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Genotype and environment interaction effect on yield and yield components in Desi-type Chickpea [*Cicer arietinum* (L.)]

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Chickpea is the major pulse crop cultivated in Ethiopia. However, its production is constrained due to genotype instability and environmental variability. This research was carried out to examine the magnitude of environmental effect on yield of chickpea genotypes and to investigate the stability and adaptability of genotypes under different agro-ecologies. Twelve genotypes evaluated in randomized complete block design with three replications in three locations for two continuative years. Various stability indices used to assess stability and genotype by environment performances. Combined analysis of variance for yield and yield components revealed highly significant (P≤0.01) differences for genotypes, environments and their interaction. Growing years do not show difference. The significant interaction showed genotypes respond differently across environments. At Guduru, Hareto and Gitilo, top performing genotype in grain yield were genotype 229961 (2.33ton/ha), genotype 225887 (3.6ton/ha), and genotype 225887 (2.23/ha), respectively. The first two principal components (PC1 and PC2), which were used to create a two-dimensional bi-plot, explained 7.5 and 3.75% of AMMI sum of squares, respectively. Hareto and Guduru are the most differentiating environments, while Gitilo is more responsive environment than the other environments since it is far away from the other in altitude. Genotype 212476 and 212976 were the most stable as well as productive at Hreto environment, genotype 229961 and 225887 were the most stable as well as productive at Guduru environment. Genotype 229959 and 215189 were stable with intermediate productive in both years and at three of the growing locations. Genotype 219804 and 225889 are less responsive. The best genotypes with respect to Guduru site are 229959 and 215189: the best genotype for environments with respect to Hareto was 212476 and 212976, and to Gitilo environment 229961 and 225887 genotypes.

Key words: Additive main effects and multiplicative interaction (AMMI), Desi-type, interaction, AMMI stability value (ASV).

INTRODUCTION

A diploid (2n=16 chromosomes) and self-pollinated plant, chickpea is a temperate pulse crop, probably originated in Southeastern Turkey and spread to other parts of the world. Crop improvement efforts have improved adaptation

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of chickpea to warmer conditions in the subtropics. Chickpea is frequently divided for breeding purpose into two main types' desi and Kabuli. This distinction is mainly made on the basis of seed size and color. Desi showing small (1500 seeds/lb) and colored seeds while the Kabuli types with large (800 seeds/lb) and white seeds (Singh, 1987; Moussa et al., 2000). It is believed that the Desi type originates first and the Kabuli type originated later through natural mutation. Although both types differ in many traits, they cross easily with each other and the transfer of genes from one type to another is easy (Singh and Saxena, 1999). Chickpea is an important source of protein in the diets of the poor in the SAT and WANA regions, and is particularly important in vegetarian diets. In addition, it is being used increasingly as a substitute for animal protein.

Environmental factors such as soil moisture, sowing time, fertility and temperature and day length have strong influence during various stages of plant growth (Bull et al., 1992). The environment is changing day-by-day and this implies that it is necessary to evaluate crop genotypes at different locations to assess their performances. One approach to improve the chickpea yield is to identify stable genotypes that perform consistently better under diverse environments (Ghulam et al., 2012). The performance of a genotype is not always the same in different locations as it influenced by environmental factors. To assess yield stability among varieties, multi-location trials with appropriate stability analysis method is required. Differences in genotype stability and adaptability to environment can be qualitatively assessed using the bi-plot graphical representation that scatters the genotypes according to their principal component values (Vita et al., 2010).

In Ethiopia, especially in Horo Guduru Wollega area, there is no sufficient information on the genotype by environment interaction effects on yield and yield related traits of chickpea. Therefore, the current research was undertaken to examine the magnitude of environmental effect on yield and yield related traits of Desi-type chickpea genotypes, to study the nature and extent of genotype by environment interaction on seed yield of Desi-type -chickpea genotypes.

MATERIALS AND METHODS

The experiment was conducted during the 2015 and 2016 main cropping season at three locations representing various chickpea growing agro-ecologies of Horo Guduru Wollega Zone, Western Ethiopia. The environments were Guduru, Gitilo and Hreto. Twelve (12) Desi-type chickpea genotypes were included in the study (Table 1). The plant materials were obtained from Ethiopian Biodiversity Institute. Planting of the genotypes was done in early and mid-August up to first week of September depending on moisture duration of each environment using randomized complete block design with three replications at each site under rain fed conditions (Table 2). Each genotype was planted in four rows of 2 m length and at 1.2 m width. A spacing of 30 cm row to row distance and 10 cm plant to plants were used on a plot size of 2.4 m^2. Recommended fertilizer type and rate was applied. Weeding and other management practices were done as required for each site. Data were recorded on days to 50% flowering, 90% physiological maturity, plant height, the number of pods per plant, the number of seeds per plant, number of primary branches per plant, and grain yield in kg per plot and then converted to ton per hectare. The collected data was analysed using SAS V.9.2 for Combined analysis, Genst.13th edition (SP2) for additive main effects and multiplicative interaction (MMI) and AMMI stability value (ASV).

