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GGE BIPLOT ANALYSIS BASED SELECTION OF SUPERIOR CHICKPEA (*CICER ARIETINUM* L.) INBRED LINES UNDER VARIABLE WATER ENVIRONMENTS

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Abstract

Chickpea is an important legume crop and grown mainly on the marginal lands in Pakistan. Insufficient and erratic water availability is severe problem for this crop. Hence, breeding chickpea for low moisture stress tolerance is absolutely important in this era of climate change. Research work was started with evaluation of mini core collection of 450 chickpea lines and 42 lines were retained after three years of selection under different water treatments. These 42 lines were used in current study for evaluation and further selection under three water treatments. Detailed study on these lines was conducted under irrigated, rainfed and tunnel conditions (no rainfall and irrigation) during 2012-13 and 2013-14. Data were collected for yield and yield components which were subjected to analysis of variance and GGE biplot analysis. Analysis showed highly significant differences among lines for all traits under study. Mean comparison showed less differences between irrigated and rainfed conditions than tunnel for all traits. GGE biplot ranked chickpea lines as; above average, below average, stable, unstable and ideally performing. Lines present closer to ideal genotype on GGE biplot were worthy for selection because these had higher mean values with stable performances across different water treatments. The ideal lines in these experiments; K008-11, CM1592/08, CM526/05, D089-11, TGDX201, D094-11 and K051-11 were selected with higher yield potential.

Key words: Chickpea, GGE biplot, Grain yield, Rainfed, Stable lines and Water stress.

Introduction

Plant breeders use to develop the crop varieties that adapt to certain geographic region, normally which tolerate certain biotic and abiotic stresses (Nakashima *et al*., 2000). Germplasm is evaluated under stress conditions for the development of stress tolerant stock (Narusaka *et al*., 2003). Exploitation of environments which discriminate the varieties is very effective (Blanche & Myers, 2006; Yan *et al*., 2007; Shinwari *et al*., 1998). Chickpea is grown on marginal lands in Pakistan and suffer from severe water shortage especially during terminal growth stages. So, for development of low moisture stress tolerant genotypes it is mandatory to evaluate the chickpea genotypes under insufficient moisture stress prevailing environments.

Stability and desired response of genotypes across different environments is very crucial for plant breeders (Yang *et al*., 2009; Kidokoro *et al*., 2009; Masood *et al*., 2005). There is strong existence of genotype into environment (GE) interaction which changes performance of genotypes across environments. There are different univariate and multivariate procedures for interpreting and studying the GE interaction (Lin *et al*., 1986). Linear-bilinear models (Crossa & Cornelius, 1997), the additive main effects and multiplicative interactions (AMMI) and genotype plus GE interaction (GGE) biplot models are multivariate procedures for GE interaction studies (Zobel *et al*., 1988; Yan *et al*., 2000). Sabaghpour *et al*. (2012) used the AMMI analysis for evaluation of chickpea genotype main effects and genotype environment interaction.

GGE biplot was recommended as the most appropriate analysis to evaluate the genotypes under different target environments (Yan *et al*., 2007). It has been reported that the genotype main effect (G) should be integrated with genotype into environment interaction (GEI) for evaluation of genotypes under different environments using GGE biplot analysis (Yan & Kang, 2003; Yan & Holland, 2010). Environments are evaluated for discrimination ability (ability to differentiate between genotypes), representativeness (ability to represent the target region) and desirability index (distance from ideal location; Yan, 2001). GGE biplot is also used for evaluation of genotypes for average performance and stability.

Biplots were used for the first time in agriculture by Gabriel (1971), who analyzed the data of cotton for model selection. Kempton (1984), Gauch & Zobel (1997), and Kroonenberg (1995) were among pioneers to use biplot. GGE biplot is new version of biplots which considers the genotype (G) and genotypes × environment (GE) as two separate sources of variations and must be considered simultaneously for evaluation of genotypes and environment. Evolution of GGE biplots into comprehensive analysis has extended the applicability of the analysis. GGE biplots are used in study of genotype by environment tables (Yan, 2001; Yan & Kang, 2003), genotype by trait tables (Yan & Rajcan, 2002), diallel cross tables (Yan & Hunt, 2002), host by pathogen tables (Yan & Falk, 2002) and QTLs by environment tables (Yan & Tinker, 2005). GGE biplot analysis has been used by researchers for different crops: Yan *et al*., (2000) used for evaluation of Ontario winter wheat; Blanche & Myers (2006) for variety registration scheme of cotton; Fan *et al*., (2007) for evaluation of grain yield in maize genotypes at ten locations for two years. High yielding and stable genotypes of rice (Samonte *et al*., 2005), chickpea (Farshadfar *et al*., 2011), barley (Yan & Tinker, 2005) and field pea (Rezene *et al*., 2014) were selected with the help of GGE Biplot.

