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GGE BI-PLOT ANALYSIS FOR ASSESSMENT OF MEAN PERFORMANCE AND STABILITY FOR YIELD OF CHICKPEA AT DIVERSE LOCATION IN CHHATTISGARH STATE OF INDIA

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ABSTRACT

Yield data of promising varieties of chickpea of Chhattisgarh state across 15 varied environments were subjected to genotype x environment interaction (GEI) and yield stability analysis to determine the suitable varieties for varied environments. The ANOVA indicated highly significant differences ($P<0.01$) for environments, genotypes and importantly genotype x environment interaction (GEI). The PC 1 and PC 2 axes were also highly significant ($P<0.01$). Variance components (%) of the sum of squares, ranged from 14.20% for genotypes, 39.50% for environments and 46.28% for GEI. This indicated the great influence of environments on the yield performance of chickpea varieties in Chhattisgarh. GGE bi-plot analysis depicted the adaptation pattern of genotypes at varied environments and discrimination ability of environments. Thus, varieties JG-16 and JG-14 highly unstable whereas JG-63 were highly stable, followed by JG-11 and Vaibhav.

INTRODUCTION

Chickpea one of the major pulse cultivated and consumed in India. It is a major and cheap source of protein (contains 17-20%) compared to animal protein. This accounts about 45% of total pulses produced in the country and contributing for over 75% of total production in the world. Chickpea is an important *Rabi* crop mainly sown in September-November and duration is 90-120 days, depending on the variety. Uncertainty in time of sowing in rice fallows, as sowing depends on the paddy sowing, which in turn depends on release of water.

Numerous statistical methodologies have been proposed and used to analyze and visualize the nature and magnitude of genotype by environment interaction. The use of Additive main effect and multiplicative interaction (AMMI) (Zobel *et al.,* 1988 and Gauch, 2006) and Genotype plus Genotype x Environment interaction (GGE) proposed by Yan *et al*., (2000) models have been emphasized for multi environment trial data. However, GGE best fits for mega-environment analysis, genotype evaluation, and test environment evaluation which provides discriminating power vs. representativeness (Gauch and Zobel, 1997, Amira *et al.,* 2013; Yan *et al.*, 2007) of the test environment. GGE has been recognized and implemented as useful method to analyse and visualize the pattern of genotype x environment interaction in multi environment cultivar evaluation of different crops including wheat, maize, gram, and oilseeds (Asfaw *et al.*, 2009; Brar *et al.*, 2010; Fan *et al.,* 2007, Jandong *et al.*, 2011; Vishnuvardhan *et al.*, 2015 and Thakur and Dhatt , 2015). Objectives of these studies were to examine the nature and to quantify the magnitude of genotype x environment interaction effects on chickpea yield and to determine the best and suitable genotype (s) for varieties x environments in Chhattisgarh state.

MATERIALS AND METHODS

GGE biplot can perform ANOVA for multi-year, multi-location, multi-genotype, and multi-trait data based on various experimental designs. Moreover, special adjustment is now available and recommended for single trial data analysis. The biplot method originated with Gabriel (1971), and its use subsequently expanded by Kempton (1984) and Zobel *et al.*, (1988). The extensive usefulness of GGE biplot, where G = Genotype + G E = Genotype by environment effect, has only recently been elucidated (Yan, 2001 & 2002). The what-won-where pattern (which is an intrinsic property of the GGE biplot) rendered by the inner-product property of the biplot, of the chickpea genotype environment data set was also visually presented. In addition, the GGE biplot was used to identify high yielding and adapted chickpea varieties as well as suitable test environments. The best chickpea varieties were represented by large principal component scores (PC 1, high yield) and small principal component scores (PC 2, high stability) (Yan, 2001).