Analysis of variance

From the combined analysis of variance, the mean squares due to genotypes, environments, year, genotype by environment interaction, genotype by year interaction, environment by year interaction and genotype by environment and by year interaction were highly significant for the traits, days to flowering, days to maturity, plant height, number of pods per plant and number of pod bearing branches per plant. However, there were no-significant effects of all these three sources of variation on the number of seeds per pod (Table 3). The separate analysis of variance for all yield related traits, except for number of seeds per pod at each location exhibited highly significant (P≤0.01) differences among Desi-type chickpea genotypes for the days to flowering, days to maturity, number of pods per plant, plant height, and number of pods bearing branches per plant at all locations. Similar results were reported by different researchers who worked on chickpea (Singh et al., 1990; Bozoglu and Gulumser, 2000; Vargas et al., 2007). The responses of genotypes in terms of all yield related traits were different both within and across locations. This indicated that the efficiency of a breeding program aimed at yield improvement is impaired due to genotype by environment interaction, which complicates the process of crop variety development especially when varieties are selected in one environment and used in others (Ahmad et al., 2011).

Significant effects observed for plant height, number of pods per plant not only for genotypes but also for locations, year, and genotype by environment interaction, genotype by year interaction, environment by year interaction and genotype by environment and by year interaction, reflecting genetic variability in experimental material as well as difference in the environmental conditions even through the two continuative growing years (Table 3). Averaged over all genotypes the highest plant height was recorded at Hareto (49.7 cm) and the shortest was at Gitilo (33.6 cm) (Table 6). Number of pods per plant is an important selection criterion for the development of high yielding genotypes and strongly influenced by environment in chickpea (Malik et al., 1988). Marked variation was observed in the performance of genotypes over the three locations (Table 3). Number of pods per branch was highest at Hareto (10.5) and least at Guduru (2.5). The genotypes mean values for number of pods per branch varied from 4.52 for genotype 215189 to 7.2 for genotype 225887. The highest mean number of pods per branch was recorded for genotypes 225887 (11) followed by 229961 (9.5) and 212916 (9) in Table 2. These results are consistent with the findings of Singh and Bains (1984) and Malik et al. (1988). These results indicate variability for number of pods per branch and its sensitiveness to environmental fluctuations.

RESULTS AND DISCUSSION

Performance of genotypes on grain yield

The combined analysis of variance (Table 3) for grain yield exhibited significant (P≤0.01) effects of locations,

Table 1. Location and descriptions of weather conditions for the three tested locations.

Location	Annual temperature (°C)	Annual rainfall (mm)	Locatation	
			Altitude (m)	Latitude
Gitilo	Min 9.24 - max 23.28	1844.19	2854	09° 12'N/37° 0'E 28.7'
Guduru	Min 16.60 - max 26.19	1816.86	2265	09° 04' N/37° 0'E 176'
Hareto	Min 14.60 - max 23.19	1832.06	2485	09° 04' N/37° 0'E 19.64'

Table 2. Experimental material (Desi-type chick-pea genotypes) used in the experiment.

Entry No.	Genotype code	Source	Year
1	208900	IEBC	2015
2	215188	IEBC	2015
3	212476	IEBC	2015
4	212916	IEBC	2015
5	229959	IEBC	2015
6	219804	IEBC	2015
7	230795	IEBC	2015
8	229961	IEBC	2015
9	215189	IEBC	2015
10	208977	IEBC	2015
11	225887	IEBC	2015
12	225889	IEBC	2015

genotypes and genotype by environment interaction, indicating differences in environments, the presence of genetic variability among genotypes and year. Various authors (Singh et al., 1990; Bozoglu and Gulumser, 2000) reported the presence of significant genotype by environment interaction in chickpea. The overall mean yield of the location varied from 0.78 to 2.66 ton per hectare (Table 4) and thus, the three environments showed wide variation in yield potential. The highest mean grain yield was obtained at Hareto (3.13 ton/ha) and the lowest was from Gitilo (0.75 ton/ha). The possible reason was that late planting was done at Gitilo and due to this moisture; stress occurred at vegetative and pod setting stage while relatively sufficient moisture was available at Hareto. Genotypic means across the locations (mean environmental index) indicated that maximum mean grain yield across all the three locations in two year were obtained from 225887 genotype (2.68 ton/ha) and the minimum was from genotype 219804 (0.78 ton/ha). Genotype by environment interaction causes differences in yield rank of genotypes in different locations; thus, it becomes important for the chickpea breeders in terms of selection efficiency and genotype suggestions for different locations.