Rainfed, irrigated and conserved soil moisture conditions are mostly available to the chickpea in Punjab, Pakistan. The current study was planned with the objective to evaluate chickpea advanced lines under different levels of low moisture stress for the selection of high yielding inbred lines with stable performance i.e. closer to virtual ideal genotypes. Water treatments were applied to develop the target water stress environments (irrigated, rainfed and tunnel conditions).

Materials and Methods

Chickpea germplasm: The germplasm used in this study included 42 desi and kabuli chickpea advanced lines (Table 1). Experiment was conducted at research field of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan during cropping seasons of 2012-13 and 2013-14.

Sowing method and water treatments: Land was prepared following standard agronomic practices. Sowing of 42 chickpea advanced lines was done using dibbling method in field following two factor factorial (genotypes and treatments) randomized complete block design with three replications of each line. Plant to plant and row to row distance was maintained at 15cm and 30cm, respectively. Total ten seeds of each line were sown in row. Efforts were made to reduce the standard error by carrying out the uniform standard field practices (hoeing, weeding etc.) as per requirement. Experiments were conducted for two years under the following three different water treatments (environments):

1. Irrigated (irrigation was applied during field bed preparation and initiation of flowering + rainfall)
2. Rain-fed (irrigation applied only during field bed preparation, no irrigation at initiation of flowering + rainfall)
3. Tunnel (irrigation applied only at field bed preparation stage and prevented from rainfall by covering field with tunnel).

Data for rainfall during two chickpea growing seasons is given in Table 2.

Parameters studied: Data were recorded for different morphological traits and yield components. Total five plants per entry were selected for data recording on the parameters like; plant height (cm), number of primary branches, number of secondary branches, number of pods per plant, number of seeds per pod, 100 seed weight (g), days to initiation of flowering and grain yield (g). Data were subjected to analysis of variance following Steel *et al*. (1997). Tukey's HSD (honest significant difference) mean comparison analysis was used for mean comparison of environments and genotypes. All these analysis were conducted by using Statistix 9.1 version.

Table 1. List of 42 chickpea genotypes used for current research experiment.

Sr. No.	Genotypes	Type	Origin	Sr. No.	Genotypes	Type	Origin
1.	Noor2009	Kabuli	AARI	22	D086-11	Desi	AARI
2.	Thall2011	Desi	AZRI	23	D088-11	Desi	AARI
3.	K008-11	Kabuli	AARI	24	D089-11	Desi	AARI
4.	K0032-11	Kabuli	AARI	25	D090-11	Desi	AARI
5.	K0034-11	Kabuli	AARI	26	TGDX201	Desi	AZRI
6.	K0041-11	Kabuli	AARI	27	CH16/06	Desi	NIAB
7.	K0048-11	Kabuli	AARI	28	CH30/06	Desi	NIAB
8.	K0063-11	Kabuli	AARI	29	CH36/06	Desi	NIAB
9.	K0065-11	Kabuli	AARI	30	CH70/06	Desi	NIAB
10.	K0070-11	Kabuli	AARI	31	CH81/06	Desi	NIAB
11.	CH53/07	Kabuli	NIAB	32	CH84/06	Desi	NIAB
12.	CM1529/03	Kabuli	NIAB	33	CH85/06	Desi	NIAB
13.	K051-11	Kabuli	AARI	34	D094-11	Desi	AARI
14.	K055-11	Kabuli	AARI	35	D097-11	Desi	AARI
15.	K064-11	Kabuli	AARI	36	D098-11	Desi	AARI
16.	CH46/07	Kabuli	NIAB	37	CM98/05	Desi	NIAB
17.	CH48/07	Kabuli	NIAB	38	CH104/06	Desi	NIAB
18.	11K113	Kabuli	AZRI	39	CH107/06	Desi	NIAB
19.	CM1592/08	Kabuli	NIAB	40	CM510/06	Desi	NIAB
20.	D072-11	Desi	AARI	41	CM526/05	Desi	NIAB
21.	D078-11	Desi	AARI	42	CM562/05	Desi	NIAB

Note: NIAB = Nuclear Institute for Agriculture and Biology, Faisalabad; AARI = Ayub Agriculture Research Institute, Faisalabad; AZRI = Arid Zone Research Institute, Bhakkar

Table 2. Rainfall (mm) pattern of two consecutive chickpea growing seasons (2012-13 & 2013-14).

