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GENOTYPE BY ENVIRONMENT AND PHENOTYPIC ADAPTABILITY STUDIES FOR YIELD AND FIBER VARIABLES IN UPLAND COTTON

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ABSTRACT

Identification of adaptable and stable genotypes is an important aspect of applied plant breeding which can insure sustainable crop production. Adaptability studies in cotton is an essential part of breeding for adequate evaluation of genotypes accomplished through environments (years/locations). Present studies were conducted in a randomized complete block design with three replications during 2010 and 2011 to evaluate adaptability of eight upland cotton genotypes through genotype by environment interaction (GEI). Genotype (G), environment (E) and GEI share in total sum of squares were also studied. Significant ($p \leq 0.01$) differences were observed among genotypes, environments (years) and G × E interaction means for majority traits, which assured greater genetic variability among the genotypes due to their divergent genetic make-up, as well as environments. The contribution to total sum of squares regardless of trait revealed that environments (0.42 to 89.55%) and genotypes (5.02 to 46.21%) play principal role followed by genotype × environment (3.40 to 40.00%), while experimental error share was negligible (0.12 to 21.37%). Larger effects of environment in combination with genotypes persuade the plant growth and morphology. Based on two-year studies, genotype CIM-496 showed best performance for seed cotton and fiber yields and its contributing traits followed by cultivars CIM-554 and SLH-284. Seed cotton yield revealed significant positive correlation with majority traits. The above promising genotypes could be further explored for improvement in seed cotton and lint yields.

Key words: Genotypes; environments; genotype-by-environment interaction; genotypic malleability; correlation; *Gossypium hirsutum* L.

INTRODUCTION

In crop performance, three factors are very important i.e. genotype, the environment in which the crop is grown, and the interactions between genotype and environment (G × E) (Gomez, Gomez, 1984). Genotype has an individual's genetic make-up and the phenotypic expression of a genotype depends on environments that may be defined as the sum total of circumstances surrounding or affecting an organism or a group of organisms. Cultivars of a crop as genotypes, when grown under a wide range of environmental conditions, are exposed to different soil types, fertility levels, moisture contents, temperatures, photoperiods, biotic and abiotic stresses and cultural practices.

Climatic, soil, insect, disease and cultural conditions differ from one place to another, and also differ from year to year at the same location (Killi *et al*., 2005). Cotton is highly responsive to changes in temperature, humidity, and soil moisture, which may affect its yield, yield components and fiber properties. Therefore, genetic and environmental variability for seed cotton yield, yield contributing and fiber quality traits should be estimated in different environments to conduct successful breeding program.

Yield is polygenic trait and thus, it is mostly influenced by environmental factors, so the phenotypic response of a genotype is determined by the genetic and environmental effects upon it, however, with a high frequency of occurrence of a third effect, of no less importance, which is the genotype by environment interaction (Ali *et al*., 2005). Such interaction, in the process of widely adapted cultivar development, constitutes one of the great problems in breeding programs and when recommendation of cultivars for a wide spectrum of environments is to be considered (Gul *et al*., 2014). Therefore, a genotype that presents a good performance in one place does not necessarily perform similarly in another location.

Genotype × environment interactions are of major concern to plant breeders for developing improved cultivars. A cultivar, to be commercially successful, must perform well across the range of environments in which allowed to grow (Suinaga *et al*., 2006). G x E interaction alters the correlation between phenotype and genotype, and makes it difficult to judge the genetic potential of a genotype. Further, the stability of a cultivar refers to its consistency in performance across environments and is affected by the presence of GE interactions. In the presence of significant GE interactions, stability parameters are estimated to determine the superiority of individual genotypes across the range of environments. Genotype × location, genotype × year and genotype × location × year interaction components were found to be significant for seed cotton yield in past studies (Campbell *et al*., 2012; Killi and Harem, 2006).

Genotype by environment interaction decreases the stability of genotypes under varied environmental conditions, however, environmental impact on phenology varies due to crop specie and cultivar, and consequently, for assessing the impact of environment on genotypes, the genotypes should be tested over years and locations. Therefore, the current research was designed to assess the performance of the newly developed cotton cultivars for their adaptability and genetic potential over different environments, and association of component traits with seed cotton yield in upland cotton.

MATERIALS AND METHODS

Breeding material and procedure : The study was carried out during 2010 and 2011 at the University of Agriculture, Peshawar, Pakistan. Peshawar which lies between 34°, 02′ North latitude and 71°, 37′ East longitude. The experimental material consisted of eight upland cotton genotypes i.e. SLH-284, CIM-446, CIM-473, CIM-496, CIM-499, CIM-506, CIM-544 and CIM-707 varying in pedigree, year of release and morph-yield traits (Table 1). Maximum and minimum temperatures, and rainfall data of both crop seasons (2010 and 2011) are provided in Figures 1 and 2, respectively. The experiments were sown during May 2010 and 2011 in a randomized complete block (RCB) design with three replications. Each cultivar was planted in four rows of five meters length each with 30 and 75 cm plant and row spacing, respectively. Cultural practices were carried out as per suggested package for cotton production. In each year, same inputs, cultural practices, and plant protections measures (insecticides spray etc.) were applied to all the genotypes in the experiment to minimize the controllable environmental factors. Picking was done each year during the month of November and the data were collected on single plant basis.

Traits measurement and analysis: Data were recorded on bolls per sympodia, boll weight, seeds per boll, seed index, lint index, lint % and seed cotton yield per plant. All the data were subjected to G × E interaction analysis (Gomez and Gomez, 1984). Significant variations among genotypes, environments and genotype by environment (G × E) interactions for various traits were compared by using the least significant difference (LSD) test at 5% level of probability. The correlation of seed cotton yield with yield traits was also worked out.

RESULTS AND DISCUSSION

According to ANOVA, genotype and year means indicated significant (*p≤0.01*) differences for all the traits except lint index which owned non-significant differences in year means (Table 2). The genotype by year interactions were also found significant (*p≤0.01*) for majority traits except boll weight and seeds per boll where the interaction values were non-significant. Mean squares revealed the presence of variability among cotton genotypes due to their diverse origin and genetic make-up as well as environments where the trials were carried out. The magnitude of such performance depended on the extent of genotype × environment interactions, which arise when genotypes differ in their virtual performance across the environments. According to Figures 1 and 2, maximum temperature and rainfall was observed during 2011 as compared to 2010.

