: Sympodia per plant varied from 11.09 to 18.51 among the cultivars, while 12.00 to 24.55 in F_1 cross combinations (Fig. 3). The maximum sympodia revealed by F_1 hybrid CIM-506 × CIM-554 (24.55). However, it was also found at par with 10 other F_1 hybrids with range of 16.80 to 23.41. The lowest sympodia per plant were shown by cultivar CIM-499, and were found at par with six other genotypes ranged from 12.03 to 13.03. All other genotypes showed medium values for fruiting branches per plant. Sympodia per plant were having direct relationship with bolls per plant seed cotton yield. The values for heritability (bs) and expected response to selection for sympodia per plant were 0.92 and 4.00, respectively (Table 2) and has significant positive correlation (r = 0.712) with seed cotton yield per plant (Table 3).

Sympodia, the fruiting branches has important role in managing yield through bolls per plant. Overall 6.34% increase in sympodia was noted in F_1 hybrids as compared to their parents. Results also revealed high heritability with expected genetic gain and positive correlation of sympodia with seed cotton yield. Mustafa *et al*., (2007) observed that lint yield had a significant positive correlation with sympodial branches, bolls per plant and plant height. Higher magnitudes of genetic variability and heritability with selection response were observed for the said trait (Khan *et al*., 1991, 1999, 2000 and 2009a). Hussain *et al*., (2000) determined genetic correlation using 56 F_2 families and their eight parents of G. *hirsutum*. Plant height also showed positive and significant relationship with sympodial branches. Therefore, they suggested that plant height, sympodial branches and ginning outturn may be considered as selection criteria for improvement in seed cotton yield and fiber quality traits. Memon *et al*., (2002) observed highly significant positive correlation between sympodia and seed cotton yield of upland cultivars. Greater genetic variability and significant positive correlation was observed between fruiting branches and seed cotton yield (Arshad *et al*., 1993; Murthy, 1999; Djaboutou *et al*., 2005).

Table 1. Mean squares and CV for different traits in a 6 × 6 F_1 diallel cross of upland cotton.

Parameters	Mean squares		CV%
	Genotypes	Error	
Plant height	733.70**	135.15	11.37
Monopodia plant^{-1}	0.42**	0.02	17.90
Sympodia plant^{-1}	28.79**	2.14	9.18
Bolls sympodia^{-1}	1.06**	0.10	14.85
Bolls plant^{-1}	139.56**	15.73	14.86
Seed cotton yield plant^{-1}	3009.42**	701.61	26.13

** Significant at $p \leq 0.01$, CV = Coefficient of variation

Table 2. Heritability (bs) and expected response to selection (Re) for various traits in a 6 × 6 F_1 diallel cross of upland cotton.

Parameters	Heritability (bs)	Re
Plant height	0.81	17.85 cm
Monopodia plant^{-1}	0.95	0.49 #
Sympodia plant^{-1}	0.92	4.00 #
Bolls sympodia^{-1}	0.90	0.74 #
Bolls plant^{-1}	0.88	9.25 #
Seed cotton yield plant^{-1}	0.76	38.84 g

Table 3. Correlation of seed cotton yield with other traits in a 6 × 6 F_1 diallel cross of upland cotton.

Parameters	Correlation with seed cotton yield	Std. Error
Plant height	0.56**	0.19
Monopodia plant^{-1}	-0.015^{NS}	11.46
Sympodia plant^{-1}	0.71**	0.95
Bolls sympodia^{-1}	0.46**	6.14
Bolls plant^{-1}	0.602**	0.43