Years	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May
2012-13	4.65	1.07	0.00	0.60	0.08	1.03	0.66	0.85	0.23
2013-14	0.06	0.42	0.11	0.00	0.00	0.40	0.99	0.84	2.23

Table 3. Three factor factorial analysis of variance of 42 chickpea genotypes for grain yield.

SOV	DF	PH	PB	SB	P/P	S/P	100SW	DF	GY
Block	2	32	2.01	35.5	796	0.092	20.72	3.06	39648
Genotypes (G)	41	563***	9.27***	85.7***	2742***	0.461***	73.54***	377***	59893***
Treatments (T)	2	113872***	1126.32***	30464.0***	645437***	40.42***	2425***	1853***	6753736***
Year (Y)	1	26^{ns}	63.15***	210.4***	503^{ns}	0.011^{ns}	0.89^{ns}	4.07^{ns}	2987^{ns}
G×T	82	136***	4.08***	47.9***	1024***	0.109***	22.51***	15.02***	20411***
Y×G	41	23^{ns}	0.39^{ns}	5.5^{ns}	35^{ns}	0.006^{ns}	0.78^{ns}	0.44^{ns}	59^{ns}
Y×T	2	78*	0.34^{ns}	20.9^{ns}	73^{ns}	0.007^{ns}	3.35^{ns}	0.49^{ns}	501^{ns}
Y×G×T	82	30^{ns}	0.43^{ns}	4.7^{ns}	38^{ns}	0.005^{ns}	0.79^{ns}	0.47^{ns}	45^{ns}
Error	502	24	0.46	7.6	187	0.048	3.63	5.14	4210
Total	755								

* = Significant at 5%, ** = Highly significant at 1%, *** = Highly significant at 0.1%, ns = Non-significant

PH: Plant height, PB: Primary branches, SB: Secondary branches, P/P: Pods per plant, S/P: Seeds per pod, 100SW: 100 seed weight, DF: Days to flowering, GY: Grain yield

GGE Biplot analysis: GGE biplot analysis was used for evaluation of chickpea genotypes, environments and their interaction. Different environments i.e. irrigated, rainfed and tunnel were used for biplot analysis. Scatter plot, ranking plot, comparison biplot for environment and comparison biplot for genotypes were drawn for all traits to study the G×E interaction among genotypes and water treatments. All of these GGE biplots were based on data of two years (2012-13 and 2013-14). Vectors in GGE biplots were representing the water treatments. Vector-1 (T_1) represented the irrigated treatment, vector-2 (T_2) explained the rainfed treatment and vector-3 (T_3) stands for tunnel treatment. Longer vector length showed more discriminating power relative to vectors of shorter length. Vector length was representative of standard deviation within respective treatment. Most discriminating and representative treatment was used for selection of generally or widely adapted genotypes while discriminating but not representative treatment was helpful for selection of specifically adapted chickpea genotypes only for that typical treatment.

If there is acute angle ($<90^o$) between two vectors then they are positively correlated. Whereas, if there is obtuse angle ($>90^o$) between them then these are negatively associated but in case of right angle ($=90^o$), vectors are said to be independent. Orthogonal test (all genotypes were evaluated under all test environments) for all of three treatments were conducted for evaluation of chickpea genotypes. In breeding program the treatments are subjected to orthogonal test only when there are chances of adaptability while other treatments are subjected to non-orthogonal test (Yan *et al*., 2010).

Equal vector length for treatments described that biplot was adequate and correlation between treatments could be explained by measuring angle between them. In case of a treatment variable with very short vector length relative to others, the biplot is proved as inadequate for evaluation of interrelationship of shorter variable with longer ones on the basis of cosine of angle between them (Yan *et al*., 2010). Evaluation of genotypic performance based on non-discriminating treatments (treatments with shorter vector lengths) is not reliable as this reflects the noise. Closer angle between two treatment vectors reflects their similarities whereas larger angle between treatment vectors proves them as unique or dissimilar.

