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GENOTYPE BY ENVIRONMENT INTERACTION AND ASSOCIATION OF MORPHO-YIELD VARIABLES IN UPLAND COTTON

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ABSTRACT

Legacy of seed cotton yield and other quantitative traits is highly persuaded by environmental aspects, therefore, phenotypic response of a genotype is ascertained by genetic and environmental factors upon it, although occurrence of a third effect, of no less importance i.e. genotype-by-environment interaction (GEI). Studies were conducted in 2010 and 2011 evaluating G × E interactions and correlation in upland cotton using randomized complete block design at the University of Agriculture, Peshawar, Pakistan. The GEI was characterized using eight upland cotton cultivars viz., SLH-284, CIM-446, CIM-473, CIM-496, CIM-499, CIM-506, CIM-544 and CIM-707. Significant ($p \leq 0.01$) mean squares for genotypes, environments and G × E interactions revealed genetic variability among cotton genotypes as well as environments inconsistency. The contribution to the total sums of squares, regardless of trait, revealed that genotypes and genotype × environment play principal role followed by environments, while replications (experimental error) share was minimal. The environment accounts for 61.86%, 26.99% and 18.64% of total variation for bolls plant^{-1}, seed cotton yield and sympodia plant^{-1}, respectively, considering the larger effects of environment in combination with genotypes on plant growth and morphology. Seed cotton yield has significant ($p \leq 0.01$) positive correlation with boll number, and positive with morphological traits. Based on two-year studies, CIM-496 exhibited the best performance followed by CIM-554 and SLH-284 for improvement in seed cotton and lint yields.

Keywords: G × E interactions, total sum of squares, traits association, seed cotton yield, *Gossypium hirsutum* L.

INTRODUCTION

Upland cotton dominates the world's cotton fiber production accounting for approximately 90% of the total production. Fiber from various species within this genus had been used for several thousand years for clothing and other textiles in India, Nile valley and Peru (Khan, 2011, 2013; Batool and Khan, 2012; Batool *et al*., 2013). Cotton is regarded as multipurpose agricultural product and used in the manufacturing of more than 1000 major products. Not only its fiber is important, but also the cottonseed is of economic importance and is used as an oilseed. After soybean, cotton is the second most important oilseed crop in the world. However, in Pakistan it contributes 65-70% to the local edible oil industry (Khan *et al*., 2007b, 2010a, b).

Pakistan is the fourth largest cotton producer contributing about 1.6% to GDP and 7.8% as value added in Agriculture. It earns 45 to 60% foreign exchange, depending upon the production and consumption (Khan *et al*., 2009a, b). During 2011-12, the cotton crop was grown on 2.835 million hectares and seed cotton production was 13.6 million bales with seed cotton yield of 815 kg ha^{-1} (FBS, 2012). Pakistan's cotton yields have been stagnant for the last two decades and very low as compared to other cotton growing countries (Khan and Hassan, 2011; Khan *et al*., 2009c, d). Factors responsible for the low cotton production include, excessive rains at the time of sowing, high temperature and its fluctuations at flowering stage, late wheat harvesting resulting in decline of area under cotton, incidence of cotton leaf curl virus (CLCuV) and lack of resistant cultivars, pest attack and improper production technology in the major cotton growing areas (Khan *et al*., 2009b, e).

Crop performance depends on genotype, the environment in which the crop is grown, and the interaction between the genotype and environment (Gomez and Gomez, 1984). Genotype is defined as 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 (exposed to different soil types, fertility levels, moisture contents, temperatures, photoperiods, biotic and abiotic stresses and cultural practices) also perform differently for various morphological and yield traits. Gene expression may be modified, enhanced, silenced, or timed by the cell regulatory mechanisms in response to internal and external factors. The genotypes, thus, may produce a range of phenotypic expression which is the manifestation of variability in the phenotype.

Genotypes and some environmental factors (fertilizer, plant population, pest control, etc.) are controllable, however, other factors of natural environment such as day length and sunshine, rainfall, and some soil properties are generally fixed and difficult to modify for a given site and planting season. The effect of the uncontrollable factors on crop performance is as important as that of controllable factors. However, the uncontrollable factors are expected to change with season and location, and the quantification of their effects on the various variables of a crop is essential and measurable (Gul, 2013). In crop research, the most commonly used way to evaluate the effects of the uncontrollable environmental factors on crop response is to repeat the experiments at several sites or several crop seasons or both.