Total sum of squares accounted for by G, E, G × E interactions and experimental error (replications) have been used as symbol of the total variation attributed to each component (Kerby *et al*., 2000). Variation due to G × E interaction is a measure of how cultivars either respond across environments or differently according to various environments. The environmental component E, represents how the cultivar means differ between environments (Blanche *et al*., 2006; Gul *et al*., 2014). In present study, contribution to the total sum of squares, regardless of trait, for environments ranged from 0.42 to 89.55%, genotypes ranged from 5.02 to 46.21%, G × E ranged from 3.40 to 40.00%, and least contribution of replications ranged from 0.12 to 21.37% (Table 2). Overall, the replications contribution was less than other components that revealed that experimental error was minimum and the results were mainly governed by G, E, and G × E interactions. In past findings, the genotypes and G × E interactions play principal role followed by environments, while share of experimental error was minimal (Gul *et al*., 2014). Present results were in symmetry with Blanche *et al*. (2006) whose findings revealed that contribution to total sum of squares, regardless of trait, for environments ranged from 11 to 92%, genotypes from 5 to 55%, and G × E from 5 to 34%. In another study, the environment accounts for 61.86%, 26.99% and 18.64% of total variation for bolls per plant, seed cotton yield and sympodia per plant, respectively, considering the larger effects of environment in combination with genotypes on various traits (Gul *et al*., 2014).

Present studies revealed that environment accounts for 89.55% of total variation in seed index followed by lint % (85.76%), seeds per boll (66.12%), bolls per sympodia (64.42%), boll weight (38.75%) and seed cotton yield per plant (26.99%) which is expected considering the large effects that environment has on plant growth and morphology. In lint index, the contribution of environment was least i.e. 0.42%. Present findings were supported by past studies of Blanche *et al*. (2006) during 2001 and 2002 which revealed share of environment to total variation for boll weight (36%), lint % (28%), seed index (26%) and seed cotton yield (92%). However, traits with high heritability are typically influenced less by environment (Kerby *et al*., 2000; Gul *et al*., 2014).

Genotypes contribution was maximum for boll weight (46.21%) followed by lint index (41.62%), seed cotton yield (28.10%), seeds per boll (19.62%), bolls per sympodia (18.07%), lint % (10.14%) and seed index (5.02%). Accumulation of G × E effects was highest for seed cotton yield (40.00%) followed by lint index (36.59%), bolls per sympodia (14.37%), boll weight (8.67%), seed index (5.30%), seeds per boll (4.85%) and lint % (3.40%), resulting that environment in combination with genotypes play greater role in manifestation of the former traits. In 1997 and 1998, a study was carried out on nine cotton cultivars with nine locations in North Carolina, USA, and their findings revealed that G, E, and G × E contributions to the total sum of squares were 1, 94, and 6%, respectively for yield (Kerby *et al*., 2000). In findings of Blanche *et al*. (2006), the traits with the least magnitude of variation attributed to environment were for lint percentage (28%) and seed index (11%). However, in studies of Gul *et al*. (2014), the environmental share was least for plant height (0.39%) and monopodia (0.72%) in upland cotton.

Cotton genotypes performance varies with environments (year/location) and mainly depending upon the environmental conditions. However, the presence of G × E interactions reduces the correlation between genotype and phenotype, and makes it difficult to arbitrate the genetic potential of a cotton genotype (Khan *et al*., 2007). The past study with four groups of cotton genotypes and environments, revealed significant genotype × year and genotype × year × location interactions for various morpho-yield traits in upland cotton (Maleia *et al*., 2010). Significant variations were observed among genotypes, years, and locations, however, year × location interactions were highly significant for seed cotton yield in upland cotton (Killi and Harem, 2006). The genotypes, environments and genotype × environment interaction means showed significant differences in upland cotton genotypes (Khan *et al*., 2008).

Genotype × environment interactions is one of the major challenges in plant breeding, either in the process of selection or cultivars evaluation, when the genotypes performance over environments is not constant (Suinaga *et al*., 2006). In present findings, significance of the three categories of means (genotypes, years, and genotype × year interactions) revealed that variations might be due to diverse genetic makeup of genotypes, and their interaction with environments; therefore, needs to be studied for a longer period for certified findings. However, in present study the trait-wise results are discussed as follows.

Bolls per sympodia: For bolls per sympodia, genotypic mean values varied from 1.05 to 1.58, while for genotype × year interactions the range was 0.63 to 2.07 (Table 3). In consideration of genotype means, three cultivars i.e. CIM-473 (1.58), CIM-506 (1.55) and CIM-554 (1.55) exhibited maximum and at par bolls per sympodia. However, these genotypes were found at par with two other genotypes CIM-499 (1.47) and CIM-496 (1.42) for bolls per sympodia. Genotype CIM-446 (1.05) showed least number of bolls per sympodia and found at par with two other genotypes i.e. SLH-284 (1.20) and CIM-707 (1.25). Overall, the genotypes produced maximum bolls per sympodia during 2011 (1.73) followed by least value during 2010 (1.04). In genotype × year interaction values, CIM-496 revealed maximum number of bolls per sympodia (2.07) during 2011. However, it was found similar in performance with four other genotypes i.e. CIM-554 (1.93) and CIM-473, CIM-506 and CIM-707 with same value of 1.77 during 2011. The cultivar CIM-446 (0.63) manifested minimum bolls per sympodia during 2010 and found alike in performance with two other genotypes i.e. CIM-707 (0.73) and CIM-496 (0.77) during 2010. All other interaction values revealed medium values for bolls per sympodia. On average, based on cultivars and genotype by environment interaction means, the cultivars CIM-473, CIM-496, CIM-506 and CIM-554 revealed maximum bolls per sympodia. Significant ($p \leq 0.01$) positive correlation (r = 0.35) was observed between bolls per sympodia and seed cotton yield (Table 10). Significant and positive correlation of seed cotton yield with yield related traits had also been reported in upland cotton (Khan *et al*., 2015).