** = Highly significant, N.S. = Non-significant

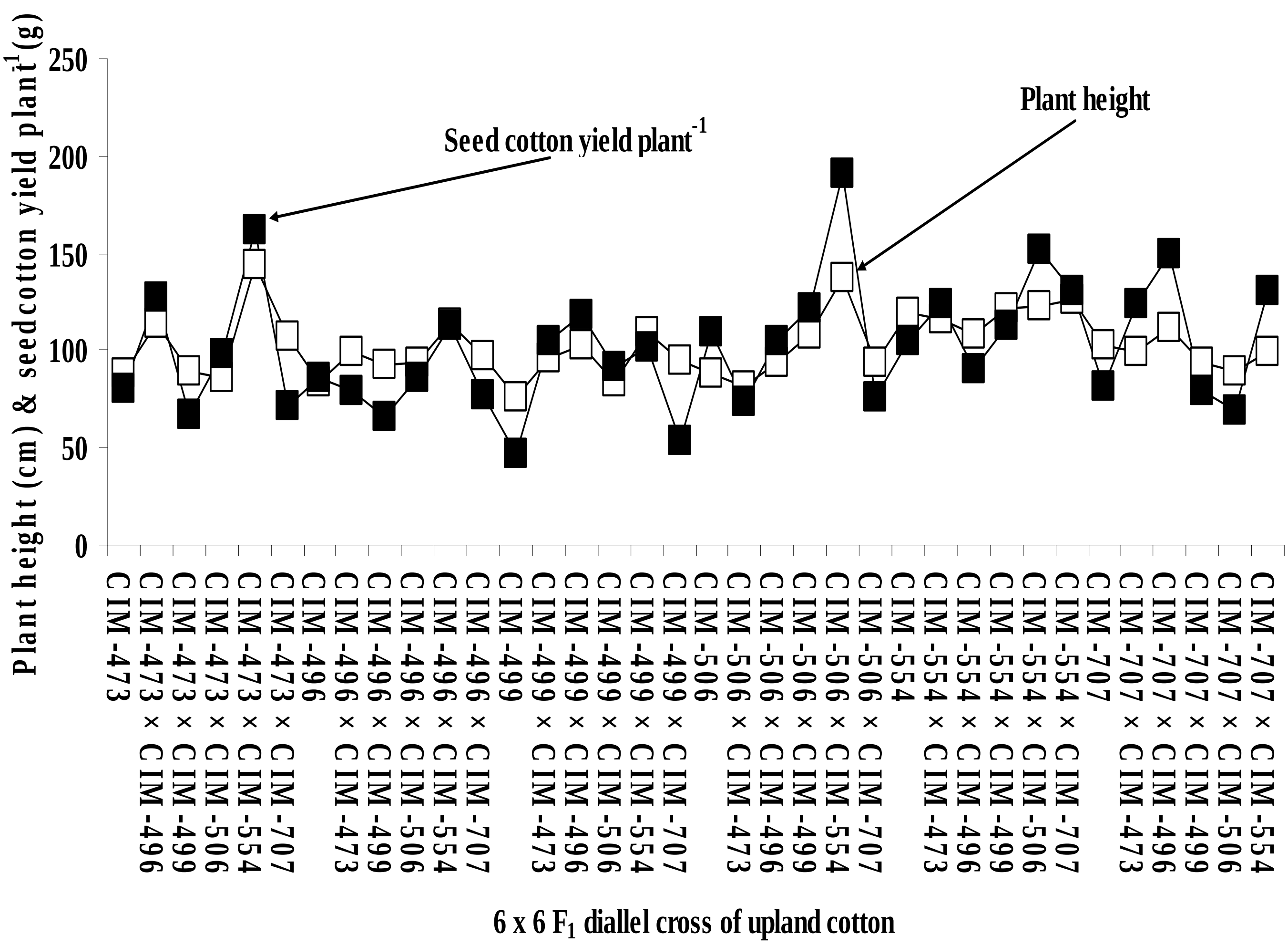

Fig. 1. Mean performance for seed cotton yield plant^{-1} and plant height in a 6 × 6 F_1 diallel cross of upland cotton.