Average treatment is displayed by arrow in biplot graph. Vector of average treatment is called average treatment axis or average tester axis or average environment axis (Yan, 2001). Average environment axis (AEA) is the vector line that passes through the average environment or treatment and origin of biplot. Ideal test environment is position on the AEA with longest distance from the biplot origin (most informative and most discriminating) in positive direction (most representative). GGE Biplot analysis was conducted in GenStat, version 13.

Results and Discussion

Analysis of variance and mean comparison test: Among main factors, genotype (G) and treatment (T) effects were highly significant for all yield components but year (Y) effects were non-significant for all traits except primary and secondary branches. The interactions of main factors, genotype × treatment (G×T) interaction was highly significant but year × genotype (Y×G) interaction, year × treatment (Y×T) interaction, year × genotype × treatment (Y×T×G) interactions were non-significant for all traits (Table 3). Year wise mean comparison grouped the plant height, pods per plant, seeds per pod, 100 seed weight, days to flowering and grain yield in one homogenous group as mean differences across the years were non-significant but mean differences for primary branches and secondary branches were significant across the years (Table 4). Treatment wise results showed that plant height, primary branches, pods per plant and grain yield were more/higher in rainfed conditions relative to irrigated and tunnel conditions. Secondary branches and days to flowering were higher in irrigated conditions whereas, 100 seed weight and seeds per pod were same in irrigated and rainfed conditions (Table 4). In case of tunnel treatment, mean values of all yield components were very lower than rainfed and irrigated treatments (Table 4).

Table 4. Treatment and Year mean comparison of 42 chickpea advanced lines for different yield components and yield.

Treatment	PH	PB	SB	P/P	S/P	100SW	DF	GY
Irrigated	63.17(B)	5.54(B)	21.52(A)	94.45(B)	1.71(A)	23.89(A)	94.74(A)	288.9(B)
Rainfed	64.77(A)	6.30(A)	20.79(B)	97.50(A)	1.74(A)	23.67(A)	93.67(B)	341.0(A)
Tunnel	27.17(C)	2.32(C)	2.12(C)	8.36(C)	1.04(B)	18.41(B)	89.60(C)	35.01(C)
Years								
2012-13	51.52(A)	4.43(B)	14.30(B)	65.95(A)	1.50(A)	22.02(A)	92.59(A)	223.63(A)
2013-14	51.89(A)	5.00(A)	15.34(A)	67.58(A)	1.50(A)	21.95(A)	92.74(A)	219.65(A)

Note: Lettering in brackets is based on Tukey-HSD test. PH: Plant height, PB: Primary branches, SB: Secondary branches, P/P: Pods per plant, S/P: Seeds per pod, 100SW: 100 seed weight, DF: Days to flowering, GY: Grain yield

Table 5. Percent variability, discriminative, representative, average, ideal treatment and association among three water treatments for studied traits.

	Percent variability (PC1+PC2=Total)	Most discriminating treatment	Least discriminating treatment	Representative treatment	Average treatment	Ideal treatment	Association among treatment
PH	79.26+13.49=92.75	Irri	Tun	Irri	Irri	Irri	+++ (Irri & Rain)
PB	79.81+14.51=94.32	Rain	Tun @	Irri	Irri, Rain	Irri, Rain	++ (Irri & Rain)
SB	69.21+25.22=94.43	Rain	Tun @	Irri	Irri	Irri	+ (Irri & Rain)
P/P	81.37+17.25=98.62	Irri	Tun @	Irri	Irri	Irri	++ (Irri & Rain)
S/P	69.48+20.09=89.57	Rain	Tun	Irri	Irri, Rain	Irri, Rain	+++ (Irri & Rain), ++ (Irri &Tun), + (Rain & Tun)
100SW	78.41+15.92=94.33	Rain	Tun	Irri	Irri	Irri	++ (Irri & Rain & Tun)
DF	92.91+4.22=97.14	Irri and Rain	Tun	Irri	Irri	Irri	++ (Irri & Rain & Tun)
GY	84.59+14.07=98.65	Irri	Tun@	Irri	Irri	Irri	++ (Rain & Irri)

PH: Plant height, PB: Primary branches, SB: Secondary branches, P/P: Pods per plant, S/P: Seeds per pod, 100SW: 100 seed weight, DF: Days to flowering, GY: Grain yield, @: very very short vector length, +: Weak positive correlation, ++: Average positive correlation, +++: Strong positive correlation, Irri: Irrigated treatment, Rain: Rainfed treatment, Tun: Tunnel treatment

