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Assessment of G X E Interaction and Adaptation of Chickpea in Chhattisgarh State Using Ammi Model

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ABSTRACT

A standard multi-factor analysis of variance showed the main effect due to years, locations and first order interactions (year x location) were highly significant. The main effect for genotype, first order interaction (varieties x locations), (variety x year) and second order interaction (varieties x locations x year) were highly significant. The highly significant interactions indicate that varieties need to be tested in severe years and locations in order to select stable variety. The IPCA 1 and IPCA 2 axes also found highly significant ($P < 0.01$). Partitioning of the variance component (%) indicated that 14.21% due to varieties, 39.50% due to environments and 46.29% due to GEI. According to the AMMI stable value give, the chickpea varieties JG-226 (0.67), JG-130 (1.03) and Vaibhav (1.33) were the three most stable varieties with higher than grand mean yield, all these chickpea varieties were early maturing. Portrait shows the JG-14 (G4) exhibited specific adaptability for environments: E1, E2, E3, E7, E8 and E9 with grain yield less than mean. As the varieties and environments of first adaptive group have the same sign on the IPCA axis, their interaction were found positive. Varieties JG-63 (G6), JG-130 (G8), JG-226 (G9), Vaibhav (G10), JAKI-9218 (G11) and Vishal (G12) (adaptive group 2) revealed specific adaptation for environments E10, E11 and E12 with high grain yield, more than mean yield and positive interaction.

Keywords

AMMI, ANOVA,
GEI, Stability,
Statistical
software.

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Introduction

As it is a short day plant and sensitive to photoperiod, temperature and prolonged moisture stress, the yield of chickpea is not stable and varies widely (Velu and Shunmugavalli, 2005). The considerable variation in soil and climate has resulted in significant variation in annual yield performance of chickpea. Genotype x environment interaction (GEI) is an important issue facing plant breeders and agronomists in Chhattisgarh as well as India. The environmental variation creates problems in a

breeding programme as selection of genotypes with improved yield performance, yield stability, grain quality and other agronomic phenotypic are based on data generated over a limited, and possibly not always a representative, number of environments and years. GEI which is associated with the differential performance of genetic materials, tested at different locations and in different years and its influence on the selection and recommendation of genotypes has long been

recognized (Lin *et al.*, 1986; Becker and Leon, 1988; Crossa, 1990; Purchase *et al.*, 2000). Evaluation of genotypic performance at a number of locations provides useful information to determine their adaptation and stability (Crossa, 1990). Lin *et al.*, (1986), Becker and Leon (1988), Crossa (1990) and Hohls (1995) discussed a wide range of methods available for the analysis of GEI and stability.

A specific different in environment may have a greater effect on some genotypes than others (Falconer, 1981). The three main purposes of multivariate analysis are: (i) to eliminate noise from the data pattern, (ii) to summarize the data and, (iii) to reveal a structure in the data (Crossa, 1990). Through multivariate analysis, genotypes with similar responses can be clustered, hypotheses generated and later tested, the data can be summarized and analysed more easily (Gauch, 1982; Crossa, 1990; Hohls, 1995). The results can be graphically represented in an easily interpretable and informative biplot that shows both main effects and GEI. The AMMI model has been used extensively with great success over the past few years to analyse and understand genotype x environment interaction in various crops (Crossa, 1990; Gauch and Zobel, 1996; Yau, 1995; Yan and Hunt, 1998).

Materials and Methods

Secondary yield data has been collected for chickpea from Department of Agriculture, Chhattisgarh state during three years (2011-12 to 2013-14). Description of promising varieties with duration and their characteristics in table 1. Table 2 represents environmental effects such as; locations, temperature, rainfall (mm) and area (in ha.). Management and fertilization at each location were done according to cultural practices by farmer. Fertilization rates with planting were

inflated with about 10% to ensure good and even stands and development.