Genotype expression over environments is a main challenge faced by the plant breeders as stability of the genotype potential affected under diverse environments (Saranga *et al*., 2001). Genotypes may perform well in some environments but not so well in others. Genotypes exhibits different behavior in different environments/locations which is due to their varied genetic make up. The behavior may be cross over (in which significant change in ranking order occurs from one environment to another) or cross over nature (in which the ranking of genotypes remains constant across environments and the interaction is significant because of change in the magnitude of response) depending upon the ranking order of genotypic performance under different environments (Ali *et al*., 2005; Ahamd *et al*., 2006). The G × E interactions may change the response and performance of a crop, and hence, the extent of the environmental effects on a trait determines the importance of testing over years and locations. Therefore, the present research was designed to study the performance of various cotton genotypes under two different environments through G × E interactions.

MATERIALS AND METHODS

Breeding material and procedure: The genotype by environment interactions study in upland cotton was carried out during 2010 and 2011 at the University of Agriculture, Peshawar, Pakistan. Peshawar lies between 34°, 02′ North latitude and 71°, 37′ East longitude. The maximum and minimum temperatures, and rainfall data of the crop season during 2010 and 2011 are provided in Figures 1 and 2. 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). The experiment was 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 plant height, monopodia plant^{-1}, sympodia plant^{-1}, bolls plant^{-1} and seed cotton yield plant^{-1}. All the data were subjected to G × E interaction analysis according to Gomez and Gomez (1984). Significant variations among genotypes, environments and genotype × environment interactions for various traits were compared by using the least significant difference (LSD) test at 5% level of probability. The correlations between seed cotton yield and other morphological/yield traits were worked out through MstatC programme (Bricker, 1991).

RESULTS

Analysis of variance revealed significant (*p≤0.01*) differences for genotypes, years, and genotype by year interaction for all the traits except years for plant height (Table 2). The extent of such performance depended on the magnitude of genotype × environment interaction, which occurs when genotypes differ in their relative performance across the environments. According to Figures 1 and 2, maximum temperature and rainfall was observed during the year 2011 than 2010.

The percentages of the total sums of squares accounted for by G, E, and G × E interactions and replications (experimental error) have been used as symbol of the total variation attributed to each component (Table 2). 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. The contribution to the total sums of squares, regardless of trait, for the genotype ranged from 20.10 to 74.05%, environments ranged from 0.39 to 61.86%, G × E ranged from 16.58 to 45.03% and the replications ranged from 0.40 to 8.02% (Table 2). Overall, the replications contribution was less than other components which revealed that experimental error was minimum, and the results were mainly governed by G, E, and G × E interactions. Studies have shown that environment accounts for 61.86% of total variation in bolls plant^{-1} followed by seed cotton yield

(26.99%) and sympodia plant^{-1} (18.64%), which is expected considering the large effects that environment has on plant growth and morphology; however, traits with high heritability are typically influenced less by environment (Table 2). In monopodia plant^{-1} and plant height, the environment contribution was least i.e. 0.72% and 0.39%, respectively. However, the genotypes contribution was maximum for plant height (74.05%) followed by monopodia (53.84%), sympodia (39.63%), seed cotton yield (28.10%) and bolls plant^{-1} (20.10%). The accumulation of G × E effects was highest for monopodia (45.03%) followed by seed cotton yield (40.00%), sympodia (33.90%), plant height (17.54%) and bolls plant^{-1} (16.58%), resulting that environment in combination with genotypes play greater role in manifestation of former traits.

For plant height, the genotypic mean values ranged from 102.03 to 119.40 cm while the means of G × E interactions ranged from 98.07 to 122.73 cm (Table 3). Considering the genotypic means, the cultivars CIM-473 (102.03 cm) and CIM-506 (103.50 cm) showed minimum and statistically similar plant height. However, the six other cultivars viz., SLH-284, CIM-554, CIM-499, CIM-707, CIM-446 and CIM-496 revealed maximum plant height (114.10 to 119.40 cm). The year means were non-significant, however, on average, during 2011, the genotypes had lesser plant height (112.92 cm) and more during 2010 (113.84 cm). In G × E interaction, the least plant height was observed for cultivar CIM-473 (98.07 cm) during 2011. The cultivar CIM-506 followed the above genotype and revealed alike plant height during 2010 and 2011 i.e. 101.67 and 105.27 cm, respectively. The maximum plant height was observed in cultivar CIM-446 (122.73 cm) and it was comparable with five other cultivars i.e. CIM-449, CIM-496, CIM-707, CIM-284 and CIM-554 ranged from 116.80 to 121.20 cm. All other interactions revealed medium values for plant height. On average, the cultivars CIM-473 and CIM-506 exhibited minimum and similar plant height for G and G × E interactions. Plant height was found non-significantly positively correlated (r = 0.007) with seed cotton yield (Table 8) which revealed that plant height contribution was secondary in management of boll setting and seed cotton yield.