Yield of chickpea genotypes in rainfed was higher than irrigated conditions as shown by genotypic grand means over the treatments. Irrigation had promoted the vegetative growth which was shown by longer days to flowering and more number of secondary branches of genotypes in irrigated conditions. Grain yield, pods per plant, number of primary branches and plant height were greater in rainfed condition. Whereas, seed size and number of seeds per pod was same for chickpea genotypes across irrigated and rainfed conditions. It was previously reported that prevalence of higher moisture contents by irrigation lead to crop lodging and reduced harvest index in sub-tropical region of India (Saxena, 1984). The experimental site for current study was also located in sub-tropical regions of Pakistan. Sub-tropical continental low lands include the main chickpea growing regions of Punjab, Pakistan like Jhang, Faisalabad, Bhakhar, Layyah, Mianwali, Chakwal and Khushab. So, irrigation to chickpea throughout these regions at flowering stage expected to be responsible for reduction in economical yield. Kanouni (2001) and Bakhsh *et al*. (2007) published that flower setting was delayed due to increase in vegetative growth by irrigation at flowering which lead towards reduced yield. Ray *et al.* (2011) reported that maximum grain yield through irrigation could be obtained only by irrigating at maximum branching and pod formation in West Bengal. So, it was concluded from findings of mean comparison that irrigation at initiation of flowering must be avoided in chickpea.

GGE Biplot analysis: Study of genotype and environment interaction is very important for evaluation of genotypes. Invention of biplot graphical analysis made the study of interaction easy. Two-way table is displayed in biplot, which reflects relationship of column factors, row factors and their interaction under one platform (Gabriel, 1971). The G×T interaction was estimated with the help of additive main effects and multiplicative interactions (AMMI; Gauch, 1992), joint regression (Perkins and Jinks, 1968) and type B genetic correlation (Burdon, 1977). Recently developed GGE biplot analysis uses features of these methods jointly. Analysis of variance is a perquisite tool to decide whether a trait has to go for GGE biplot analysis or not (Yan *et al*., 2010). In case of significant differences between interaction of main factors i.e. genotypes, environments, years, one should proceed for GGE biplot while in case of non-significant interaction use of GGE biplot analysis is of no use. Analysis of variance for different yield components of chickpea under three water treatments confirmed to proceed for GGE biplot as there were highly significant differences among genotypes and treatment effects for all chickpea genotypes. Maximum variability was observed for GGE biplot of grain yield (98.65%) while minimum variability (89.57%) was observed for seeds per pod (Table 5). All these results of GGE biplot were presented in the tabulated form instead of using large number of GGE biplot graphs. Ranking, distribution, genotype and environment comparison GGE biplots for grain yield were presented in Figs. 1-4.

Water treatments: Environment focused scaling was used for evaluation of environments. In the current study, test environments (irrigated, rainfed and tunnel) were not too much heterogeneous from each other. Irrigation treatment was most discriminating for plant height, pods per plant and grain yield whereas, for rest of traits rainfed treatment was most discriminating but not representative. Irrigation and rainfed treatments were almost equally discriminating for days to flowering. Tunnel was least discriminating for all traits but this treatment for primary branches, secondary branches, pods per plant and grain yield was too short to be used for any important interpretation (Table 5).

Table 6. Above average, below average, ideal, stable and unstable chickpea advanced lines based on GGE biplot for studied eight traits.