Statistical tools for analysis

ANOVA method

The analysis of variance of the combined data expresses the observed (Y_{ij}) mean yield of the i^{th} genotype at the j^{th} environment as

$$Y_{ij} = \mu + G_i + E_j + GE_{ij} + e_{ij}$$

Where, μ is the general mean; G_i , E_j , and GE_{ij} represent the effect of the genotype, environment, and the GEI, respectively; and e_{ij} is the average of the random errors associated with the r^{th} plot that receives the i^{th} genotype in the j^{th} environment. The non-additive interaction as defined implies that the expected value of the i^{th} genotype in the j^{th} environment (Y_{ij}) depends not only on the levels of G and separately but also on the particular combination of levels of G and E (Crossa, 1990).

Additive Main Effects and Multiplicative Interaction (AMMI)

The AMMI model was developed by Gabriel (1971) and Gollob (1968) has been applied and extended by many other authors. There are multivariate methods for the study of phenotypic stability, including AMMI as discussed by Crossa *et al.*, (1990), Gauch Jr. (1985), Gauch Jr. and Zobel (1988), Yau (1995) and Zobel *et al.*, (1988). Many studies have applied both multivariate and univariate techniques and these methods have been useful for identifying stable genotypes and environment. The aim of the AMMI analysis is to model the interaction effect through a principal component model (Johnson and Wichern, 1968). The model equation is

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^n \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}$$

Where Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; G_i and E_j are the genotype and environment deviations from the grand mean, respectively; λ_k is the eigenvalue of the PCA analysis axis k ; α_{ik} and γ_{jk} are the genotype and environment principal component scores for axis k ; n is the number of principal components retained in the model and e_{ij} is the error term.

The AMMI model does not make provision for a quantitative stability measure, such a measure is essential in order to quantify and rank genotypes according to their yield stability, the following measure was proposed by Purchase (1997)

$$\text{AMMI Stability Value (ASV)} = \sqrt{\frac{\text{IPCA1 Sum of Square}}{\text{IPCA2 Sum of Square}} (\text{IPCA1 score})}$$

In fact the ASV is the distance from zero in a two dimensional scatter of IPCA 1 (Interaction Principal Component Analysis axis 1) scores against IPCA 2 scores. Since the IPCA 1 score contributes more to G x E sum of squares, it has to be weighted by the proportional difference between IPCA 1 and IPCA 2 scores to compensate for the relative contribution of IPCA 1 and IPCA 2 total G x E sum of squares. The distance from zero is then determined by using the theorem of Pythagoras. Graph and analysis of variance at individual environment and combined ANOVA over environments were computed using the SPAR 2.0 (IASRI) and PB tools (IRRI).

Results and Discussion

ANOVA for AMMI of chickpea varieties across locations

The classic model for analysing the total yield variation contained in GEI observations is the

analysis of variance (Fisher, 1918). The combined analysis of variance (ANOVA) of the chickpea varieties over three years and 15 locations according to the AMMI 2 model are presented in table 3. The AMMI 2 is used as it gave the best fit for chickpea yield data. The ANOVA indicated highly significant differences ($P < 0.01$) for environments, varieties and importantly G x E interaction. The IPCA 1 and IPCA 2 axes also found highly significant ($P < 0.01$). Partitioning of the variance component (%) indicated that 14.21% due to varieties, 39.50% due to environments and 46.29% due to GEI. Similar results obtained by Mahto *et al.*, (2006), Maqsood *et al.*, (2007) and Mishra *et al.*, (2009) and Farshadfar *et al.*, (2012) this indicated the great influence that environments have on the yield performance of chickpea varieties in Chhattisgarh. Important fact is that the G x E variation was more than three times of the variation of varieties as main effect indicating that environmental effects on yield are large.

The IPCA 1 and IPCA 2 axes explained 44.50 % and 26.95 % of the total GEI (Mohammadi and Amri, 2009). They are both significant ($P < 0.01$) (Table 3) and this indicate that the AMMI 2 model is the best fit for this data set.