Morphological traits like sympodia and bolls per sympodia are yield contributing traits and plays an important role in managing the seed cotton yield in cotton crop. In cotton crop, progress from selection reduced due to larger genotype by environment interactions (Campbell *et al*., 2012). Therefore, the possible way to minimize the effect of genotype by environment interactions is to use stable cotton genotypes with high yield. Screening of stable cotton genotypes for morphological and yield traits under diverse environmental conditions has become vital part of breeding program (Shah *et al*., 2005). Highly significant differences were noted among cultivars, environments and cultivar × environment interactions in upland cotton, however, the significant variations in the mean values of cotton genotypes might be due to variations in their diverse nature of origin (Ali *et al*., 2005). Contradictory views might be due to different breeding material studied under varied environmental conditions.

Boll weight: For boll weight, genotypic mean values ranged from 3.44 to 4.26 g, while in genotype × year interactions, the said range was 3.08 to 4.43 g (Table 4). The genotype CIM-707 (4.26 g) and SLH-284 (4.22 g) exhibited maximum and similar boll weight. However, these genotypes were found at par along with two other genotypes CIM-496 (4.12 g) and CIM-554 (3.87 g). Genotype CIM-473 revealed minimum boll weight (3.44 g). The three genotypes i.e. CIM-506 (3.73 g), CIM-499 (3.73 g) and CIM-446 (3.76 g) revealed medium boll weight. Considering year means, the genotypes produced higher boll weight during 2011 (4.14 g) and lower boll weight during 2010 (3.65 g). Genotype × year interaction mean values were found non-significant, however, numerically and on average the cultivars CIM-707 (4.43 g) and SLH-284 (4.42 g) revealed maximum boll weight during the crop season 2011. The genotype CIM-473 (3.08 g) showed minimum boll weight during the growing season 2010. The remaining interactions revealed medium values. On average, in genotypes and genotype by environment interaction means, the cultivars CIM-707 and SLH-284 revealed maximum values for boll weight. Boll weight revealed significant ($p \leq 0.01$) positive correlation (r = 0.36) with seed cotton yield (Table 10).

Boll weight and bolls per plant contributed significantly to seed cotton yield and could be used as selection criteria in cotton breeding for yield. Positive relationship was observed between boll weight and seed cotton yield (Ali *et al.*, 2009). Significant differences were noted among cotton cultivars for boll weight, and its positive relationship with seed cotton yield (Ahmad *et al*., 2011; Khan *et al*., 2011). A study of 58 genotypes of upland cotton in three environments for yield and its component traits, revealed that significant E + (G × E) interactions showed differential response of genotypes under various environments (Deshmukh *et al*., 2008). In another past study, the magnitudes of G × E interactions variance components for boll weight and other yield contributing traits were relatively smaller as compared to their respective cultivars variances and minimal importance of interactions was reported in determination of these traits (Maleia *et al*., 2010).

Highly significant differences were recorded among cotton genotypes, environments and G × E interactions, , the disparity with our results might be due to their genetic make up (Ali *et al*., 2005). Boll weight is second important yield contributing trait after bolls per plant and has fundamental contribution in managing the seed cotton yield. Present research also discovered that there was a positive association between boll number and boll weight with direct impact on seed cotton and lint yields (data not provided). Therefore, during selection of genotypes, due attention should be paid to the boll weight.

Seeds per boll: For seeds per boll, genotypic mean values ranged from 23.97 to 29.34, while in genotype × year interactions the said values varied from 21.10 to 30.80 (Table 5). In genotypic means, cultivars CIM-446 (29.34) and CIM-496 (28.85) revealed maximum and at par seeds per boll. However, these cultivars were found at par with two other genotypes i.e. SLH-284 and CIM-707 having 29.93 and 27.43 seeds per boll, respectively. Genotype CIM-554 (23.97) revealed minimum seeds per boll, and it was found at par with cultivar CIM-506 (25.63). In case of year means, all the genotypes produced higher seeds per bolls during 2011 (30.03) and lower during 2010 (24.02). Mean values were found non-significant for genotype × year interactions. However, on average and numerically the genotypes CIM-496 (31.72) and SLH-284 (31.37) produced maximum number of seeds per boll during crop season 2011, while minimum value for said trait was noted in cultivar CIM-554 (21.10) during 2010. Other interactions of various genotypes with both crop seasons revealed medium seeds per boll. On average, in genotypes means and genotype by environment interaction values, the genotype CIM-496 revealed maximum seeds per boll. Seeds per boll revealed significant ($p \leq 0.01$) positive correlation (r = 0.35) with seed cotton yield (Table 10).

Genotype × environment interaction values were relatively smaller than their respective cultivar values for plant type (morphological traits) and other yield traits in upland cotton, revealed less importance of G × E in the determination of said traits (Maleia *et al*., 2010). In contrast, a genotype has best performance for morphological traits in one environment may not necessarily perform similarly in other environment (Naveed *et al*., 2006). Thus, a significant genotype by environment interaction for quantitatively inherited characters may seriously limit selection of superior cotton genotypes (Ali *et al*., 2005).

Seed index: For seed index, cultivars mean values varied from 7.73 to 8.29 g, while in genotype × year interaction means the range was 6.89 to 9.16 g (Table 6). Genotypic means revealed that cultivars SLH-284 (8.29 g) and CIM-499 (8.26 g) exhibited maximum and at par seed index by having bolder seeds. However, these genotypes were found at par with two other genotypes i.e. CIM-707 (8.20 g) and CIM-554 (8.12 g). Genotype CIM-473 showed least seed index (7.73 g) and it was found at par with CIM-506 (7.86 g). Two genotypes revealed medium and at par seed index i.e. CIM-446 and CIM-496 with values of 8.01 and 8.00 g, respectively. In case of year means, the genotypes grown during 2010 revealed greater seed index (8.84 g) and lower during 2011 (7.28 g). In case of G × Y interactions, five cultivars i.e. CIM-707, CIM-446, SLH-284, CIM-554 and CIM-499 grown during 2010 revealed maximum and at par seed index ranging from 8.93 to 9.16 g. Cultivar CIM-446 grown during 2011 showed least value for seed index (6.89 g). The remaining interactions of various genotypes in crop seasons 2010 and 2011 manifested medium values for seed index. On average, based on genotype means and G × E interactions, the cultivars CIM-707, SLH-284 and CIM-499 revealed maximum seed index. Seed index was found negatively correlated (r = -0.41) with seed cotton yield (Table 10). However, Khan *et al*. (2010) observed positive relationship in these variables.