Genotypic means for monopodia plant^{-1} varied from 0.43 to 1.30, while for G × E interaction, the range was 0.20 to 1.80 (Table 4). The cultivar CIM-554 (0.43) had minimum monopodia, followed by CIM-496 and CIM-499. The genotype CIM-506 (1.30) had maximum monopodia plant^{-1} followed by two other genotypes i.e. CIM-446 (1.10) and CIM-707 (1.07). In case of year means, on average the cultivars had lesser monopodia plant^{-1} during crop season 2010 (0.80) than in 2011 (0.87). While perusing G × E interaction, it was observed that the genotype CIM-554 (0.20) had minimum monopodia plant^{-1} during 2010. The two other genotypes (CIM-496, CIM-499) also followed the above cultivar with values of 0.47 and 0.53 during 2011 and 2010, respectively. However, cultivar CIM-506 (1.80) showed maximum number of monopodia followed by CIM-446 (1.53) during 2010 and CIM-707 (1.13, 1.00) during 2010 and 2011, respectively. All other interactions revealed medium values for monopodia plant^{-1}. Overall, the cultivar CIM-554 followed by CIM-496 and CIM-499 had minimum monopodia plant^{-1} for genotypes and G × E interactions. Monopodia plant^{-1} were found positively correlated (r = 0.17) with seed cotton yield (Table 8).

In genotypes, the mean values for sympodia plant^{-1} ranged from 12.90 to 17.80, while for G × E interaction, the range was 11.80 to 20.67 (Table 5). Considering genotypes, the cultivars CIM-496 (17.80) and CIM-707 (17.57) showed maximum and analogous fruiting branches. However, these genotypes were alike with two other genotypes i.e. CIM-446 (16.77) and SLH-284 (15.53) for sympodia plant^{-1}. The genotypes CIM-499 (14.57) and CIM-506 (14.40) had lesser sympodia. The genotypes CIM-554 (12.90) and CIM-473 (13.30) had minimum and same number of sympodia plant^{-1}. In case of year means, on average the genotypes had more sympodia plant^{-1} during 2010 (16.56) than during 2011 (14.15). In case of G × E interaction, the three cultivars viz., CIM-446 (20.67), CIM-707 (20.53) and CIM-496 (20.33) exhibited maximum and similar number of sympodia plant^{-1} grown during crop season 2010, while CIM-554 (11.80) showed minimum number of sympodia plant^{-1} during same crop season. However, four other genotypes i.e. SLH-284, CIM-499, CIM-506 and CIM-473 were found parallel with above cultivar and showed medium number of sympodia plant^{-1} during 2010 and 2011 ranging from 12.87 to 16.13. On average, for genotypes and G × E interaction means, the cultivars CIM-446, CIM-707 and CIM-496 revealed maximum sympodia plant^{-1}. Sympodia plant^{-1} were found positively correlated (r = 0.06) with seed cotton yield (Table 8).

For bolls plant^{-1}, the mean values for genotypes ranged from 16.13 to 23.88, while in G × E interactions, the mean values varied from 13.00 to 31.33 (Table 6). The genotypic means revealed that cultivar CIM-496 (23.88) produced maximum bolls plant^{-1} followed by two other genotypes i.e. CIM-506 (22.13) and CIM-499 (21.23). The later two genotypes were equivalent with two other genotypes i.e. CIM-707 (20.78) and CIM-473 (20.63) for bolls plant^{-1}. The genotype CIM-446 (16.13) produced minimum number of bolls plant^{-1} followed by two other cultivars. Considering year means, maximum bolls plant^{-1} were recorded during 2011 (24.20) than 2010 (16.43), which revealed that warmer climate and more rains during 2011 were found favourable in enhancement of yield related variables. In case of G × E interaction, the cultivar CIM-496 (31.33) produced maximum bolls plant^{-1} during crop season 2011. The three other cultivars i.e. CIM-506 (25.93), CIM-707 (25.80) and CIM-554 (25.53)