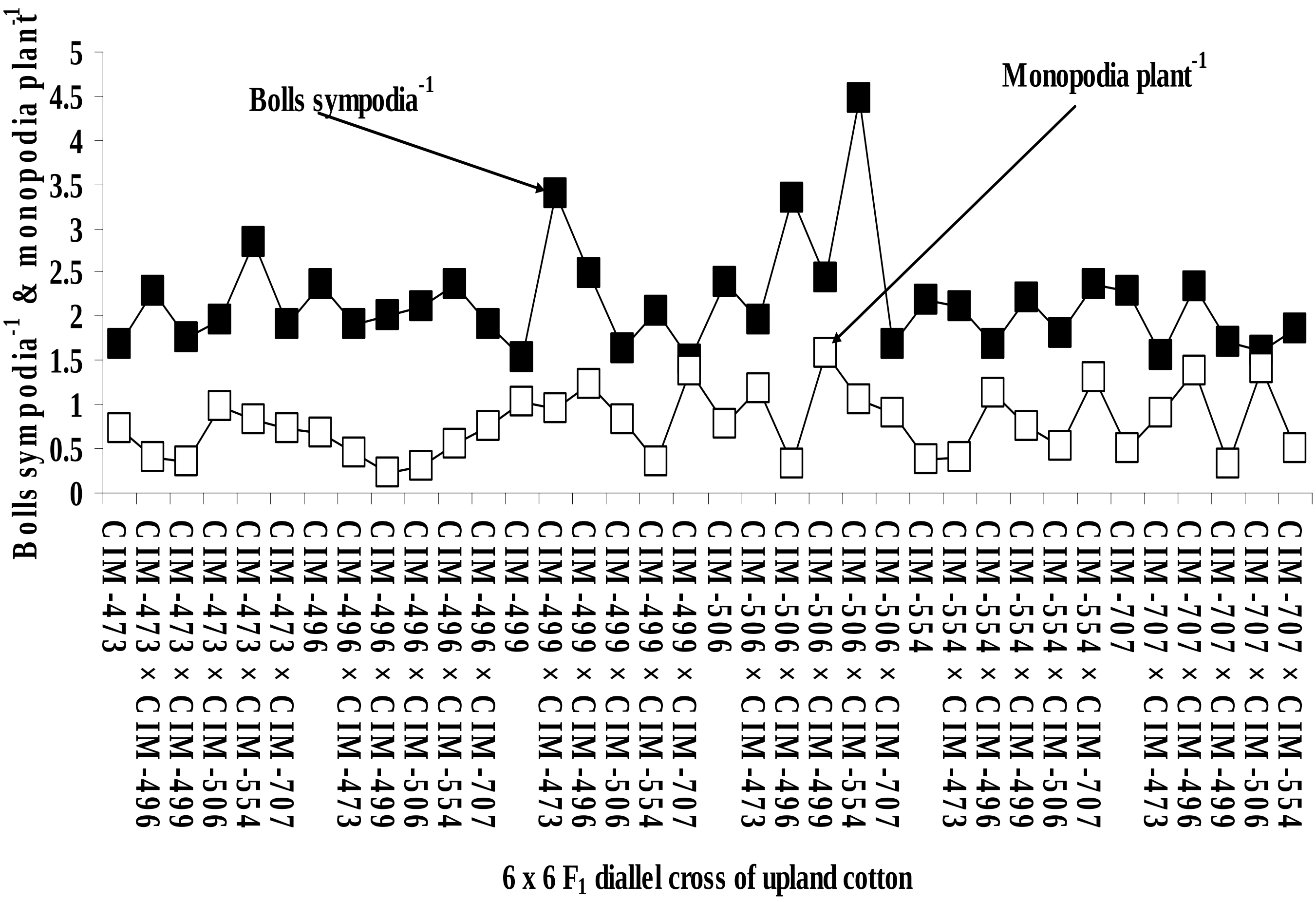

Fig. 2. Mean performance for bolls sympodia^{-1} and monopodia plant^{-1} in a 6 × 6 F_1 diallel cross of upland cotton.