Genotypes showed inconsistent yield performances across all environments. Genotypes expressed their genetic potential differently in different environments (Table 4). At Guduru, Hareto and Gitilo the top performing genotypes were 225887 (2.36 ton/ha), 229961 (3.4 ton/ha) and 225887 (2.33 ton/ha) at the first growing year (2015) and Genotype 215189 (2.7 ton/ha) genotype 225887 (3.43 ton/ha) and genotype 212916 (2.41 ton/ha) in the second year (2016), respectively. Genotype 225887 tops performing at Hareto and Guduru in both years in average with the average mean yield of 3.12 and 2.7 ton/ha, respectively and it is a rich (potential environment) genotype whereas genotype 219804 performs poorly to all location through both growing seasons, therefore called a genotype with poor environment. The mean grain yield averaged over environments, year and genotypes were 1.78 ton/ha (Tables 3 and 4). In summary, the relative ranking of genotypes at all the three environments were different and CV values of genotype ranged from 2.1 to 18.1% (Table 6).

The AMMI analysis of variance of grain yield of 12 Desi-type chickpea genotypes tested in three environments isshown in Table 5. The analysis revealed that Desi-type chickpea genotypes were significantly ($P \leq 0.01$) affected by environments (E), genotypes (G), Year(Y), genotype by environment interaction, Year by Genotype and Year by Environment by Genotype interaction. The main effects of environment and genotype accounted for 32.8 and 24.5%, respectively,

Table 3. Mean square Analysis of variance for the six yield related characters for Desi type chickpea genotypes.

Var	Gen	Year	Env	G×E	G×Y	Y×E	G×Y×E	Err	M	CV%
Df	11	1	2	222	11	2	22	142	-	-
DF	99*	661*	300*	21.6*	23*	45*	41*	6.8	59	5
DM	522*	1345*	130*	27.8*	27.3*	1343*	28.5*	9.3	101	2.1
PH	225*	340*	590*	21.2*	27*	5817*	111*	12.3	39	9
BpP	13.9*	0.5	3*	0.4	0.6	24.6*	5	0.5	3.6	18.1
PpB	19*	184*	1.5	10.6*	1.7	582*	9.2*	2	6	14
SpP	0.99	0.077	0.12	0.6	0.12	0.06	0.2	1.47	1.7	12
GY	3.3*	0.08*	11*	3.6*	0.3	10.12*	7.6*	0.3	1.75	11.7

GY=Grain yield, DF=days to 75% flowering, DM=days to 75% maturity, PH=plant height, BpP=number of pod bearing branches per plant, PpB=number of pod per branches and SpP= number of seed per pod. Gen= genotypes, Y= year, Env=environment, G×E=genotype by environmental interaction, Y×E=year and environment interaction, Y×G= year and genotype interaction, Y×E×G=interaction of year, environment & genotype, CV=coefficient of variation.

Table 4. Mean performance of the genotypes in grain yields in ton/hactar at three of the locations.

Genotype	Guduru	Hareto	Gitilo	Mean
208900	1.58	2.6	1.1	1.5
215188	1.35	2.75	1.28	1.6
212476	1.7	2.7	1.16	1.67
212916	1.9	2.76	1.41	1.8
229959	2.06	2.75	1.12	1.89
219804	0.93	0.9	0.79	0.87
230795	1.4	2	1.3	1.2
229961	2.33*	3.03*	1.46	2.28
215189	2.2	2.87	1.43	2
208977	1.2	2.4	0.92	1.47
225887	2.25	3.13*	2.3*	2.6*
225889	1.06	2.3	1.16	1.48
Mean	1.67	2.58	1.3	1.7
CV%	9.1	7.6	8.5	12
LSD5%	0.83	0.75	0.45	0.35

*Guduru, Hareto & Gitilo=are environments, LSD=least significant difference, CV=coefficients of variation.