Table 1. Parentage and important characteristics of cotton cultivars/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	-	3,707	39.0	28.5
CIM-446	CP-15/2 × S-12	CCRI, Multan	1998	3,000	36.1	27.0
CIM-473	CIM-402 × LRA-5166	CCRI, Multan	2002	3,000	39.7	29.5
CIM-496	CIM-425 × 755-6/93	CCRI, Multan	2005	3,000	41.1	29.7
CIM-499	CIM-433 × 755-6/93	CCRI, Multan	2003	3,000	40.0	29.6
CIM-506	CIM-360 × CP-15/2	CCRI, Multan	2004	3,000	38.6	28.7
CIM-554	2579-04/97 × W-1103	CCRI, Multan	2009	4,241	41.5	28.5
CIM-707	CIM-243 × 738-6/93	CCRI, Multan	2004	3,000	39.0	32.2

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

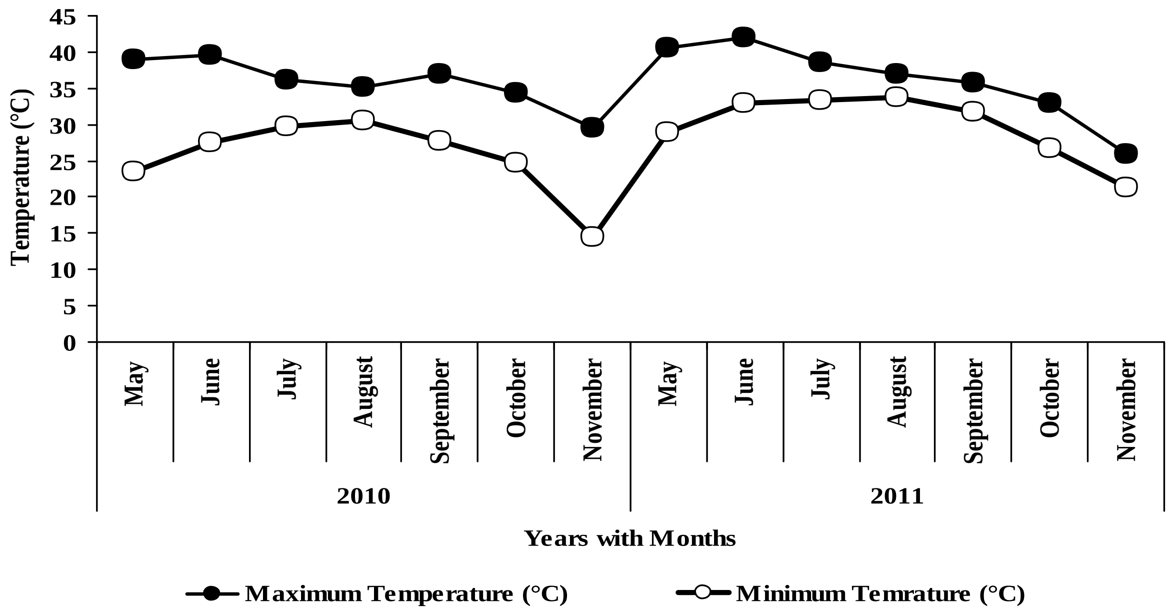

Fig. 1. Maximum and minimum temperatures for cotton crop season during 2010 and 2011