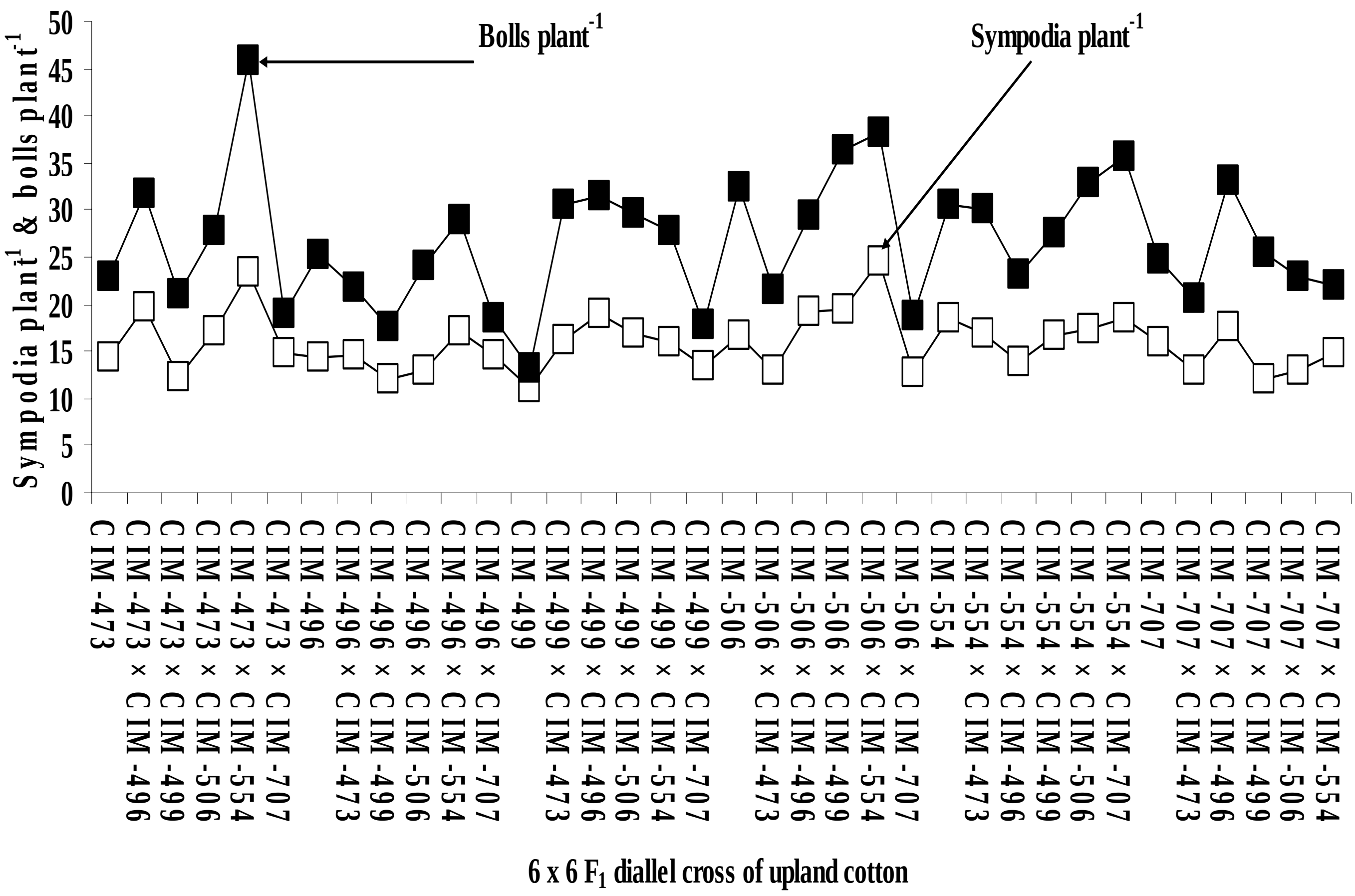

Fig. 3. Mean performance for bolls plant^{-1} and sympodia plant^{-1} in a 6 × 6 F_1 diallel cross of upland cotton.