	Above average	Below average	Ideal and closer to ideal	Stable genotypes	Unstable genotypes
PH	DO78-11, D090-11, K0041-11, CH36/06, K0034-11, K0065-11, CH53/07, CH70/06, K0048-11 and K0063-11	11K113, CH48/07, CM1592/08, CH107/06, CM510/06, D088-11, D094-11	CH81/06, K0032-11, K0048-11, K008-11, K064-11, K0063-11, CH53/07, CH70/06, D098-11, CH36/06	CM98/05,D094-11, CH81/06, D098-11, CH36/06, D072-11, CH107/06	D089-11, TGDX2-1, K055-11, K051-11, 11K113
PB	K0063-11, K008-11, K0034-11, K0041-11, K0070-11, K0048-11, CM1529/03, CH46/07, K0065-11, CH30/06	11K113, CM510/05, D097-11, CM526/05, D094-11, CM562/05	K008-11, K0034-11, K0041-11, K0048-11, K0063-11, K0070-11, CM1529/03, CH30/06, K0065-11, CH46/07	Noor2009, K0034-11, K064-11, CH81/06, CH84/06	D072-11, D089-11, TGDX201, CH30/06, K0063-11, CM510/06, CM526/05, 11K113
SB	CH84/06, TGDX201, D089-11, K0034-11, K0032-11, CH16/06, D088-11	11K113, CM1592/08, CH46/07, CH48/06, CM562/05, K051-11, D078-11, CM510/06	CH85/06, K008-11, K0041-11, K064-11, CH81/06, D090-11, CH104/06	D094-11, D097-11, CM526/05, CM98/05, D098-11, D072-11, CM1529/03, CH81/06	K055-11, D089-11, TGDX201, CH84/06, 11K113, K0070-11
P/P	K0065-11, K0032-11, CM1529/03, CH30/06, CH53/07, CH36/06, D094-11, K0041-11, K0063-11, D089-11	11K113, K064-11, K051-11, CH48/07, K055-11, CM562/05	K008-11, CH104/06, CH16/06, CH85/06, CM510/06, D097-11, CH70/06, D090-11, CM526/05	11K113, K064-11, CH48/07, D089-11, D078-11, CM1592/08, CH81/06, CH107/06	K0065-11, K0070-11, K0048-11, CH30/06, CH53/07, CH16/06, CM510/06
S/P	D094-11, D097-11, CM526/05, CH16/06, D072-11, CH70/06, CM510/06, CH36/06, CH104/06, D078-11, D089-11	11K113, CH46/07, CM1592/08, TGDX201, K0070-11, CH53/07	CH53/07, K0065-11, TGDX201, K0070-11, D098-11, CH81/06, K0048-11, CH85/06	D094-11, CM510, CH107/06, D088-11, CH81/06, D098-11, K008-11	CH48/07, K055-11, K064-11, 11K113, CM1529/03
100SW	CH16/06, CH85/06, K051-11, K064-11, CM98/05, CH81/06, CH107/06, CM1592/08, CH30/06, D090-11	11K113	K008-11, CM1529/03, K0065-11, K0063-11, K0034-11, D094-11	D094-11, K0032-11, CH104/06, D089-11, D078-11, TGDX201, CH84/06, K05511	K0048-11, CH16/06, CH85/06, K0070-11, CH53/07, CM562/05, CH46/07
DF	TGDX201, CM526/05, K0032-11, CH81/06, CM510/06, K0070-11, D090-11	11K113, CM562/05, D098-11, CH46/07, CM1592/08	K008-11, K0063-11, D090-11, CM1529/03, D078-11, D088-11, CH85/06	11K113, CH46/07, Thall2011, CM510/06, K0048-11, D086-11, CM1529/03, K051-11, K064-11, K055-11, D094-11, CM98/05, CH36/06, D072-11	CM562/05, TGDX201, CM526/05, CH36/06, CM98/05
GY	CH36/06, D088-11, K0034-11, CH70/06, K0063-11, K0065-11, K0041-11, CM526/05, CM510/06, K008-11	11K116, CM562/05, CH48/07, K064-11, K055-11	K008-11, CM1592/08, CM526/05, D089-11, TGDX201, D094-11, K051-11	K055-11, K064-11, CH48/07, CM510/06, D072-11, CM98/05, CH70/06, Noor2009, D094-11	D088-11, CH36/06, K0048-11, Thall2011

Note: These tabulated results were derived from GGE biplot for yield and related components of chickpea. These were summarized in table instead of large number of figures to avoid the inconvenience for reader. PH: plant height, PB: primary branches, SB: secondary branches, P/P: pods per plant, S/P: seeds per pod, 100SW: 100 seed weight, DF: days to flowering, GY: grain yield.

Irrigation was representative treatment for all traits and the most discriminative and representative for plant height, pods per plant and grain yield. Irrigation treatment was ideal and average treatment for all studied traits whereas, being very closer to irrigation treatment, rainfed treatment was also average and ideal treatment for primary branches and seeds per pod. Irrigated treatment was most discriminating for plant height, pods per plant and grain yield which showed that selection of advanced lines for these traits could easily be done with this treatment. Rainfed treatment was most discriminating for primary branches, secondary branches, seeds per pod and 100 seed weight so, selection of genotypes for these traits could be done with this treatment. Irrigation and rainfed treatments had strong positive correlation for plant height and seeds per pod while these treatments had average positive correlation for primary branches, pods per plant, 100 seed weight, days to flowering and grain yield. As tunnel treatment harbors shortest vector length for primary branches, secondary branches, pods per plant and grain yield so, its correlation was not of worth consideration with other treatments (Table 5). Finally it was concluded that, irrigation treatment was ideal and representative for most of the traits. There was a stronger positive association among irrigated and rainfed treatments for most of the traits.