The biplot has many utilities, and based on the following two basic principles

The inner-product property

A biplot is a graphical display of a two-way table. If the two-way table is 100% displayed by the biplot, then there is a strict trimetric relationship between the value of entry i in tester j, Y_{ij}, and their coordinates in the biplot. Verbally, the value of Entry i in Tester j is the vector length of Entry i multiplied by the vector length of Tester j and multiplied by the cosine of the angle between Entry i and Tester j (aij). Many important interpretations of biplots are based on this principle.

The cosine-correlation equality

When the biplot is based on tester centered data (all GGE biplots are based on this type of centering), and when the tester-focused singular-value partitioning, i.e., SVP = 2, is used, the correlation between two testers can be approximated by the cosine of the angle between them:

$\cos(a_{ij}) = r_{ij}$

where a_{ij} is the angle between tester i and tester j, and r_{ij} is the correlation coefficient between tester i and tester j.

Used Model for GGE biplot

GGE biplot analysis also used to generate graphs showing; comparison of environments to ideal environment (Yan and Kang, 2003); "what-won-where" pattern; and environment vectors. The angles between environment vectors were used to judge correlations (similarities/dissimilarities) between pairs of environments (Yan and Kang, 2003). These aspects make GGE biplot a most comprehensive tool in quantitative genetics and varietal stability.

The basic model for a GGE biplot is

$yij = \mu + \alpha + \beta + \phi\iota\varphi$

Or

$yij = \mu - \alpha - \beta j = \phi\iota j$

Where yij = the expected yield of i^{th} genotype in j^{th} environment ì = the grand mean of all observations, α_i = the main effect of i^{th} = genotype, βj = the main effect of j^{th} environment and $\phi\iota j$ = the interaction between i^{th} genotype and j^{th} environment. Instead of trying to separate G and GE, a GGE biplot model keeps G and GE together and partitions this mixture GGE into two multiplicative terms:

$yij - \mu - \beta_j = \vartheta i1 + \vartheta_{i2} + e_{2j} + \varepsilon_{ij}$

Where $\vartheta i1$ and e1j are called the primary scores for i^{th} genotype and j^{th} environment, respectively; $\vartheta 1j$ 12 and e_{2j}, the secondary scores for i^{th} genotype and j^{th} environment, respectively; and ε_{ij} is the residue not explained by the primary and secondary effects. A GGE biplot is constructed by plotting, against, and against in a single scatter plot. The primary scores can be obtained through singular value decomposition (SVD) of the GGE or through regression of GGE against genotype main effects.

Yield data were collected from various sources for three years *i.e.*, 2011-12 to 2013-14. For different varieties of 15 environments of Chhattisgarh state. Analysis of variance on grain yield was done by SPSS software to determine the effect of environment (E), genotype (G) and GE interaction. Coefficients between pairs of locations were computed via PB Tools software (IRRI). The first two components resulted from principal components were used to obtain a bi-plot by GGE bi-plot software.

RESULTS AND DISCUSSION

Major findings

Combined analysis of variance (ANOVA)

The combined analysis of variance (ANOVA) of the 12 chickpea varieties over three years and 15 locations according to the AMMI 2 model are presented in Table1. The ANOVA indicated highly significant differences ($P<0.01$) for environments, genotypes and importantly genotype x environment interaction (GEI). The IPCA 1 and IPCA 2 axes were also highly significant ($P<0.01$). Variance components (%) of the sum of squares, ranged from 14.20% for genotypes, 39.50% for environments and 46.28% for GEI. This indicated the overwhelming influence that environments have on the yield performance of chickpea varieties in Chhattisgarh. Important is the fact that the G x E variation is more than three