Variances due to G, E and G × E have changed little during the last 50 years in upland cotton, and the genotypes, environments and G × E interactions equally influenced yield (Meredith *et al*., 2012). However, yield components (seed weight, boll weight, lint yield) and fiber quality traits were not as influenced by environments and G × E over the years, locations, and genotypes in their studies. Mean squares for seed traits, yield, and its components over four years indicated that there were significant differences among genotypes and genotype × year interactions for all traits except 100-seed weight in upland cotton (Killi *et al*., 2005). The conflicting views might be due to different breeding material grown under diverse climatic conditions. The seed traits i.e. seeds per locule, seeds per boll and seed index are important yield factors and plays imperative role in increasing seed cotton yield and cottonseed oil %.

Lint index: In genotypes, mean values for lint index ranged from 4.22 to 4.99 g, while for genotype × year interaction values the said range was 3.77 to 5.24 g (Table 7). Considering genotypic means, cultivar CIM-506 (4.99 g) revealed maximum lint index and was at par with cultivar CIM-707 (4.68 g). However, these genotypes were followed by four other cultivars i.e. CIM-499 (4.53 g), CIM-554 (4.49 g), CIM-446 (4.36 g) and SLH-284 (4.28 g) for lint index. Two genotypes i.e. CIM-496 (4.22 g) and CIM-473 (4.22 g) revealed minimum lint index. For lint index, year means revealed non-significant differences, and the genotypes produced same lint index grown during crop season 2010 (4.49 g) and 2011 (4.45 g). In G × Y interactions, cultivar CIM-506 (5.24 g) revealed maximum value for lint index during growing season 2010. However, it was at par with four other cultivars i.e. CIM-707 (5.02 g) grown during 2010 and CIM-506 (4.74 g), CIM-499 (4.66 g) and CIM-496 (4.66 g) planted in 2011. Minimum lint index was governed by genotype CIM-496 (3.77 g) during 2010 and found at par with five other cultivars i.e. CIM-473 (4.09 g), SLH-284 (4.15 g) sown during 2010, and CIM-446 (4.27 g), CIM-707 (4.34 g) and CIM-473 (4.35 g) grown during 2011. On average, based on genotype means and genotype by environment interactions, the genotypes CIM-506 and CIM-707 revealed maximum lint index. Lint index was found negatively correlated (r = -0.13) with seed cotton yield (Table 10), however, Khan *et al*. (2010) observed significant positive association in above two variables.

In upland cotton, mean squares revealed significant cultivar × year, cultivar × location and cultivar × year × location interactions for lint index and lint % (Elsiddig *et al*., 2006). Cotton genotypes exhibited varied mean values for years, locations, and their interactions (C × Y × L) and all the three components have their role in manifestation of yield and fiber traits (Suinaga *et al*., 2006). Significant cultivar × location interactions concluded that fiber and yield measurement from single year/location were inadequate for recommendations and that interactions cannot be attributed to year or to location (Blanche *et al*., 2006; Gul *et al*., 2014). Significant variances were recorded due to genotypes, environments and genotype × environment interactions for seed cotton yield and its attributes in upland cotton, however, the major share of G × E interactions was accounted for majority traits except lint index, sympodia and bolls per plant (Satish *et al*., 2009). The inconsistent findings might be due to genetic make-up of the genotypes grown under assorted environmental conditions.

Lint %: For lint %, the cultivars ranged from 34.54 to 36.52%, while for genotype × year interactions the mean values for said trait varied from 32.20 to 38.25% (Table 8). In case of genotype means for lint %, four cultivars CIM-506 (36.52%), CIM-473 (36.20%), CIM-499 (36.15%) and CIM-496 (35.97%) showed highest and at par lint %. Minimum lint % was exhibited by four genotypes i.e. CIM-707 (34.54%), CIM-554 (34.88%), CIM-446 (35.02%) and SLH-284 (35.10%). In year means, genotypes grown during 2011 produced greater lint % (37.57%) and lower during 2010 (33.53%). In case of genotype × year interactions, three cultivars CIM-506 (38.25%), CIM-496 (38.23%) and CIM-499 (38.23%) showed maximum and at par lint % during 2011. However, these genotypes were found at par in performance with two other cultivars i.e. CIM-446 and CIM-473 with values of 37.78 and 37.59%, respectively grown during 2011. However, least and at par lint % was observed in cultivars CIM-707 (32.20%) and CIM-446 (32.27%) grown during 2010. These two genotypes were found at par with two other cultivars i.e. CIM-554 and SLH-284 with mean values of 33.12 and 33.27%, respectively grown during 2010. On average, the genotype means and G × E interactions revealed that cultivars CIM-506, CIM-499 and CIM-496 possessed highest lint %. Lint % was found significantly ($p \leq 0.05$) and positively correlated (r = 0.40) with seed cotton yield (Table 10). Lint percentage showed significant positive association with seed cotton yield in upland cotton (Khan *et al*., 2010; Kazmi *et al*., 2015). In another study, the correlation of seed cotton yield was significant and positive with yield traits while negative with lint % (Khan *et al*., 2011, 2015).

Genotype × season, genotype × location and genotype × location × season were significant for fiber yield and quality traits indicating that genotypes ranking was not constant in the tested environments in upland cotton (Elsiddig *et al*., 2006). Analysis of variance across the environments indicated significant variations among genotypes, environments and G × E for lint % and yield, however, G × E interactions were four times larger than genotype constituent for lint % and lint yield in upland cotton (Khan *et al*., 2008). Possible effects of environment and genotypic differences were determined for lint %, lint yield and seed cotton yield, and the genotypes, environments and genotypes by environment interactions were highly significant indicating genetic variability between cotton genotypes (Ali *et al*., 2005). Varied response of cotton cultivars observed due to genotypes, environments and genotype by environment interactions in upland cotton (Shah *et al*., 2005). The incompatible views might be due to diverse environmental conditions and varied origin of cotton populations. Therefore, it was suggested to opt for breeding cotton cultivars with higher lint yield based on synchronous selection of more bolls per plant.