and G × E interaction accounted for 19.2% of the total variation of genotype by environment on data for grain yield indicating environment had larger effect for its variability. G×E×Y also accounts for 19.7% of the total variation for Desi-type chickpea genotypes. However, this variation is not due to year but due to the contribution effect of genotype and environment. The first two principal components (PC1 and PC2), which were used to create a two-dimensional bi-plot, explained 89.4 and 6.5% of AMMI sum of squares, respectively. According to the AMMI model, the genotypes, which characterized by means greater than grand mean and the IPCA, score nearly zero are considered as generally adaptable to all environment (Ezatollah et al., 2013). However, the genotype with high mean performance and with large value of IPCA score is considered as having specific adaptability to the environments. The large sum of squares for environments showed that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. This is in synchronization with the findings of Singh et al. (1990), Yan (2002) and Yan and Tinker (2006) in chickpea production. This result also indicates the considerable influence of environments on the yield performance of Desi-type chickpea genotypes in Horo Guduru Wollega Zone. The magnitude of the genotype by environment sum of squares was more than two times that for genotypes and year, indicating that there were considerable differential genotype responses across environments rather than year.

Table 5. AMMI analysis of variance for branch per plant, pod per branch and grain yield in ton/hectare.

Var	Df	B/Plant			Pod/branch			Grain yield(ton/hac)		
		SS	MS	SS%	SS	MS	SS%	SS	MS	SS%
Tot		400.8	-	-	2059	-	-	112	-	-
Gen	11	60.3	13.9**	15	212.8	19.3*	10.3	27.3	2.4*	24.5
Year	1	0.6	0.5	0.2	184	184.6**	8.9	3.7	3.6*	3.3
Env	2	49	24.9*	24.4	22.9	12.4*	56.8	22.2	11**	32.8
G×E	22	99.7	4.5*	22.9	1165	52.9**	6.6	36	21.6**	19.2
G×Y	11	6.2	0.6	1.6	18.2	1.7*	1.2	1.4	0.3	1.2
Y×E	2	8.9	4.6*	2.2	9.4	4.7*	0.45	2.4	1.2*	13.4
G×Y×E	22	101	5*	25.5	202	9.2**	9.8	22.7	1.55*	19.7
PCI1	12	19.76	1.8*	4.9	7.8	0.62	0.37	8.3	0.7*	7.4
PCI2	10	0.89	0.02	0.09	1.6	0.26	0.13	4.2	0.42*	3.75
Err	142	7.4	0.5	1.12	19.8	2	7	10.3	0.23	1.6

GY=Grain yield, DH=days to 75% flowering, DM=days to 75% maturity, PH=plant height, BpP=number of pod bearing branches per plant, PpB= number of pod per branches and SpP=number of seed per pod. Gen=genotypes, Y=year, Env=environment, G×E=genotype by environmental interaction, Y×E=year and environment interaction, Y×G=year and genotype interaction, Y×E×G= interaction of year, environment & IPC1=the first principal component and IPC2= the second principal component.

Table 6. Genotype, environment and year G/Y means and scores ASV.

Genotype	Genotype mean	IPCAg[1]	IPCAg[2]	ASV
208900	1.515	0.10963	0.09800	0.33
215188	1.607	0.02568	0.14697	0.15
212476	1.664	0.07454	0.18151	0.124
212916	1.803	-0.01127	0.22023	0.12
229959	1.899	0.28170	-0.51571	0.5
219804	1.050	-0.57628	-0.16883	0.59
230795	1.297	-0.37405	0.17166	0.4
229961	2.289	0.49426	0.10729	0.09
215189	2.051	-0.02130	-0.42623	0.4
208977	1.474	0.02164	0.11215	0.1
225887	2.679	0.12476	0.12034	0.07
225889	1.481	-0.14932	-0.04740	0.13
Environment	**Env. mean**	**IPCAe[1]**	**IPCAe[2]**	
Guduru	1.3	0.057	-0.66	
Hareto	2.064	0.62	0.37	
Gitilo	1.7	-0.68	0.29	
Year	**Year mean**	**IPCAy(1)**	**IPCAy(2)**	
2015	1.84	-0.43	0.002	
2016	1.59	0.438	0.000	

The AMMI I, bi-plot for grain yield of the 12 Desi-type chickpea genotypes at three environmental conditions for two consecutive years is as shown in Figure 1. The main effects (genotypes, environments and year) accounted for 95.9% of the total variation and IPCA 1 accounted for 89.4% of the total variation due to genotype by environment interaction alone. Environments showed high variation in both main effects and interactions (IPCA1) (Figure 1). Hareto is the most favorable environments; Gitilo is the least favorable environments, while Guduru is the averaged environment.