The AMMI stability value (ASV)

For this ASV was proposed by Purchase (1997). Table 4 indicated the AMMI 2 model IPCA 1 and IPCA 2 scores for each chickpea varieties and also the ASV with its ranking. According to the ASV ranking, the chickpea varieties JG-226 (0.67), JG-130 (1.03) and Vaibhav (1.33) were the three most stable varieties with higher than grand mean yield, all these chickpea varieties were early maturing. The three most unstable varieties found were JG-16 (3.45), Vishal (3.04) second last rank and JG-14 (2.88) ranked third last; these varieties have medium to long maturity.

Identification of high yielding stable variety by AMMI model

Tables 5 and 6 for chickpea presented the AMMI analysis with the IPCA 1 and IPCA 2 scores for the environments and the varieties, respectively. It indicated the names and graph ID of the environments and the varieties, when interpreting the AMMI 2 bi-plot (Kempton, 1984).

To study the main effects and interactions, AMMI1 bi-plot were constructed for yield. In figure 1, AMMI-1 bi-plot of additive main effects or mean yield showed along the abscissa and the ordinate represents the first IPCA or multiplicative interaction.

The interpretation of a bi-plot assay is that if main effects have IPCA score close to zero, it indicated negligible interaction effects and when a variety and an environment have the same sign on the IPCA axis, their interaction was positive; if different, their interaction found negative. Bi-plot space of figure 1 divided into 4 sections from low yielding environments in sections I (upper left) and IV (lower left) to high yielding environments in sections II (upper right) and III (lower right). It was clear from the bi-plot of figure 1 that the points for environment were more scattered than the point for varieties indicating that variability due to environments was higher than that due to varietal difference which was in complete agreement of ANOVA (Table 2). On the bi-plot, the points for the generally adapted varieties would be at right hand side of grand mean levels (this suggests high mean performance) and close to the line showing IPCA= 0 (this suggests negligible or no $G \times E$ Interaction).

According to the AMMI model, the varieties which characterized by means greater than grand mean and the IPCA score nearly zero were considered as generally adaptable to all

environment. However, those varieties with high mean performance and with large value of IPCA score were considered to have specific adaptability to the environments. According to figure 1; JG-14 (G4) (adaptive group 1) exhibited specific adaptability for environments: E1, E2, E3, E7, E8 and E9 with grain yield less than mean. As the varieties and environments of first adaptive group have the same sign on the IPCA axis, their interaction were found positive.

Varieties JG-63 (G6), JG-130 (G8), JG-226 (G9), Vaibhav (G10), JAKI-9218 (G11) and Vishal (G12) (adaptive group 2) revealed specific adaptation for environments E10, E11 and E12 with high grain yield, more than mean yield and positive interaction. The accessions JG-74 (G7) (adaptive group 3) on the IPCA= 0 showed stability and general adaptability with grain yield close to mean yield and negligible interaction. The entries Vijay (G1), JG-6 (G2), JG-11 (G3) and JG-16 (G5) (adaptive group 4) are identified with specific adaptability environment with positive interaction and JG-63 (G6) and JG-130 (G-8) (adaptive group 5) were screened with general adaptability for stress and non-stress environments (close to IPCA = 0) with high grain yield, more than mean yield and negligible interaction (Moreno-González *et al.*, 2004).

Identifying favorable environments for chickpea varieties

Environment that appears almost in a perpendicular line have similar means and those that fall almost in a horizontal line have similar interaction pattern. AMMI1 bi-plot (Fig. 1) thus exhibited that environment differed in main effect and interactions. The environment E1, E2, E3, E7, E8 and E9 had similar main effect but differed in interaction with varieties.