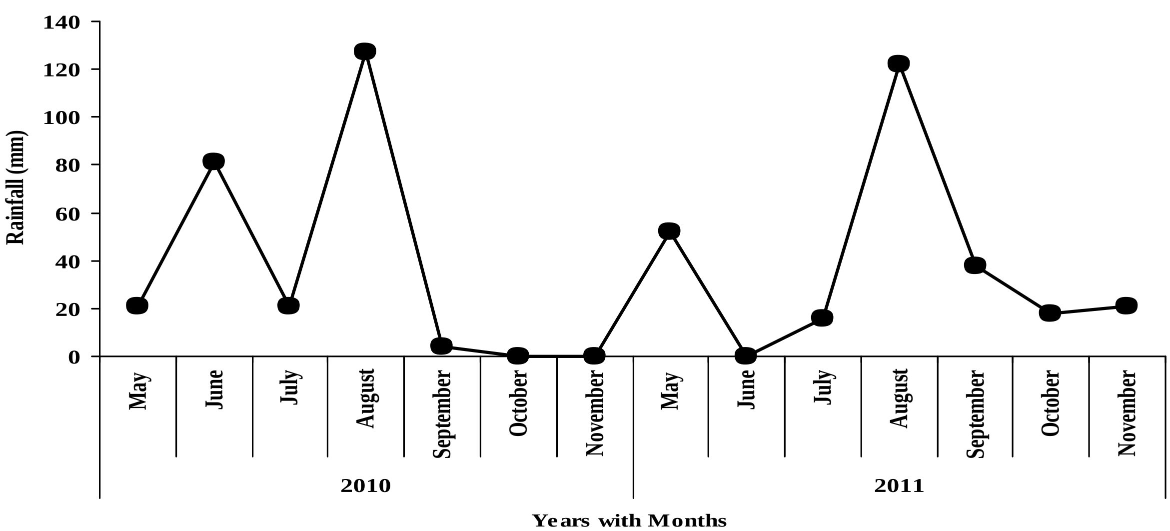

Fig. 2. Rainfall data for cotton crop season during 2010 and 2011

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

Traits	S.O.V.	D.F.	S.S.	M.S.	Prob.	% Total variation	C.V. (%)
Plant height	G	7	1946.68	278.1^{**}	0.0000	74.05	4.15
	E	1	10.18	$10.18^{N.S.}$	-	0.39	
	G × E	7	461.13	65.88^{*}	0.0182	17.54	
	Replications	4	210.791	52.698	-	8.02	
Monopodia plant^{-1}	G	7	3.73	0.53^{**}	0.0000	53.84	12.66
	E	1	0.05	0.05^{*}	0.0517	0.72	
	G × E	7	3.12	0.45^{**}	0.0000	45.03	
	Replications	4	0.028	0.007	-	0.40	
Sympodia plant^{-1}	G	7	148.02	21.15^{**}	0.0034	39.63	14.84
	E	1	69.61	69.61^{*}	0.0368	18.64	
	G × E	7	126.64	18.1^{**}	0.0082	33.90	
	Replications	4	29.251	7.313	-	7.83	
Bolls plant^{-1}	G	7	235.23	33.6^{**}	0.0000	20.10	6.41
	E	1	723.85	723.85^{**}	0.0002	61.86	
	G × E	7	194.04	27.72^{**}	0.0000	16.58	
	Replications	4	16.966	4.241	-	1.45	
Seed cotton yield plant^{-1}	G	7	2874.07	410.6^{**}	0.0022	28.10	12.58
	E	1	2759.88	2759.8^{**}	0.0094	26.99	
	G × E	7	4091.31	584.5^{**}	0.0002	40.00	
	Replications	4	501.993	125.498	-	4.91	

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

Table 3. Mean performance of cotton genotypes for plant height as affected by environments.

Genotypes	2010	2011	Means (cm)
SLH-284	110.53 efg	117.67 a-e	114.10 a
CIM-446	122.73 a	113.67 b-f	118.20 a
CIM-473	106.00 fgh	98.07 i	102.03 b
CIM-496	119.67 abc	119.07 a-d	119.40 a
CIM-499	113.27 c-f	121.20 ab	117.23 a
CIM-506	101.67 hi	105.27 ghi	103.50 b
CIM-554	117.60 a-e	111.60 d-g	114.60 a
CIM-707	119.23 a-d	116.80 a-e	118.02 a
Means (cm)	113.84	112.92	-

Genotypes $LSD_{0.05}$ = 5.562, Years = NS, GEI $LSD_{0.05}$ = 7.866

Table 4. Mean performance of cotton genotypes for monopodia plant^{-1} as affected by environments.

Genotypes	2010	2011	Means (#)
SLH-284	0.73 f	0.93 de	0.83 c
CIM-446	1.53 b	0.67 fg	1.10 b
CIM-473	0.73 f	0.73 f	0.73 c
CIM-496	0.73 f	0.47 h	0.60 d
CIM-499	0.53 gh	0.67 fg	0.60 d
CIM-506	0.80 ef	1.80 a	1.30 a
CIM-554	0.20 i	0.67 fg	0.43 e
CIM-707	1.13 c	1.00 cd	1.07 b
Means (#)	0.80 b	0.87 a	-

Genotypes $LSD_{0.05}$ = 0.124, Years $LSD_{0.05}$ = 0.059, GEI $LSD_{0.05}$ = 0.175

Table 5: Mean performance of cotton genotypes for sympodia plant^{-1} as affected by environments.

Genotypes	2010	2011	Means (#)
SLH-284	16.13 b	14.93 bc	15.53 abc
CIM-446	20.67 a	12.87 bc	16.77 ab
CIM-473	13.33 bc	13.27 bc	13.30 c
CIM-496	20.33 a	15.27 bc	17.80 a
CIM-499	15.40 bc	13.73 bc	14.57 bc
CIM-506	14.27 bc	14.53 bc	14.40 bc
CIM-554	11.80 c	14.00 bc	12.90 c
CIM-707	20.53 a	14.60 bc	17.57 a
Means (#)	16.56 a	14.15 b	-

Genotypes $LSD_{0.05}$ = 2.695, Years $LSD_{0.05}$ =1.348, GEI $LSD_{0.05}$ = 3.811

Table 6: Mean performance of cotton genotypes for bolls plant^{-1} as affected by environments.