All environments are almost the same based on their

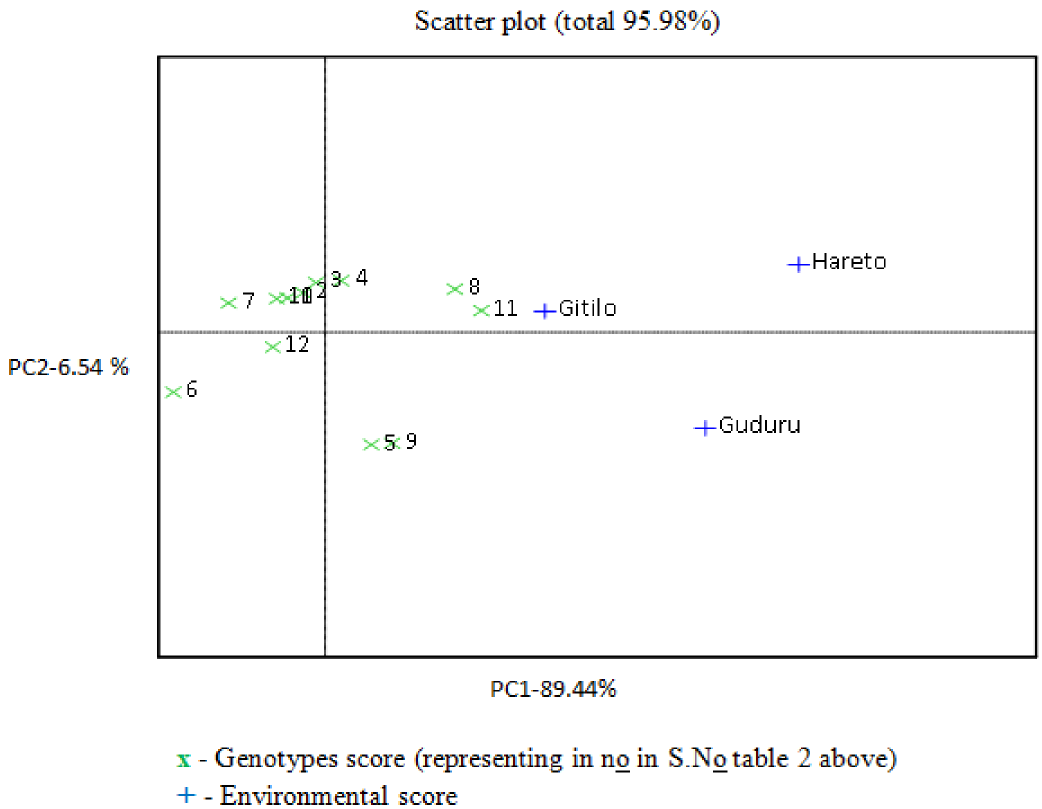

Figure 1. AMMI bi-plot analysis of IPCA scores genotype and environment means for Desi-type genotypes.

IPCA 1 scores. Hareto and Gitilo are in quadrant I and have got large positive IPCA1 scores, which interact positively with genotypes that have positive IPCA1 scores and negatively with those genotypes having negative IPCA1 scores. Guduru in quadrants IV and have got small positive IPCA1 scores, which interact positively with genotypes that have positive IPCA1 scores and negatively with those genotypes having negative IPCA1 scores (Figure 1). The environments can be sub-grouped according to their average yield over the genotypes. According to environmental IPCA1 scores, Hareto and Gitilo were more stable and had lower genotype by environment interaction, and had high yield performance. On the other hand, the highest IPCA1 scores belonged to Hareto and Guduru, and they had high yield performance. According to IPCA1, environment Hareto was an ideal environment for selecting genotypes with specific adaptation to high input conditions.

Genotypes that fall near the origin are relatively wider adapted while genotypes that fall far from the origin are most probably specific adaptors. In Figure 1, the genotypes and locations that are located far away from the origin are more responsive. Hareto and Guduru are the most differentiating environments, while Gitilo is more responsive environment than the other environments since it is near to the origin. Genotypes 212476, 212976, 229961 and 225887 were the most stable as well as productive. Genotypes 229959 and 215189 were stable with intermediate productivity. 219804 and 225889 are less responsive. Genotypes and environments that fall into the same sector interact positively; negatively if they fall into opposite sectors (Osiru et al., 2009). A genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment. If they fall into adjacent sectors, interaction is somewhat more complex. In this case, the best genotypes with respect to Guduru site are 229959 and 215189; the best genotype for environments with respect to Hareto and Gitilo is 212476, 212976, 229961 and 225887. Genotypes 219804 and 225889 respond negatively to all Hareto, Guduru and Gitilo environments.