Seed cotton yield per plant: For seed cotton yield per plant, cultivars mean values ranged from 60.59 to 85.71 g, while for genotype × year interactions this range was 55.74 to 107.41 g (Table 9). In genotypic means, two cultivars CIM-496 (85.71 g) and SLH-284 (85.37 g) revealed maximum and at par seed cotton yield per plant. However, these genotypes were at par with four other genotypes i.e. CIM-554 (81.57 g), CIM-707 (81.01 g), CIM-506 (77.44 g) and CIM-473 (75.55 g) for seed cotton yield per plant. Minimum seed cotton yield per plant was exhibited by genotype CIM-446 (60.59 g), however, it was found at par with genotype CIM-499 (70.65 g) for seed cotton yield. In case of year means, on average the genotypes grown during 2011 produced greater seed cotton yield per plant (84.70 g) than during 2010 (69.53 g). In genotype by year interactions, cultivar CIM-554 (107.41 g) revealed maximum seed cotton yield per plant sown during crop season 2011. However, it was found at par with cultivar SLH-284 (101.24 g) grown during 2011. The above interactions were followed by three other genotypes grown during 2011 for seed cotton yield per plant i.e. CIM-707 (88.96 g), CIM-506 (88.20 g) and CIM-496 (87.82 g). Minimum seed cotton yield per plant was exhibited by genotype CIM-554 (55.74 g) grown during 2010, however, it was found at par with six other interactions of various genotypes ranged from 58.32 to 71.24 g seed cotton yield per plant grown during crop seasons 2010 and 2011. Based on genotype means and G × E interactions, on average the cultivars CIM-496, SLH-284 and CIM-554 produced maximum seed cotton yield. Seed cotton showed significant and positive correlation with most of the traits except seed and lint indices where the association was negative (Table 10).

In various past studies, positive correlations existed between yield components and seed cotton yield in upland cotton (Ahmad *et al*., 2011; Khan *et al*., 2010, 2011; Gul *et al*., 2014). Cotton genotypes, environments and genotype × environment interactions were significant for seed cotton yield, and mentioned that magnitude of such performance testing depends on the significance of genotype × environment interactions which appears when genotypes differ in their comparative performance across environments (Khan *et al*., 2007). Genotype, environments (years) and genotype by environment interactions were significant for seed cotton yield in upland cotton genotypes (Khan *et al*., 2008).

Specific adaptation and high seed cotton yield, genotype × environment interactions for seed cotton yield was found to be significant in upland cotton in many past findings (Shah *et al*., 2005; Satish *et al*., 2009). Variations among cotton genotypes, environments and genotype by environments interactions for seed cotton yield were significant ($p \leq 0.01$), showing existence of genetic variability among the genotypes as well as environments under which the experiments were conducted (Naveed *et al*., 2006). Genotype by environment interactions affects the yielding ability of the cotton genotypes. Environmental factors include temperature, moisture, day length, soil fertility and sowing time that vary across years and locations.

Cotton genotypes differed significantly over years for seed cotton yield, indicating the existence of sufficient degree of genetic variability. Larger year-to-year and field-to-field variations were observed in seed cotton yield under various planting conditions, and both environment and genetic makeup of the cotton genotypes contribute to yield variations with environmental complex being the primary yield effect (Ali *et al*., 2009). Other studies have also shown environment as the predominant source of variation in seed cotton and lint yields in upland cotton (Kerby *et al*., 2000).

Table 1. Parentage and some important characteristics of upland cotton genotypes used in the studies.

Cultivars	Parentage	Breeding Centre	Release (year)	Seed cotton yield (kg ha^{-1})	GOT (%)	Staple length (mm)
SLH-284	Not yet released	CRS, Sahiwal, Pakistan	-	3,707	39.0	28.5
CIM-446	CP-15/2 × S-12	CCRI, Multan, Pakistan	1998	3,000	36.1	27.0
CIM-473	CIM-402 × LRA-5166	-do-	2002	3,000	39.7	29.5
CIM-496	CIM-425 × 755-6/93	-do-	2005	3,000	41.1	29.7
CIM-499	CIM-433 × 755-6/93	-do-	2003	3,000	40.0	29.6
CIM-506	CIM-360 × CP-15/2	-do-	2004	3,000	38.6	28.7
CIM-554	2579-04/97 × W-1103	-do-	2009	4,241	41.5	28.5
CIM-707	CIM-243 × 738-6/93	-do-	2004	3,000	39.0	32.2

CRS Sahiwal - Cotton Research Station, Sahiwal, Pakistan, CCRI Multan - Central Cotton Research Institute, Multan, Pakistan

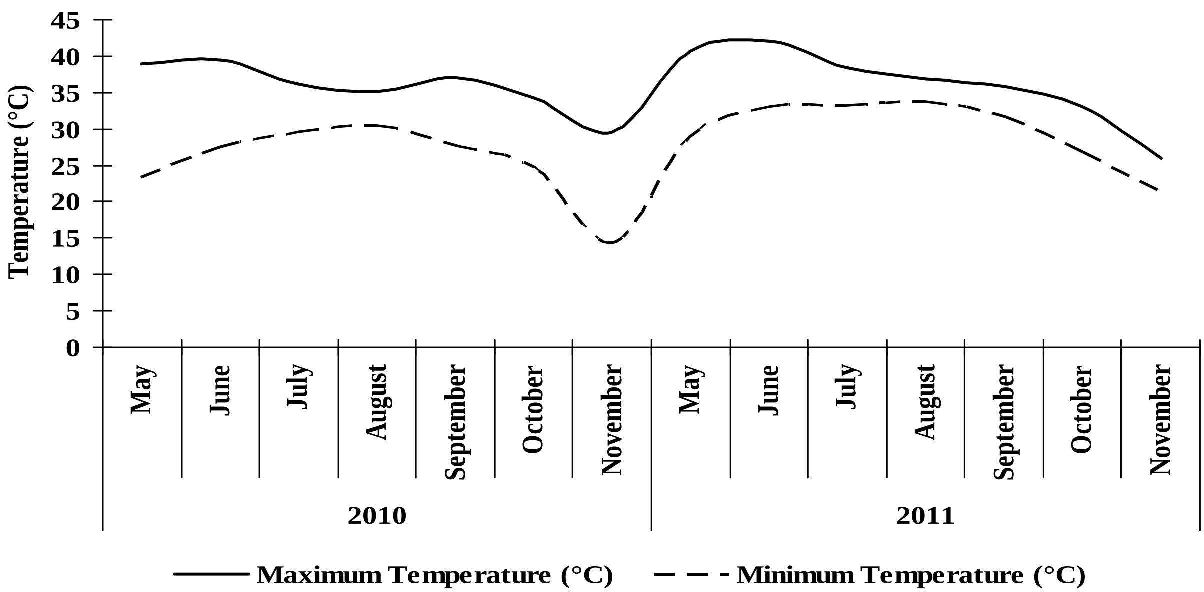

Fig. 1. Maximum and minimum temperatures for cotton crop seasons during 2010 and 2011.