Table 1: Combined analysis of variance (ANOVA) for the three years for chickpea

SV	DF	SS	MS	F ratio	Prob.	Variance	GxE Explained %	Cumulative %
Trials	179	1293.95	7.23	1.86	0.00			
Genotypes	11	183.83	16.71	4.30	0.00			
Environments	14	511.15	36.51	9.39	0.00			
G x E Interaction	154	598.96	3.89	0.00	0.00			
PCA I	24	266.56	11.11	60.78	0.00	266.56	44.50%	44.50%
PCA II	22	161.39	7.34	40.15	0.00	161.39	26.95%	71.45%
PCA III	20	106.96	5.35	29.27	0.00	106.96	17.86%	89.31%
PCA IV	18	51.49	2.86	15.66	0.00	51.49	8.60%	97.90%
PCA V	16	8.33	0.52	2.85	0.00	8.33	1.39%	99.30%
PCA VI	14	2.33	0.17	0.91	0.55	2.33	0.39%	99.68%
PCA VII	12	0.95	0.08	0.44	0.95			
Residual	28	0.94	0.03	0.18	1.00			
Pooled Residual	108	171.01	1.58	0.00				
Error	180	32.89	0.18					
Grand mean	12.58	CV	19.58%					

Table 2: The twelve chickpea varieties sorted on mean yield with graph ID

Var. No.	Varieties	Graph ID	Mean(q/ha)
1	Vijay	G1	11.94
2	JG-6	G2	10.53
3	JG-11	G3	11.84
4	JG-14	G4	11.49
5	JG-16	G5	12.01
6	JG-63	G6	12.59
7	JG-74	G7	13.99
8	JG-130	G8	13.01
9	JG-226	G9	12.75
10	Vaibhav	G10	13.14
11	JAKI-9218	G11	13.66
12	Vishal	G12	13.97

Table 3: The fifteen locations with graph ID sorted on environmental mean yield.

Env. No.	Locations	Graph ID	Env. Mean
1	Bilaspur	E1	11.01
2	Bilaspur	E2	10.91
3	Bilaspur	E3	11.12
4	Kabirdham	E4	13.69
5	Kabirdham	E5	13.36
6	Kabirdham	E6	13.48
7	Raipur	E7	10.14
8	Raipur	E8	10.20
9	Raipur	E9	10.17
10	Durg	E10	13.55
11	Durg	E11	13.68
12	Durg	E12	13.80
13	Rajnandgaon	E13	14.59
14	Rajnandgaon	E14	14.52
15	Rajnandgaon	E15	14.50

times of the variation of genotypes as main effect. The IPCA 1 and IPCA 2 axes explained 44.50 % and 26.95 % of the total GEI.

Environment evaluation based on GGE bi-plots:

Table 2 and 3 showed the varieties and environment mean yield and graph ID respectively.

Relationships among used environments

The 15 environments fell into three apparent groups: E1, E2 and E3 formed group1, E9, E7, E8, E10, E11 and E12 formed group 2 and E5, E4, E6, E13, E14 and E15 formed group3. The smallest angle between E1 and E2 groups 1environments implies that there was the highest correlation between them. The large angle between E3 and E6 indicates the poor correlation between these locations (Figure 1).

What-Won-Where pattern of chickpea varieties

One of the smartest facial appearances of a GGE bi-plot is its facility to show the what-won-where model of a genotype by environment dataset (Figure 2). Many researchers find this use of a bi-plot intriguing, as it graphically addresses important concepts such as crossover GE, mega environment differentiation, particular adaptation, etc (Yan and Tinker, 2005& 2006). The polygon is created by involving the markers of the varieties that are further away from the bi-plot source such that all other varieties are restricted in the polygon. Varieties G2 (JG-6), G4 (JG-14), G11 (JAKI-9218), G12 (Vishal),