Bolls sympodia^{-1}: Bolls per sympodia varied from 1.54 to 2.38 among the parent cultivars, while 1.52 to 4.48 in their F_1 diallel hybrids. Maximum bolls per sympodia were recorded in cross CIM-506 × CIM-554 (4.48) (Fig. 2). Four other F_1 cross combinations with range of 2.50 to 3.38 followed the said promising hybrid. The minimum bolls per sympodia were revealed by cross combinations CIM-499 × CIM-707 (1.52) and CIM-707 × CIM-506 (1.53) and were also found at par with three parental cultivars and 18 F_1 hybrids having range of 1.53 to 2.20. Other genotypes have medium number of bolls per sympodia. The estimates of heritability (bs) and expected genetic gain for boll per sympodia were 0.90 and 0.74, respectively (Table 2) and also has significant positive correlation (r = 0.46) with seed cotton yield per plant (Table 3).

Bolls per sympodia also play an important role in managing seed cotton yield and act as a major yield component and showed 4.83% increase in F_1 hybrids as compared to parents. Results exhibited that bolls per sympodia were found positively correlated with seed cotton yield, therefore, the cultivars having maximum bolls per sympodia also provided increased seed cotton yield. The heritability and expected response to selection also exhibited that bolls per sympodia were mostly administered by genetic variance and has span for further improvement. Tariq *et al*., (1992) observed positive correlation between seed cotton yield and six other yield components including bolls per sympodia in *G. hirsutum* cultivars. Arshad *et al*., (1993) and Baloch (2004) observed positive correlation among plant type characteristic like bolls per sympodia and seed cotton yield. Plant height showed positive and significant relationship with fruiting branches and that association may be considered as selection criteria to have indirect improvement in seed cotton yield (Hussain *et al*., 2000).

Bolls plant^{-1}: Regarding the mean performance, the bolls per plant varied from 13.30 to 32.23 among the parent cultivars, while 17.55 to 45.83 in F_1 cross combinations (Fig. 3). Maximum bolls per plant revealed by cross CIM-473 × CIM-554 (45.83) and was also found statistically at par with three cross combinations CIM-506 × CIM-554 (38.18), CIM-506 × CIM-499 (36.43) and CIM-554 × CIM-707 (35.67). The minimum bolls per plant were exhibited by parental genotype CIM-499 (13.30) and were closely followed by one parent and 10 F_1 genotypes (17.55 to 22.96). The remaining genotypes showed medium values for bolls per plant. The heritability (bs) and genetic gain values for bolls per plant were 0.88 and 9.25, respectively (Table 2) and has significant positive association (r = 0.602) with seed cotton yield (Table 3).

Bolls per plant is a major yield component and has extra ordinary role in supervision of seed cotton yield. By comparing with parent cultivars, 9.95% enhancement for bolls per plant was noticed in F_1 hybrids. Greater genetic variability and significant increase in bolls per plant was also noticed in F_1 hybrids as compared to their parental cultivars and positive correlation between bolls and seed cotton yield (Desalegn *et al*., 2009; Khan *et al*., 1999, 2000 & 2007). Correlation analysis showed that bolls per plant had the closest relation with lint yield. Moreover, there were significantly positive correlations among bolls per plant, boll weight and lint %, which indicated that these three yield traits, can be simultaneously improved. High positive and significant correlation was observed between bolls plant^{-1} and seed cotton yield, along with heritability and expected response to selection. Correlations of bolls per plant and boll weight with seed cotton yield were significantly positive and had profound direct positive influence on yield (Azhar *et al*., 1997). Alam & Islam (1991) and Desalegn *et al*., (2009) derived that high lint %, more bolls per plant and a small seed size were positively correlated to high lint yield. High heritability and genetic gain were recorded for bolls sympodia^{-1}, bolls plant^{-1} and seed cotton yield (Elsiddig *et al.*, 2007; Khan *et al.*, 2009a). This type of correlation is desirable by cotton breeders and little genetic gain in bolls per plant, boll weight and bolls per sympodia will be a great accomplishment.