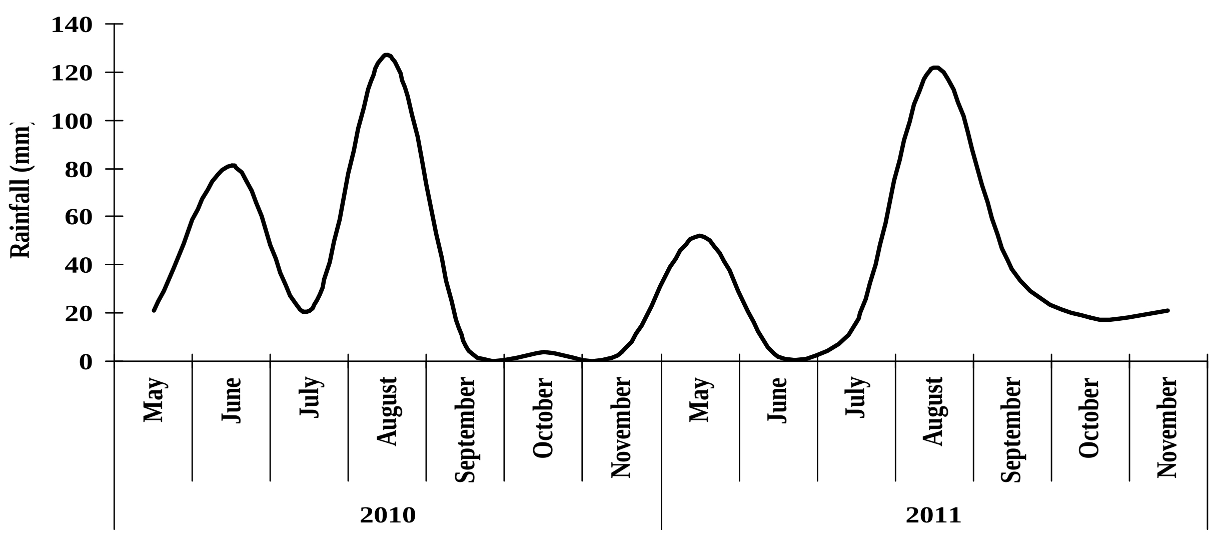

Fig. 2. Rainfall data for cotton crop seasons during 2010 and 2011.

Table 2. Sum of squares, mean squares and percentages of total variation of G, E, G × E interaction and experimental error (replications) for various traits in upland cotton.

Variables	S.O.V.	D.F.	S.S.	M.S.	Prob.	% Total variation*	C.V. (%)
	G	7	1.61	0.23^{**}	0.0002	18.07	
	E	1	5.74	5.74^{**}	0.008	64.42	
Bolls per sympodia	G × E	7	1.28	0.18^{**}	0.001	14.37	13.97
	Replications	4	0.28	0.07	-	3.14	
	Error	28	1.05	0.04	-	-	
	G	7	3.41	0.49^{**}	0.0030	46.21	
	E	1	2.86	2.90^{**}	0.0080	38.75	
Boll weight	G × E	7	0.64	$0.09^{N.S.}$	-	8.67	8.81
	Replications	4	0.47	0.12	-	6.37	
	Error	28	3.31	0.12	-	-	
	G	7	128.70	18.41^{**}	0.0003	19.62	
	E	1	433.70	433.68^{**}	0.0061	66.12	
Seeds per boll	G × E	7	31.82	$4.54^{N.S.}$	0.2161	4.85	6.49
	Replications	4	61.69	15.39	-	9.41	
	Error	28	86.21	3.08	-	-	
	G	7	1.63	0.23^{**}	0.0002	5.02	
	E	1	29.05	29.05^{**}	0.0000	89.55	
Seed index	G × E	7	1.72	0.24^{**}	0.0002	5.30	2.43
	Replications	4	0.04	0.01	-	0.12	
	Error	28	1.07	0.04	-	-	
	G	7	2.98	0.43^{**}	0.0091	41.62	
	E	1	0.03	$0.03^{N.S.}$	-	0.42	
Lint index	G × E	7	2.62	0.40^{**}	0.0173	36.59	7.89
	Replications	4	1.53	0.40	-	21.37	
	Error	28	3.48	0.12	-	-	
	G	7	23.11	3.30^{**}	0.0001	10.14	
	E	1	195.54	195.54^{**}	0.0000	85.76	
Lint %	G × E	7	7.76	1.11^{*}	0.0502	3.40	1.93
	Replications	4	1.60	0.41	-	0.70	
	Error	28	13.16	0.47	-	-	
	G	7	2874.07	410.6^{**}	0.0022	28.10	
	E	1	2759.88	2759.8^{**}	0.0094	26.99	
Seed cotton yield $plant^{-1}$	G × E	7	4091.31	584.5^{**}	0.0002	40.00	12.58
	Replications	4	501.993	125.498	-	4.91	
	Error	28	2634.57	94.10	-	-	

S.O.V. = Source of variation, D.F. = Degree of freedom, S.S. = Sum of square, M.S. = Mean square, Prob. = Probability, C.V. = Coefficient of variation, G = genotype, E = environment (year)

*Variation due to each source as a percentage of total sums of squares of E, G, and GE.