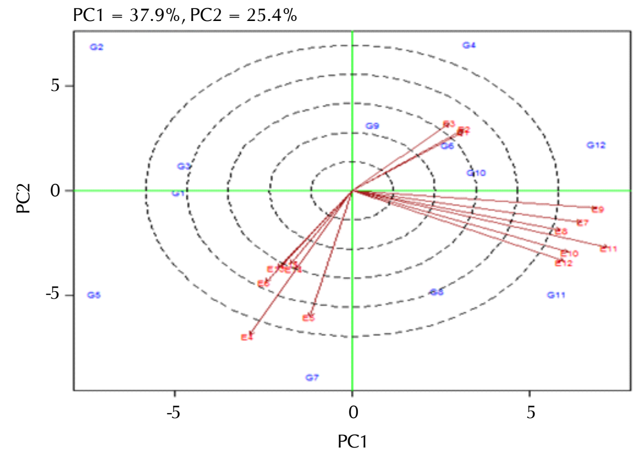

Figure 1: GGE bi-plot relationship among environments

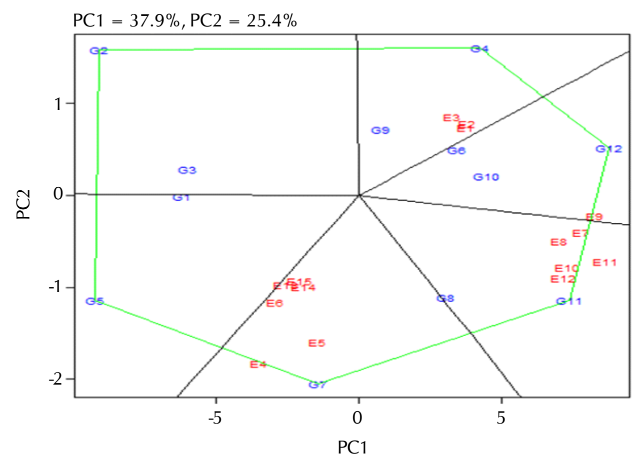

Figure 2: GGE bi-plot based on symmetrical scaling for chickpea what-won-where pattern

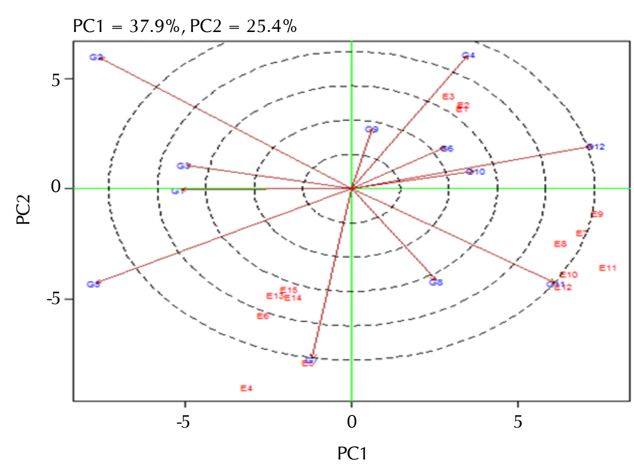

Figure 3: GGE bi-plot based on genotype focused scaling for chickpea

G7 (JG-74) and G5 (JG-16) located on the vertices of the polygon performed either the best or the poorest in one or more environments since they had the long distance from the origin of bi-plot. The perpendicular lines are equality lines between adjacent varieties G6 (JG-63), G9 (JG-226) and G10