Seed cotton yield plant^{-1}: Seed cotton yield per plant ranged from 46.77 to 109.56 g among the parental cultivars, while 53.68 to 190.88 g in F_1 hybrids (Fig. 1). The maximum seed cotton yield per plant (190.88 g) was owned by F_1 hybrid CIM-506 × CIM-554. It was also found statistically at par with three F_1 cross combination i.e., CIM-473 × CIM-554 (162.12 g), CIM-554 × CIM-506 (151.29 g) and CIM-707 × CIM-496 (149.12 g). The lowest seed cotton yield was noted in parent cultivar CIM-499 (46.77 g) and F_1 hybrid CIM-499 × CIM-707 (53.68 g). Other genotypes showed medium values for seed cotton yield per plant. The broad sense heritability and expected genetic advance for seed cotton yield were 0.76 and 38.84 g, respectively (Table 2). Khan *et al*., (1999 & 2000) also observed greater genetic variability and significant increase in seed cotton yield in F_1 hybrids as compared to their parental cultivars.

Seed cotton yield is an ultimate goal in growing cotton besides lint and overall 26.07% increase was noted in F_1 hybrids as compared to parents. Results revealed that heritability was high with desired expected response to selection and has positive correlation with majority of the yield components. It further authenticated that there is an opportunity for further improvement in seed cotton yield. Alam & Islam (1991), Baloch (2004) and Khan *et al*., (2007) observed that seed cotton yield exhibited positive and significant genotypic and phenotypic correlations with bolls per plant and boll weight. Path coefficient analysis revealed that bolls per plant had the maximum direct positive effect on seed cotton yield followed by boll weight. Selection for these two characters seemed to be most effective in the present materials. Genetic correlation of bolls per plant and boll weight with seed cotton yield was significantly positive (Azhar *et al*., 1997). Direct selection for greater number of big bolls will increase seed cotton yield. Bolls per plant and lint % had significant positive relationship with seed cotton yield (Hussain *et al*., 2000). Genetic variability, heritability, genetic advance and correlation of seed cotton yield at both phenotypic and genotypic levels was found significantly positive with bolls per plant and lint yield (Elsiddig *et al.*, 2007; Desalegn *et al*., 2009; Khan *et al*., 2009a & 2009b).

Conclusion

The parental cultivars CIM-506 and CIM-554 performed better in their specific cross combinations (CIM-506 × CIM-554, CIM-473 × CIM-554, CIM-554 × CIM-506 and CIM-554 × CIM-707) by crossing with each other or as paternal/maternal parent with other parental cultivars. These F_1 hybrids manifested best genetic potential and highest genetic variability for majority of the traits which can be used for hybrid cotton production and for selection in segregating generations for further improvement.

Acknowledgments

The authors wish to thank Muhammad Arshad, Director Central Cotton Research Institute (CCRI) Multan, and Sultan Masood and Hayatullah SSO,s Cotton Research Station, Dera Ismail Khan, Pakistan for their untiring guidance and help to provide free of cost cotton seed, and the full facilities of ginning seed cotton and testing of fiber quality traits.

References

Ahmad, M. 2010. *Heterotic performance and genetic variability in upland cotton* (*G. hirsutum*). M.Sc (Hons.) Thesis, Khyber Pakhtunkhwa Agril. Univ. Peshawar, Pakistan.

Ahmad, W., N.U. Khan, M.R. Khalil, A. Parveen, U. Aimen, M. Saeed, Samiullah and S.A. Shah. 2008. Genetic variability and correlation analysis in upland cotton. *Sarhad J. Agric*., 24(4): 573-580.

Alam, A.K.M.R. and H. Islam. 1991. Correlation and path coefficient analysis of yield and yield contributing characters in upland cotton in Bangladesh. *Annals of Bangladesh Agric*., 1(2): 87-90.

Alishah, O., M.B. Bagherieh-Najjar and L. Fahmideh. 2008. Correlation, path coefficient analysis of some quantitative and agronomic traits in cotton. *Asian. J. Biol. Sci*., 1(2): 61-68.

Arshad, M., M. Hanif, N. Ilahi and S.M. Shah. 1993. Correlation studies on some commercial cotton varieties of *G. hirsutum*. *Sarhad J. Agric*., 9(1): 49-53.

Azhar, F.M., T.M. Khan and A.M. Khan. 1997. Genetic correlation and path coefficient analysis of yield and its components in upland cotton. *J. Animal Plant. Sci*., 7(3-4): 69-71.