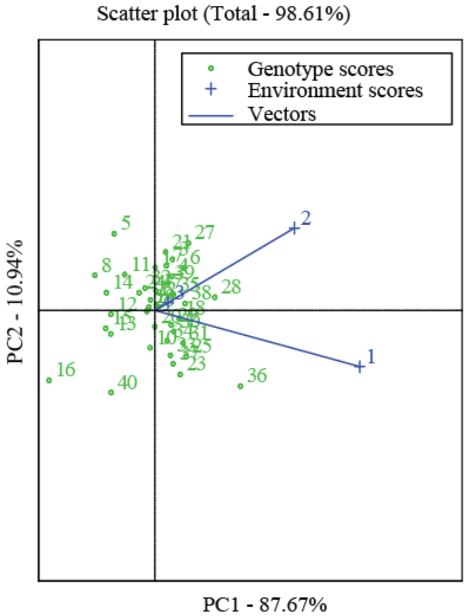

Fig. 1. Scatter GGE biplot for grain yield of chickpea genotypes.

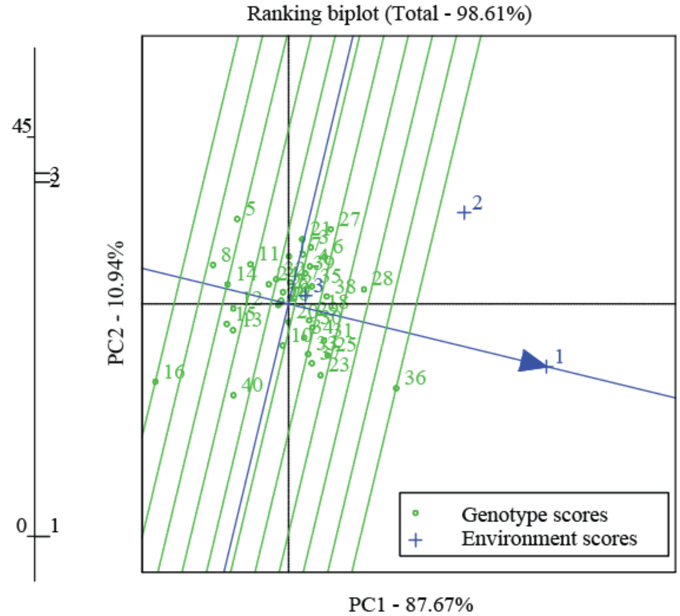

Fig. 2. Ranking GGE biplot for grain yield of chickpea genotypes.

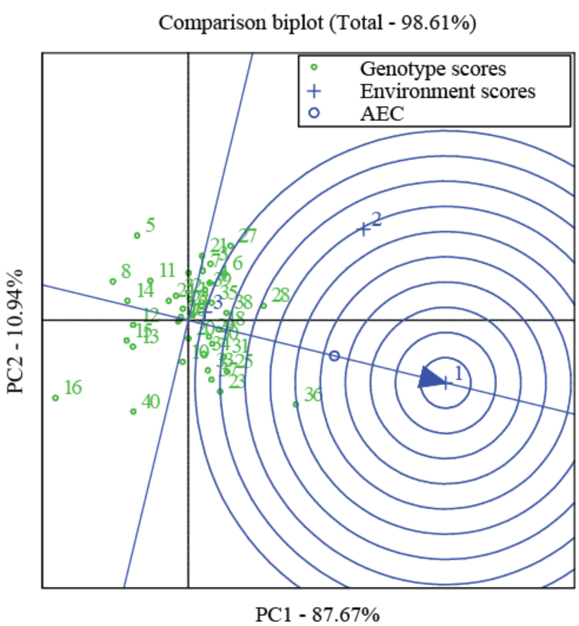

Fig. 3. Environment comparison GGE biplot for grain yield of chickpea genotypes.