Genotypes	2010	2011	Means (#)
SLH-284	16.07 g	20.87 cd	18.47 d
CIM-446	13.67 hi	18.60 ef	16.13 e
CIM-473	18.67 e	22.60 c	20.63 bc
CIM-496	16.43 fg	31.33 a	23.88 a
CIM-499	19.53 de	22.93 c	21.23 b
CIM-506	18.33 ef	25.93 b	22.13 b
CIM-554	13.00 i	25.53 b	19.27 cd
CIM-707	15.77 gh	25.80 b	20.78 bc
Means (#)	16.43 b	24.20 a	-

Genotypes $LSD_{0.05}$ = 1.540, Years $LSD_{0.05}$ = 0.639, GEI $LSD_{0.05}$ = 2.178

followed the above genotype and showed similar bolls plant^{-1} during crop season 2011. The cultivar SLH-284 (13.00) produced least number of bolls plant^{-1} and found similar with cultivar CIM-446 (13.67) during 2010. All other genotypes grown during both crop seasons revealed medium values for bolls plant^{-1}. On average, for genotypes means and G × E interaction, the cultivar CIM-496 revealed maximum bolls plant^{-1}. In case of correlation, the bolls plant^{-1} showed significant ($p \leq 0.01$) positive correlation ($r = 0.57^{**}$) with seed cotton yield (Table 8).

For seed cotton yield plant^{-1}, mean values of genotypes ranged from 60.59 to 85.71 g, while for G × E interaction, the range was 55.74 to 107.41 g (Table 7). Considering genotypes, two cultivars CIM-496 (85.71 g) and SLH-284 (85.37 g) had maximum and comparable seed cotton yield plant^{-1}. However, these genotypes were also parallel with four other genotypes i.e. CIM-554, CIM-707, CIM-506 and CIM-473 ranged from 75.55 to 81.57 g for seed cotton yield plant^{-1}. The minimum seed cotton yield was exhibited by genotype CIM-446 (60.59 g), however, it was similar with genotype CIM-499 (70.65 g). Regarding year means, the genotypes produced maximum seed cotton yield (84.70 g) during 2011 and least during crop season 2010 (69.53 g), which confirmed that more temperature and rainfall during 2011 play key role in boll setting and eventually increased the seed cotton yield.

While considering G × E interaction, the cultivars CIM-554 (107.41 g) revealed maximum seed cotton yield plant^{-1} during crop season 2011. However, it was comparable with cultivar SLH-284 (101.24 g) during 2010. These genotypes were followed by three other alike genotypes i.e. CIM-707, CIM-506 and CIM-496 ranging from 87.82 to 88.96 g seed cotton yield plant^{-1} sown during 2011. The minimum seed cotton yield was exhibited by genotype CIM-554 (55.74 g) grown during 2010, however, it was equivalent with six other combinations of genotypes with both years producing 58.32 to 71.24 g seed cotton yield plant^{-1}. On average, for genotypes and G × E interaction means, the cultivars CIM-496, SLH-284 and CIM-554 produced maximum seed cotton yield plant^{-1}.

In case of correlation, the seed cotton yield association was positive with morphological traits (plant height, monopodia plant^{-1} and sympodia plant^{-1}), however, the correlation between bolls per plant and seed cotton yield was highly significant ($p \leq 0.01$) and positive, revealed that boll number was the major contributor in managing the variations in seed cotton yield. Based on two-year studies, the cultivar CIM-496 followed by CIM-554 and SLH-284 displayed maximum seed cotton yield and bolls plant^{-1} and were found as best adapted cotton cultivars to environmental conditions of Peshawar, Khyber Pakhtunkhwa – Pakistan.

Table 7. Mean performance of cotton genotypes for seed cotton yield plant^{-1} as affected by environments.

Genotypes	2010	2011	Means (g)
SLH-284	67.51 d-g	101.24 ab	84.37 a
CIM-446	62.87 efg	58.32 fg	60.59 c
CIM-473	76.72 cde	74.39 c-f	75.55 ab
CIM-496	83.59 cd	87.82 bc	85.71 a
CIM-499	70.05 d-g	71.24 d-g	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 c-f	88.96 bc	81.03 ab
Means (g)	69.53 b	84.70 a	-

Genotypes $LSD_{0.05}$ = 11.47, Years $LSD_{0.05}$ = 5.735, GEI $LSD_{0.05}$ = 16.22

Table 8. Correlation of seed cotton yield with morpho-yield traits in upland cotton as affected by environments.