Baloch, M.J. 2004. Genetic variability and heritability estimates of some polygenic traits in upland cotton. *Pak. J. Sci. Indus. Res*., 42: 451-454.

Batool, S. 2011. *Diallel studies and heritability estimates using Hayman's approach in upland cotton*. M.Sc (Hons.) Thesis, Khyber Pakhtunkhwa Agril. Univ. Peshawar, Pakistan.

Batool, S., N.U. Khan, K. Makhdoom, Z. Bibi, G. Hassan, K.B. Marwat, Farhatullah, F. Mohammad, Raziuddin and I.A. Khan. 2010. Heritability and genetic potential of upland cotton genotypes for morpho-yield traits. *Pak. J. Bot*., 42(2): 1057-1064.

Desalegn, Z., N. Ratanadilok and R. Kaveeta. 2009. Correlation and heritability for yield and fiber quality parameters of Ethiopian cotton. *Kasetsart J. Nat. Sci*., 43(1): 1-11.

Djaboutou, C.M., S.O. Alabi, C.A. Echewku and F.C. Orakwue. 2005. Variability and interrelationship of some agronomic and fiber quality traits in multi–adversity cotton (*G. hirsutum* L.). *Agric. Trop. Subtrop*., 38(3-4): 7-13.

Elsiddig, A.A., M.M. Sid-Ahmed and A.E. Ibrahim. 2007. Variability, heritability and association of some characters in upland cotton. *Univ. of Khartoum J. Agril. Sci*., 15(2): 191-203.

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

Hussain, S.S., F.M. Azhar and I. Mahmood. 2000. Path coefficient and correlation analysis of some important plant traits of *G. hirsutum*. *Pak. J. Biol. Sci*., 3(9): 1399-1400.

Iqbal, M., M.A., Chang, M.Z. Iqbal, M. U. Hassan, A. Nasir and N.U. Islam. 2003. Correlation and path coefficient analysis of earliness and agronomic characters of upland cotton in Multan. *Pak. J. Agron*., 2: 160-168.

Khan, M.A., M. Hussain, M.A. Khan and R.A. Kainth. 1991. Estimation on heritable variation in four crosses of upland cotton. *J. Agric Res*., 29(3): 305-310.

Khan, N.U. 2003. *Genetic analysis, combining ability and heterotic studies for yield, its components, fibre and oil quality traits in upland cotton* (*G. hirsutum*). Ph.D Dissertation, Sindh Agril. Univ. Tandojam, Pakistan.

Khan, N.U., G. Hassan, K.B. Marwat, Farhatullah, S. Batool, K. Makhdoom, I. Khan, I.A. Khan and W. Ahmad. 2009a. Genetic variability and heritability in upland cotton. *Pak. J. Bot*., 41(4): 1695-1705.

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

Khan, N.U., G. Hassan, M.B. Kumbhar, S. Kang, I. Khan, A. Parveen, U. Aiman and M. Saeed. 2007. Heterosis and inbreeding depression and mean performance in segregating generations in upland cotton. *Eur. J. Scien. Res*., 17: 531-546.

Khan, N.U., H.K. Abro, M.B. Kumbhar, G. Hassan and G. Mahmood. 2000. Study of heterosis in upland cotton-II. Morphology and yield traits. *The Pak. Cottons*, 44: 13-23.

Khan, N.U., H.K. Abro, M.B. Kumbhar, G. Hassan and M. Khan. 1999. Exploitation of heterosis can combat cotton leaf curl virus (CLCuV) incidence in cotton (*G. hirsutum*). *The Pak. Cottons*, 43: 21-33.

Khan, N.U., K.B. Marwat, G. Hassan, Farhatullah, S. Batool, K. Makhdoom, W. Ahmad and H.U. Khan. 2010. Genetic variation and heritability for cottonseed, fiber and oil traits in *G. hirsutum*. *Pak. J. Bot*., 42(1): 615-625.