The AMMI stability (ASV) value is the distance from zero in a bi-plot between the IPCA 1 scores and the IPCA 2 scores (Getachew et al., 2015). In the AMMI analysis, the IPCA 1 score contributes more to the genotype-environment (GE) interaction sum of squares. Thus, the relative contribution of IPCA 1 and IPCA 2 to the total G × E interaction sum of squares has to be weighted by the proportional difference between IPCA 1 and IPCA 2 scores.

Genotypes 208977, 225889, 225887, 215188 and 212476 had little interaction because of their weakest reaction to IPCA 2. Similarly, their little interaction was confirmed by their least AMMI stability value and thus, better stability in yield across environments. From thus genotypes some were the highest yielder of all. In addition to their greater interaction (strong reaction to IPCA 2), genotypes 229959, 219804 and 229961; however, showed high AMMI stability values, reflecting unstable in yield performance across environments (Table 5). Although no genotype was superior in all the test environments, the genotypes 208900, 212476 and 230795 were stable across environments both in their mean performance and ASV.

Conclusion

Genotype by environment interaction causes differences in yield rank of genotypes in different locations; thus, it becomes important for the chickpea breeders in terms of selection efficiency and genotype suggestions for different locations. Important approach to improve the chickpea yield is to identify stable genotypes that perform consistently better under diverse environments (Ghulam et al., 2012). The performance of a genotype is not always the same in different locations as it influenced by environmental factors. To assess yield stability among varieties, multi-location trials with appropriate stability analysis method is required. Differences in genotype stability and adaptability to environment can qualitatively assessed using the bi-plot graphical representation that scatters the genotypes according to their principal component values.

From the combined analysis of variance, the mean squares due to genotypes, environments, year, and their interactions were highly significant for all the traits studied. However, there were no-significant effects of all these three source of variation on the number of seeds per pod. The separate analysis of variance for all yield related traits, except for number of seed per pod at each location exhibited highly significant ($P \leq 0.01$) differences among Desi-type chickpea genotypes for the days to flowering, days to maturity, number of pods per plant, plant height, and number of pod bearing branches per plant at all locations. Significant difference due to genotypes showed inconsistent performances across all environments and expressed their genetic potential differently in different environments. The significant effect shown in G×E indicated genotypes need separate evaluation for each location. In the other way, the non-significant effect observed for the two growing season depicts there were no more micro-environmental variation at both season at the locations. But, the results of some genotypes showing little variant in yield result through growing season tell as there may be some preference of these genotypes to even little micro-climate. The mean grain yield averaged over environments, year and genotypes were 1.78 ton/ha (Tables 3 and 4). In summary, the relative ranking of genotypes at all the three environments were different and CV values of genotype ranged from 2.1 to 18.1%. The AMMI analysis of variance for grain yield of 12 Desi-type chickpea genotypes tested in three environments were significantly ($P \leq 0.01$) affected by Environments (E), Genotypes (G), Year, Genotype by Environment interaction, Year by Genotype and Year by Environment by Genotype. The main effects of E and G accounted for 19.8 and 24.5%, respectively, and G × E interaction accounted for 32.2% of the total variation of genotype by environment data for grain yield. G×E×Y also accounts 19.7% of the total variation for Desi-type chickpea genotypes. However, this variation is not due to year but due to the contribution effect of G and E. The first two principal components (PC1 and PC2), which were used to create a two-dimensional bi-plot, explained 7.5 and 3.75% of AMMI sum of squares, respectively. According to the AMMI model, the genotypes, which is characterized by means greater than grand mean and the IPCA, score nearly zero are considered as generally adaptable to all environment (Ezatollah et al., 2013). However, the genotype with high mean performance and with large value of IPCA score are consider as having specific adaptability to the environments.

In AMMI stability (ASV) value, some genotypes had little interaction because of their weakest reaction to IPCA 2. Similarly, their little interaction was confirmed by their least AMMI stability value and thus, better stability in yield across environments. Thus, some genotypes were the highest yielder of all.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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