Variables	Correlation of yield with other traits	Probability
Plant height	0.007	0.960
Monopodia plant^{-1}	0.17	0.249
Sympodia plant^{-1}	0.06	0.671
Bolls plant^{-1}	0.57^{**}	0.000

** Significant at *p*á*0.01*.

DISCUSSION

Significant mean squares due to G, E and G × E interaction revealed greater genetic variability among cotton genotypes due to their diverse genetic background, as well as environments under which the genotypes were grown. In previous studies, the four groups of cotton genotypes and environments observed with significant genotype × year and genotype × year × location interactions for various morphological and yield traits in upland cotton (Machado *et al*., 2002). In various environments, the genotypes perform differently and revealed significant G × E interactions in upland cotton (Unay *et al*., 2004; Satish *et al*., 2009). Mean squares due to G, E and G × E interactions were highly significant for various agronomic traits in *G. hirsutum* L. (Khan *et al*., 2007a, 2008; Gul, 2013).

In present studies, the G, E and G × E interactions play principal role in manifestation of the total variation for various traits, although genotypes in combination with environments were predominant. However, the contribution of experimental error due to replications was minimal than environments and genotypes. Identification of high yielding cotton genotypes over environments is of special interest for the breeders, and G × E interactions are of major concern for developing improved cultivars. In past studies, the G × E interactions were predominant in total phenotypic variation than the cultivar and environment effects by itself (Campbell and Jones, 2005; Satish *et al.*, 2009; Maleia *et al*., 2010). Therefore, a cotton cultivar, to be commercially successful, must perform well across the wide range of environments in which it is grown (Unay *et al*., 2004). Environmental factors had significant effects on plant stature and full contribution in managing the varied mean values of the genotypes for plant height and other agronomic traits in upland cotton (Elsiddig *et al*., 2006; Killi and Harem, 2006). However, Ehsan *et al*. (2008) and Khan *et al*., (2009a, b) mentioned that varied values of plant height and other yield contributing traits could be attributed to diverse base of cotton genotypes. Significant differences were noted among cotton cultivars, environments, cultivar × environment interactions about plant height and other yield traits which may be due to distinct cotton genotypes grown under diverse environmental conditions (Ali *et al*., 2005).

In present studies, positive association was observed between plant height and seed cotton yield, revealed that there was no lodging in cotton plants. In cotton crop, the plant height has imperative role by having close association with bolls setting and has ultimate positive impact on the seed cotton yield. In previous studies, positive association was also observed between yield and plant height in *G. hirsutum* L. (Killi *et al*., 2005; Khan *et al*., 2009b, d, e; Batool *et al*., 2010). However, negative association was reported between the plant height and boll number/seed cotton yield which may be due to lodging of cotton plants in worse environmental conditions (Elsiddig *et al*., 2007; Makhdoom *et al*., 2010). Hence, the cotton breeders are mostly interested in least plant height due to lodging and picking problems. However, plant height can play positive role in managing bolls and seed cotton yield if lodging did not occur. The inconsistent views might be due to different cotton genotypes studied under assorted environmental conditions.

Results authenticated that environment in combination with genotypes play greater role in manifestation of monopodial branches. For vegetative branches, the genotypes showed significant, while E and G × E interactions revealed highly significant variations. The upland cotton genotypes studied in various environments, observed with significant variances due to G, E and G × E interactions for most of the traits including vegetative branches (Satish *et al*., 2009; Gul, 2013). In present findings, genotypic and environmental components were significantly varied for vegetative and fruiting branches, however, the boll number was sequential trait for yield development in upland cotton, and the same findings also concluded by Elsiddig *et al*. (2004). The association between monopodia and seed cotton yield was positive. Positive correlation between yield and monopodia with significant variations among cotton genotypes had been observed in upland cotton (Killi *et al*., 2005; Khan and Hassan, 2011; Batool *et al*., 2013). However, Batool *et al*. (2010) and Batool and Khan (2012) reported significant variations among cotton populations for monopodia but negative impact on seed cotton yield. Because, due to more vegetative branches the cotton plant become bushy with less flowering and boll bearing, however, it also depends on the genotype morphology and structure. Therefore, the direct effect of vegetative branches could not be recognized for increasing seed cotton yield (Rauf *et al*., 2004). The contradictory findings may be due to different genetic background of the cotton populations used under diverse environmental conditions.