Khan, N.U., K.B. Marwat, G. Hassan, M.B. Kumbhar, Farhatullah, Z.A. Soomro, N. Khan, A. Parveen and U. Aiman. 2009c. Study of fiber quality traits in upland cotton using additive-dominance model. *Pak. J. Bot*., 41(3): 1271-1383.

Khan, U.Q., R.G. Cantrell and R. Steiner. 2003. Genetic variability for maturity characteristics in narrow rows cotton. *Sarhad J. Agric*., 19(4): 525-528.

Kwon, S.H. and J.H. Torrie. 1964. Heritability and interrelationship among traits of two soybean population. *Crop Sci*., 4: 194-198.

Larik, A.S., S.I. Malik, A.A. Kakar and M.A. Naz. 2000. Assessment of heritability and genetic advance for yield components in *G. hirsutum*. *Sci. Khyber*, 13: 39-44.

Larik, A.S., S.R. Ansari and M.B. Kumbhar. 1997. Heritability analysis of yield and quality components in *G. hirsutum*. *Pak. J. Bot*. 29: 97-101.

Makhdoom, K. 2011. *Combining ability estimates through line x tester analysis and heritability in upland cotton*. M.Sc (Hons.) Thesis, Khyber Pakhtunkhwa Agril. Univ. Peshawar, Pakistan.

Makhdoom, K., N.U. Khan, S. Batool, Z. Bibi, Farhatullah, S. Khan, F. Mohammad, D. Hussain, Raziuddin, M. Sajjad and N. Khan. 2010. Genetic aptitude and correlation studies in *Gossypium hirsutum*. *Pak. J. Bot*., 42(3): 2011-2017.

Mandloi, K.C., G.K. Koutu, and U.S. Mishra. 1996. Genotype × environment interaction and correlation studies in upland cotton. *JNKVV Res. J*., 30 (1-2): 16-18.

Meena, R., A.D. Monga and R. Kumar. 2007. Undiscriptive cotton cultivars of north zone: an evaluation. *J. Cotton Res. Dev*., 21: 21-23.

Memon, A.M., A.R. Soomro, R. Anjum and S. Bano. 2002. Correlation studies in four commercial upland varieties. *Indus J. Plant Sci*., 1(1): 49-52.

Murthy, J.S.V.S. 1999. Character association and component analysis in upland cotton. *Madras Agric. J*., 86(1-3): 39-42.

Mustafa, A., Y.M.A. Elsheikh and E.A. Babiker. 2007. Genetic variability and character association and selection criteria in cotton (G*. hirsutum*). *Sudan J. Agric. Res*., 8: 43-50.

Singh R.K. and B.D. Chaudhary. 1985. *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers Ludhiana, New Delhi. pp. 102-164.

Soomro, Z.A., A.S. Larik, M.B. Kumbhar, N.U. Khan and N.A. Panhwar. 2008. Correlation and path analysis in hybrid cotton. *SABRAO J. Breed. Genet*., 40: 49-56..

Steel, R.G.D. and J.H. Torrie. 1980. *Principles and procedures of statistics, a biological approach*, 2^{nd} ed. McGraw Hill, Inc. New York.

Suinaga, F.A., C.S. Bastos and L.E.P. Rangel. 2006. Phenotype adaptability and stability of cotton cultivars in Mato Grosso State, Brazil. *Pesquisa Agropecuaria Trop*., 36: 145-150.

Taohua, Z. and Z. Haipeng. 2006. Comparative study on yield and main agri-characters of five hybrids colored varieties. *J. Anhui Agric. Uni*., 33: 533-536.

Tariq, M., A.M. Khan and G. Idrees. 1992. Correlation and path coefficient analysis in upland cotton. *Sarhad J. Agric*., 8(3): 335-341.

Tyagi, A.P. 1994. Correlation coefficients and selection indices in upland cotton. *Ind. J. Agric. Res*., 28(3): 189-196.

Wang, C., A. Isoda and P. Wang. 2004. Growth and yield performance of some cotton cultivars in Xinjiang, China, an arid area with short growing period. *J. Agron. Crop Sci*., 190: 177-183.

(Received for publication 15 January 2010)