Table 3. Mean performance of the genotypes for bolls per sympodia in G × E interactions in upland cotton

Genotypes	2010	2011	Means (#)
SLH-284	1.00 fg	1.40 de	1.20 CD
CIM-446	0.63 h	1.47 cde	1.05 D
CIM-473	1.40 de	1.77 abc	1.58 A
CIM-496	0.77 gh	2.07 a	1.42 ABC
CIM-499	1.27 ef	1.67 bcd	1.47 AB
CIM-506	1.33 e	1.77 abc	1.55 A
CIM-554	1.17 ef	1.93 ab	1.55 A
CIM-707	0.73 gh	1.77 abc	1.25 BCD
Means (#)	1.04 B	1.73 A	-

Genotypes $LSD_{0.05}$ = 0.228, Years $LSD_{0.05}$ = 0.118, G × Y Interactions $LSD_{0.05}$ = 0.322

Table 4. Mean performance of genotypes for boll weight in G × E interactions in upland cotton.

Genotypes	2010	2011	Means (g)
SLH-284	4.02	4.42	4.22 A
CIM-446	3.34	4.17	3.76 BC
CIM-473	3.08	3.80	3.44 C
CIM-496	3.84	4.39	4.12 AB
CIM-499	3.71	3.76	3.73 BC
CIM-506	3.41	4.05	3.73 BC
CIM-554	3.67	4.06	3.87 AB
CIM-707	4.10	4.43	4.26 A
Means (g)	3.65 B	4.14 A	-

Genotypes $LSD_{0.05}$ = 0.405, Years $LSD_{0.05}$ = 0.204, G × Y Interactions $LSD_{0.05}$ = NS

Table 5. Mean performance of genotypes for seeds per boll in G × E interactions in upland cotton.

Genotypes	2010	2011	Means (#)
SLH-284	24.50	31.37	27.93 AB
CIM-446	28.02	30.65	29.34 A
CIM-473	24.12	29.08	26.60 BC
CIM-496	26.00	31.72	28.85 A
CIM-499	22.16	30.72	26.44 BC
CIM-506	22.20	29.06	25.63 CD
CIM-554	21.10	26.84	23.97 D
CIM-707	24.07	30.80	27.43 ABC
Means (#)	24.02 B	30.03 A	-

Genotypes $LSD_{0.05}$ = 2.075, Years $LSD_{0.05}$ = 1.038, G × Y Interactions $LSD_{0.05}$ = NS

Table 6. Mean performance of genotypes for seed index in G × E interactions in upland cotton.

Genotypes	2010	2011	Means (g)
SLH-284	9.06 a	7.52 cd	8.29 A
CIM-446	9.13 a	6.89 f	8.01 BC
CIM-473	8.45 b	7.01 ef	7.73 D
CIM-496	8.52 b	7.48 cd	8.00 BC
CIM-499	8.93 a	7.59 c	8.26 A
CIM-506	8.43 b	7.28 cde	7.86 CD
CIM-554	9.01 a	7.22 de	8.12 AB
CIM-707	9.16 a	7.24 de	8.20 AB
Means (g)	8.84 A	7.28 B	-

Genotypes $LSD_{0.05}$ = 0.231, Years $LSD_{0.05}$ = 0.118, G × Y Interactions $LSD_{0.05}$ = 0.326

Table 7. Mean performance of genotypes for lint index in G × E interactions in upland cotton.

Genotypes	2010	2011	Means (g)
SLH-284	4.15 de	4.41 cd	4.28 BC
CIM-446	4.45 bcd	4.27 cde	4.36 BC
CIM-473	4.35 cde	4.09 de	4.22 C
CIM-496	3.77 e	4.66 abcd	4.22 C
CIM-499	4.40 cd	4.66 abcd	4.53 BC
CIM-506	5.24 a	4.74 abc	4.99 A
CIM-554	4.56 bcd	4.41 cd	4.49 BC
CIM-707	5.02 ab	4.34 cde	4.68 AB
Means (g)	4.49	4.45	-

Genotypes $LSD_{0.05}$ = 0.417, Years $LSD_{0.05}$ = NS, G × Y Interactions $LSD_{0.05}$ = 0.589

Table 8. Mean performance of genotypes for lint % in G × E interactions in upland cotton.

Genotypes	2010	2011	Means (%)
SLH-284	33.27 de	36.93 b	35.10 B
CIM-446	32.27 e	37.78 ab	35.02 B
CIM-473	34.81 c	37.59 ab	36.20 A
CIM-496	33.70 cd	38.23 a	35.97 A
CIM-499	34.07 cd	38.23 a	36.15 A
CIM-506	34.80 c	38.25 a	36.52 A
CIM-554	33.12 de	36.64 b	34.88 B
CIM-707	32.20 e	36.88 b	34.54 B
Means (%)	33.53 B	37.57 A	-

Genotypes $LSD_{0.05}$ = 0.811, Years $LSD_{0.05}$ = 0.405, G × Y Interactions $LSD_{0.05}$ = 1.147

Table 9. Mean performance of genotypes for seed cotton yield in G × E interactions in upland cotton

Genotypes	2010	2011	Means (g)
SLH-284	67.51 defg	101.24 ab	84.37 A
CIM-446	62.87 efg	58.32 fg	60.59 C
CIM-473	76.72 cde	74.39 cdef	75.55 AB
CIM-496	83.59 cd	87.82 bc	85.71 A
CIM-499	70.05 defg	71.24 defg	70.65 BC
CIM-506	66.68 efg	88.20 bc	77.44 AB
CIM-554	55.74 g	107.41 a	81.57 AB
CIM-707	73.09 cdef	88.96 bc	81.03 AB
Means (g)	69.53 B	84.70 A	-

Genotypes $LSD_{0.05}$ = 11.470, Years $LSD_{0.05}$ = 5.735, G × Y Interactions $LSD_{0.05}$ = 16.22

Table 10. Correlation of seed cotton yield with other traits in upland cotton.

Variables	Correlation of seed cotton yield with other traits
Bolls per sympodia	0.35**
Boll weight	0.36**
Seeds per boll	0.35**
Seed index	$-0.41^{N.S.}$
Lint index	$-0.13^{N.S.}$
Lint %	0.40*

**, * significant at p≤0.01 and p≤0.05, respectively, N.S. = Nonsignificant

Conclusion: Based on two-year studies, it was concluded that environments in combination with genotypes play principal role in phenotypic manifestation of the various traits followed by G × E interaction. Overall, genotype CIM-496 showed best performance and found more adaptive to the existing environmental conditions followed by CIM-554 and SLH-284. These genotypes could be grown for improvement in seed cotton and lint yields.