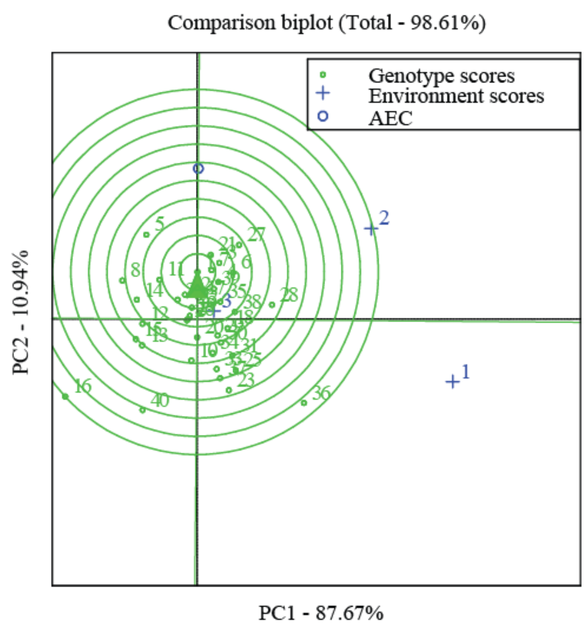

Fig. 4. Environment comparison GGE biplot for grain yield of chickpea genotypes.

Chickpea inbred lines: In current study, genotype focused scaling was used for evaluation of genotypes. Average environment coordination (AEC) method was used for assessment of yield performance and stability of genotypes. AEC abscissa was used for estimation of higher mean yield and AEC ordinate was used for estimation of greater variability or poor stability (Yan, 2001; Yan & Hunt, 2002). Out of 42 different chickpea lines; Ten lines had above average plant height; ten had above average primary branches; seven had above average secondary branches; ten had above average pods per plant; eleven had above average seeds per plant; ten had above average 100 seed weight; seven had above average days to flowering; and ten had above average grain yield (Table 6).

Stability estimation was based on GEI (genotype into environment interaction), which was effective only when considered together with mean value of genotype (G). Stability showed consistency in performance which might be better or poor. GGE biplot provided both aspects under one umbrella i.e. mean performance and stability could be assessed in one graph (Yan & Kang, 2003). Genotypes with shorter vector lengths or closer to origin showed the similar performance across all subjected treatments. Genotypes which were present farther away from origin showed that genotypes were more responsive to treatment while genotypes which were present closer to the origin had similar performance across all treatments (Yan & Kang, 2003). Average environment coordinate (AEC) was drawn for genotypes to evaluate the average performance and stability of genotypes. In GGE biplot, PC1 described the genotypic average performance and PC2 described the genotype by environment interaction which was used as measure of unstability (Yan *et al*., 2000). AEC was indicator of average yield across all treatments. Total seven lines were found stable for plant height, five for primary branches, eight for secondary branches, eight for pods per plant, seven for seeds per pod, eight for 100 seed weight, 14 for days to flowering and nine for grain yield (Table 6).

It was reported that an ideal genotype is a virtual genotype which has higher mean yield and stable yield (Yan & Rajcan, 2002). Ideal genotype has large PC1 score (high mean yield) and very low PC2 value (high stability). Ideal genotype position procedure of GGE biplot analysis is recommended to be most appropriate application for selection of high yielding and stable genotypes. A genotype was said to be ideal if it was present at the center of concentric circles and in the positive direction of AEA in GGE biplot. Several chickpea genotypes were found ideal for different traits like; Ten for plant height, ten for primary branches, seven for secondary branches, nine for pods per plant, eight were ideal for seeds per pod, six for 100 seed weight, seven for days to flowering and seven for grain yield (Table 6).

It was worthy to mention in concluding remarks that with the help of GGE biplot chickpea inbred lines were sorted as; above average performing, below average performing, stable inbred lines, unstable inbred lines and ideal or closer to ideal genotypes. Inbred lines with below average or unstable performance are not given due importance for further consideration when focus is to breed for stable high yielding drought tolerant chickpea genotypes. Below average performance of genotypes showed that the values for yield and it components were lower than the mean value and these were important only when there is need to use them as contrasting parents for breeding. Unstable performance of inbred lines showed that yield and yield components of chickpea were variable across different water treatments so, these were not important for selection. Stable inbred lines included the lines with consistence performance but that consistency could be either in the form of lower mean value or higher mean value. Ideal genotypes were very important for selection because only those are considered ideal which have high values for yield and yield components with stable performance. Ideal is not absolute term here but only means the relatively better performance of genotypes among all studied genotypes. Inbred lines; K008-11, CM1592/08, CM526/05, D089-11, TGDX201, D094-11 and K051-11 were selected for breeding against drought stress with higher yield potential. Above mentioned inbred lines were selected because these showed stability and higher grain yield across three diverse water treatments i.e. these were present closer to ideal genotype on GGE biplot.

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