Table.1 List of chickpea varieties used for analysis

S N.	Varieties	Duration	Characteristics
1	Vijay	120-125	Resistant to wilt, tolerant to terminal moisture stress.
2	JG-6	110-115	Resistant to <i>fusarium</i> wilt and moderate resistant to dry root, tolerant to pod borer
3	JG-11	95-100	Rainfed and up to 3.5 t/ha under irrigated conditions, attractive large seed and high resistance to <i>fusarium</i> wilt (<10% mortality).
4	JG-14	100-115	Drought resistance, moderate resistant to wilt, dry root and pod borer
5	JG-16	110-115	Resistant to wilt
6	JG-63	110-115	Resistance to wilt, dry root rot, with collar rot and <i>Helicoverpa</i> Species.
7	JG-74	110-115	Resistance to wilt
8	JG-130	110-115	Resistance to wilt and bold grain
9	JG-226	110-115	Resistant to wilt and root rot complex
10	Vaibhav	110-115	Resistant to wilt, seeds wrinkled and bold
11	JAKI-9218	110-115	Resistant to <i>fusarium</i> wilt, root rot and collar rot, bold and brightness
12	Vishal	110-115	Resistant to wilt, tolerant to pod borer, early maturing.

Table.2 Locations that were used in the study from 2011-12 to 2013-14 for varieties of chickpea

S N.	Location	Latitudes	Longitude	Temp.	Rainfall (mm)	Area
1	Bilaspur	22.07	82.13	23°-43°	1229	1 Ha.
2	Kabirdham	22.00	81.22	20°-39°	860	1 Ha.
3	Raipur	21.23	81.63	28°-47°	1352	1 Ha.
4	Durg	21.18	81.28	27°-45°	1330	1 Ha.
5	Rajnandgaon	21.09	81.03	30°-46°	1505	1 Ha.

Table.3 Combined ANOVA according to the AMMI 2 models and IPCA axis for chickpea

Source of variation	DF	SS	SS%	MS	F Ratio	P<0.01
Trials	179	1293.94		7.22	1.85	0.000 **
Varieties	11	183.83	14.21%	16.71	4.29	0.000 **
Environments	14	511.15	39.50%	36.51	9.38	0.000 **
G x E Interaction	154	598.95	46.29%	3.88	0.00	0.000 **
PCA I	24	266.55	44.51%	11.10	60.78	0.000 **
PCA II	22	161.39	26.95%	7.33	40.14	0.000 **
PCA III	20	106.96	17.86%	5.34	29.26	0.000 **
PCA IV	18	51.49	8.60%	2.86	15.65	0.000 **
PCA V	16	8.32	1.39%	0.52	2.84	0.000 **
PCA VI	14	2.32	0.39%	0.16	0.91	0.540
PCA VII	12	0.95	0.16%	0.07	0.43	0.940
Residual	28	0.93	0.16%	0.03	0.18	1.000
Pooled Residual	108	171		1.58	0.00	0.000 **
Error	180	32.89		0.18		
Total	359	1326.83		3.69		
Grand mean	12.58	CV	19.58%			
IPCA Axis	Variance	GxE Explained %	Cumulative%			
PCA I	266.55	44.50%	44.50%			
PCA II	161.39	26.95%	71.45%			
PCA III	106.96	17.86%	89.31%			
PCA IV	51.49	8.60%	97.90%			
PCA V	8.32	1.39%	99.30%			
PCA VI	2.32	0.39%	99.68%			

Table.4 AMMI stability value (ASV) of chickpea varieties and environments to the IPCA scores 1 and 2 at across locations

SN	Varieties	Mean Yield (q/ha)	Rank	IPCA Score1	IPCA Score2	ASV	Rank
G1	Vijay	11.94	9	1.053	0.328	1.77	6
G2	JG-6	10.53	12	0.733	-0.975	1.55	5
G3	JG-11	11.84	10	0.970	-0.880	1.82	7
G4	JG-14	11.49	11	-1.746	0.053	2.88	10
G5	JG-16	12.01	8	2.079	0.341	3.45	12
G6	JG-63	12.59	7	-0.843	-0.059	1.39	4
G7	JG-74	13.99	1	1.418	-0.032	2.34	8
G8	JG-130	13.01	5	-0.143	1.008	1.03	2
G9	JG-226	12.75	6	-0.401	0.127	0.67	1
G10	Vaibhav	13.14	4	-0.775	-0.364	1.33	3
G11	JAKI-9218	13.66	3	-0.932	2.402	2.85	9
G12	Vishal	13.97	2	-1.415	-1.952	3.04	11
	Grand mean	12.58					