REFERENCES

Ahmad, M., N.U. Khan, F. Mohammad, S.A. Khan, I. Munir, Z. Bibi and S. Shaheen (2011). Genetic potential and heritability studies for some polygenic traits in cotton (*G. hirsutum* L.). Pakistan J. Bot. 43(3): 1713-1718.

Ali, H., M.N. Afzal and D. Muhammad (2009). Effect of sowing date and plant spacing on growth and dry matter partitioning in cotton (*G. hirsutum* L.). Pakistan J. Bot. 41(5): 2145-2155.

Ali, Y., Z. Aslam and F. Hussain (2005). Genotype and environment interaction effect on yield of cotton under naturally salt stress condition. Int. J. Environ. Sci. Tech. 2(2): 169-173.

Blanche S.B., G.O. Myers, J.Z. Zumba, D. Caldwell and J. Hayes (2006). Stability comparisons between conventional and near-isogenic transgenic cotton cultivars. J. Cotton Sci. 10: 17-28.

Campbell, B.T., P.W. Chee, E. Lubbers, D.T. Bowman, W.R. Meredith, J. Johnson, D. Fraser, W. Bridges and D.C. Jones (2012). Dissecting genotype × environment interactions and trait correlations present in the pee dee cotton germplasm collection following seventy years of plant breeding. Crop Sci. 52(2): 690-699.

Deshmukh, S.B., M.B. Misal, S.S. Gomashe, S.B. Sarode and H.V. Kalpande (2008). Genotype-environment interaction studies for seed cotton yield and its component characters. Asian J. Bio-Sci. 3(1): 66-72.

Elsiddig, A.A., A.H. Abdalla and A.S. Fadlalla (2006). A note on the stability of five medium staple cotton (*G. hirsutum* L.) varieties for some fiber properties in the Gezira Scheme of the Sudan. Univ. of Khartoum J. Agric. Sci. 14(2): 313-319.

Gomez, K.A. and A.A. Gomez (1984). Statistical Procedures for Agricultural Research (2nd ed.). John Wiley & Sons Inc., New York. USA.

Gul, S., N.U. Khan, S. Batool, M.J. Baloch, M. Munir, M. Sajid, A.A. Khakwani, S.H. Ghaloo, Z.A. Soomro and S.F. Kazmi (2014). Genotype by environment interaction and association of morpho-yield variables in upland cotton. The J. Anim. Plant Sci. 24(1): 262-271.

Kazmi, S.F., N.U. Khan, S. Gul and I. Ali (2015). Fatty acid profile of upland cotton genotypes through NIR-near infrared spectroscopy. The J. Anim. Plant Sci. 25(1): 212-225.

Kerby T.A., J. Burgess, M. Bates, D. Albers and K. Lege (2000). Partitioning variety and environmental contribution to variation in yield, plant growth, and fiber quality. Proceedings. Beltwide Cotton Conferences, San Antonio, USA, Jan 4-8, 1: 528-532.

Khan, N.G., M. Naveed and N.I. Khan (2008). Assessment of some novel upland cotton genotypes for yield constancy and malleability. Int. J. Agric. Biol. 10(1): 109-111.

Khan, N.G., M. Naveed, N.I. Khan and M.S. Iqbal (2007). Assessment of some new upland cotton (*G. hirsutum* L.) genotypes for yield stability and adaptability. Int. J. Plant Sci. 6(6): 1012-1015.

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* L. Pakistan J. Bot., 42(1): 615-625.

Khan, S.A., N.U. Khan, F. Mohammad, M. Ahmad, I.A. Khan, Z. Bibi and I.U. Khan (2011). Combining ability analysis in intraspecific F_1 diallel cross of upland cotton. Pakistan J. Bot. 43(3): 1719-1723.

Khan S.A., N.U. Khan, R. Gul, Z. Bibi, I.U. Khan, S. Gul, S. Ali and M. Baloch (2015). Combining ability studies for yield and fiber traits in upland cotton. The J. Anim. Plant Sci. 25 (3): 698-707.

Killi, F. and E. Harem (2006). Genotype × environment interaction and stability analysis of cotton yield in Aegean region of Turkey. J. Environ. Biol. 27(2): 427-430.

Killi, F., L. Efe and S. Mustafayev (2005). Genetic and environmental variability in yield, yield components and lint quality traits of cotton. Int. J. Agric. Biol. 7: 1007-1010.

Maleia, M.P., P.S.V. Filho, M.V. Kvitschal and M.C.G. Vidigal (2010). Stability and adaptability of commercial cotton cultivars (*G. hirsutum* L. race *latifolium* H.) in Mozambique. Afr. J. Agric. Res. 5(7): 539-550.

Meredith., W.R.J., D.L. Boykin, F.M. Bourland, W.D.Caldwell, B.T. Campbell, J. R. Gannaway, K. Glass, A.P. Jones, L.M. May, C. W. Smith and J. Zhang (2012). Genotype × environment interactions over seven years for yield, yield components, fiber quality, and gossypol traits in the regional high quality tests. J. Cotton Sci. 16: 160-169.

Naveed, M., M.S. Iqbal, N. Mukhtar and N. Islam (2006). Genotype environment interaction and phenotypic stability analysis for seed cotton yield in *G. hirsutum* L. genotypes. Caderno de Pesquisa Sér Bio. Santa Cruz do Sul. 18: 87-97.

Satish, Y., P.P. Jain and B.S. Chhabra (2009). Stability analysis for yield and its component traits in American cotton (*G. hirsutum* L.). J. Cotton Res. Dev. 23(2): 175-182.

Shah, M.K.N., S.A. Malik and M. Saleem (2005). Stability of cotton cultivars for early crop maturity across variable plant spacing and sowing times. Pakistan J. Bot. 37(2): 345-353.

Suinaga, F.A., C.S. Bastos and L.E.P. Rangel (2006). Phenotypic adaptability and stability of cotton cultivars in Mato Grosso State, Brazil. Pesq. Agropec. Bras. 36: 145-150.