The sympodia plant^{-1} and bolls sympodia^{-1} perform major role in yield protection, and during selection, such important morphological traits should not be evaded. In present studies, all the components of variation (G, E, G × E) revealed significant differences for fruiting branches, which may be due to genetic makeup and the environments in which the genotypes were grown. In the past findings, significant differences were observed among cotton genotypes for fruiting branches, which can be attributed to diverse nature of the cotton genotypes and environment (Ehsan *et al*., 2008). Genotype × location, genotype × year and genotype × location × year interaction components were found to be significant for fruiting branches and yield related traits in upland cotton (Killi *et al*., 2005; Killi and Harem, 2006). In current studies, the positive association was observed between sympodia and seed cotton yield. Significant differences were noted among cotton genotypes for sympodial branches, and their positive association with yield also revealed their affirmative impact on yield in upland cotton (Khan, 2011; Batool and Khan, 2012). Positive correlation between sympodia and seed cotton yield is mainly due to boll number, however, the sympodial branches could not be regarded as a reliable source of getting high yields in cotton (Rauf *et al*., 2004). The conflicting views may be due to different cotton genotypes studied under various environmental conditions.

Bolls per plant is the major independent yield component, positively correlated with yield and plays primary role in managing the variations in seed cotton yield. Therefore, the bolls plant^{-1} should receive greater emphasis in cotton improvement programme. Hence, the selection should be made for larger number of bolls plant^{-1} and high lint %, for breeding cotton with high seed cotton and lint yields. Highly significant variations were observed for genotypes, years and G × E interaction for boll number due to varied genetic makeup of the genotypes and the environments. In environments, the significant differences indicated an existence of variation due to G × E interactions for boll setting (Ali *et al*., 2005), and its positive relationship with yield in upland cotton (Khan *et al*., 2010a, b; Makhdoom *et al*., 2010; Gul, 2013). Significant G × E interactions and positive association among yield contributing traits, primarily influenced the efforts to develop high-yielding cotton cultivars (Campbell and Jones, 2005; Campbell *et al*., 2012). Present results revealed highly significant positive correlation between boll number and yield. Significant positive association between yield and boll setting indicated that boll number was the main contributor towards G × E interactions for seed cotton yield in upland cotton (Elsiddig *et al*., 2004). Seed cotton yield was highly affected directly and indirectly by boll number and boll weight in upland cotton (Rauf *et al*., 2004; Khan, 2011, 2013; Batool *et al*., 2013; Khan and Hassan, 2011), and the significant variations among cotton genotypes for these traits manage the yield differences (Khan *et al*., 2009b).

In considering the seed cotton yield, the mean squares due to G, E, GEI revealed significant ($p \leq 0.01$) variations, and extent of such performance depends upon the magnitude of GE interactions, which occurs when genotypes differ in their relative performance across environments (Khan *et al*., 2007a, 2008). The yielding ability of the present cotton genotypes was the result of their interaction with environmental factors i.e. temperature, moisture, day length and soil fertility which vary across the years. Cotton genotypes revealed significant variations through environments and G × E interactions for yield, indicating variability among genotypes as well as environments (Unay *et al*., 2004; Naveed *et al*., 2006a, b; Gul, 2013). Larger year-to-year and field-to-field variations were observed in the yield under different growing conditions, and both environment and cotton genotypes contributed to yield variations, however, the environmental complex has shown primary yield effect (Best, 2005; Ahmad *et al*., 2006). In present studies, the environments in combination with genotypes were predominant for yield and yield related traits. However, according to Blanche (2005), the environment, genotypes and G × E associations contributed in descending order to the total variations in seed cotton yield, and the environment was the major source of variation in seed cotton and lint yields in upland cotton (Kerby *et al*., 2000; Suinaga *et al*., 2006). The G × E interaction mostly reduce the correlation between genotype and phenotype, and makes it difficult to judge the genuine genetic potential of a genotype (Killi and Harem, 2006).

In present findings, the genotypes showed good boll setting and maximum seed cotton yield during 2011 than 2010, revealed that warmer environment and more rainfall during 2011 play key role in setting of increased bolls and seed cotton yield. The significant mean differences due to G, E, and G × E interactions revealed that variations were due to diverse genetic makeup of the genotypes, and their interaction with environments; therefore, need to be studied for a longer period for certified findings.

Conclusion: Based on the two-year observations, it was concluded that genotypes in combination with environments play principal role in phenotypic manifestation of the various traits. Genotype CIM-496 showed remarkable performance for morphological and yield traits followed by CIM-554 and SLH-284 over all the environments. Therefore, cultivar CIM-496 had good adaptation to environmental conditions of Peshawar valley, Khyber Pakhtunkhwa – Pakistan and can be grown for improvement in seed cotton and lint yields.

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