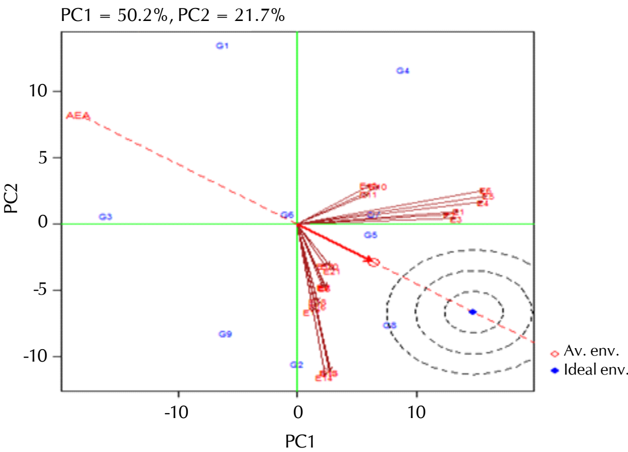

Figure 4: GGE bi-plot based on environment-focused scaling for chickpea

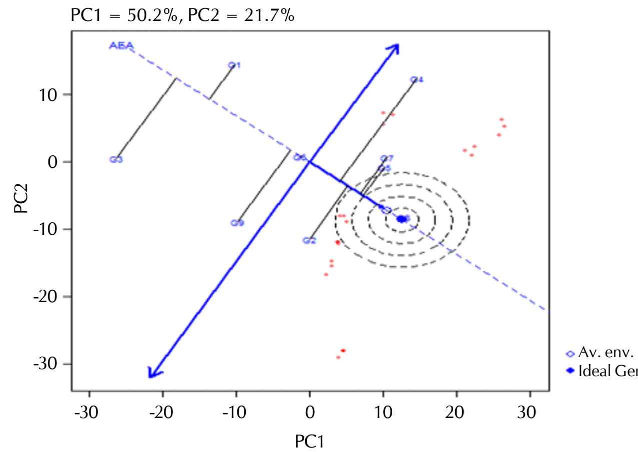

Figure 5: The IPCA 1 and IPCA 2 scores for the 15 environments, sorted on environmental mean yield, used in the study of chickpea varieties

(Vaibhav) on the polygon, which facilitate visual comparison of them.

Ranking of chickpea varieties based on yield and stability

The ranking of varieties based on their mean grain yield and yield stability for environments is shown in figures 3, 4 and 5. It has been reported that when PC1 in a GGE bi-plot approximates the G (mean performance), PC2 must approximate the G × E associated with each genotype, which is a measure of instability (Yan *et al.,* 2003; Yan, 2002). The line passing through the bi-plot origin and the environmental average is indicated by circles and is known as the average environment coordinate (AEC) axis, which is defined by the average PC1 and PC2 scores for all environments. (Gauch and Zobel, 1997).

Projection of variety markers onto this axis should, therefore, approximate the mean yield of the varieties. Thus, varieties G4 (JG-14), G12 (Vishal), G9 (JG-226), G6 (JG-63) and G10 (Vaibhav) had higher grain yield, followed by varieties G2 (JG-6) and G3 for all dataset. The line which passes through the origin but is perpendicular to the AEC with double arrows represents the status of the varieties stability. A position in either direction away from the bi-plot origin, on this axis, indicates greater G × E interaction and reduced stability (Yan, 2002). Therefore, varieties G2 (JG-6), G5 (JG-16) and G7 (JG-74) showed a more variable and less stable performance than the other varieties. Varieties G9 (JG-226), G6 (JG-63), G10 (Vaibhav), G12 (Vishal), G3 (JG-11) and G1 (Vijay) were more stable than the others (Fig. 3).

Another interesting observation from the vector point of view of the bi-plot is that the length of the environment vectors approximates the standard deviation within each environment, which is a measure of its discriminating ability (Yan and Kang, 2003). Thus E11 (Durg), E12 (Durg) and E13 (Rajnandgaon) are the most discriminative environments (Fig. 4).

Yield performance and stability of varieties were evaluated by an average environment coordination (AEC) method. Within a single mega-environment, varieties should be evaluated on both mean performance and stability across environments. Figure 5 is the average environment coordination (AEC) view of the GGE bi-plot. The single-arrowed line is the AEC abscissa, it points to higher mean yield across environments. Thus, G5 (JG-16), G10 (Vaibhav) and G12 (Vishal) had the highest mean yield *i.e.* 12.01, 13.14 and 13.97 q/ha respectively. The double-arrowed line is the AEC ordinate; it points to greater variability (poorer stability) in either direction. Thus, G5 (JG-16) and G4 (JG-14) were highly unstable whereas G6 (JG-63) were highly stable, followed by G3 (JG-11) and G10 (Vaibhav).

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