Table.5 The IPCA 1 and IPCA 2 scores for the 15 locations, sorted on environmental mean yield, used in the study of chickpea varieties

Env. No.	Locations	Graph ID	Env. mean	Score 1	Score 2
1	Bilaspur	E1	11.01	-0.65	-1.05
2	Bilaspur	E2	10.91	-0.56	-1.10
3	Bilaspur	E3	11.12	-0.71	-1.09
4	Kabirdham	E4	13.69	1.74	0.03
5	Kabirdham	E5	13.36	1.24	-0.03
6	Kabirdham	E6	13.48	1.32	0.00
7	Raipur	E7	10.14	-0.92	-0.67
8	Raipur	E8	10.20	-0.96	-0.70
9	Raipur	E9	10.17	-0.87	-0.71
10	Durg	E10	13.55	-0.93	1.81
11	Durg	E11	13.68	-0.89	1.43
12	Durg	E12	13.80	-1.05	1.52
13	Rajnandgaon	E13	14.59	1.16	0.08
14	Rajnandgaon	E14	14.52	1.03	0.29
15	Rajnandgaon	E15	14.50	1.04	0.19

Environments GM=12.58

Table.6 The IPCA 1 and IPCA 2 scores for the 12 chickpea varieties sorted on mean yield at 15 locations over three years 2011-12 to 2013-14

Varieties	Graph ID	Env. Mean (q/ha)	IPCA Score 1	IPCA Score 2
Vijay	G1	11.94	1.053	0.332
JG-6	G2	10.53	0.733	-0.972
JG-11	G3	11.84	0.970	-0.880
JG-14	G4	11.49	-1.745	0.054
JG-16	G5	12.01	2.079	0.339
JG-63	G6	12.59	-0.843	-0.059
JG-74	G7	13.99	1.418	-0.036
JG-130	G8	13.01	-0.143	1.004
JG-226	G9	12.75	-0.401	0.133
Vaibhav	G10	13.14	-0.775	-0.364
JAKI-9218	G11	13.66	-0.931	2.403
Vishal	G12	13.97	-1.415	-1.954
Grand mean		12.58		

Fig.1 AMMI model 2 bi-plot for 12 chickpea varieties and 15 environments during 2011-12 to 2013-14 in Chhattisgarh state

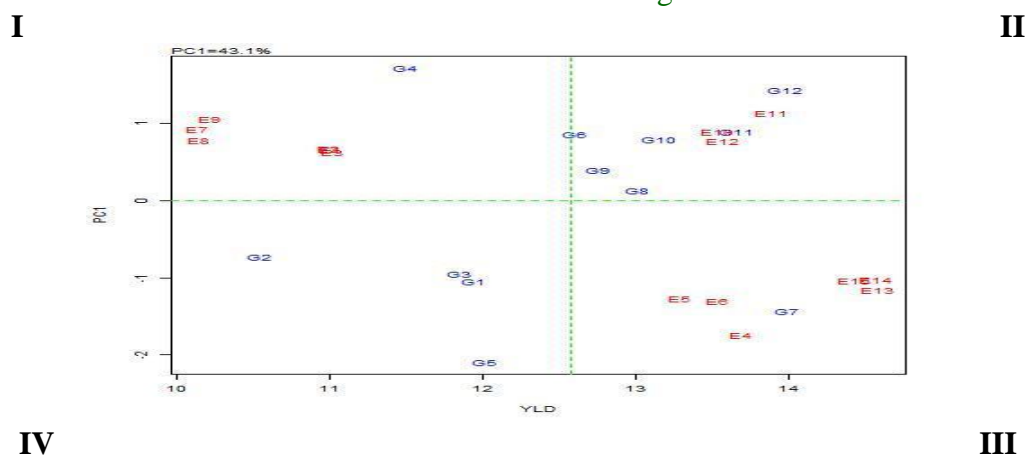


Fig.2 Plotted IPCA 1 and IPCA 2 scores of chickpea varieties during 2011-12 to 2013-14 in Chhattisgarh state

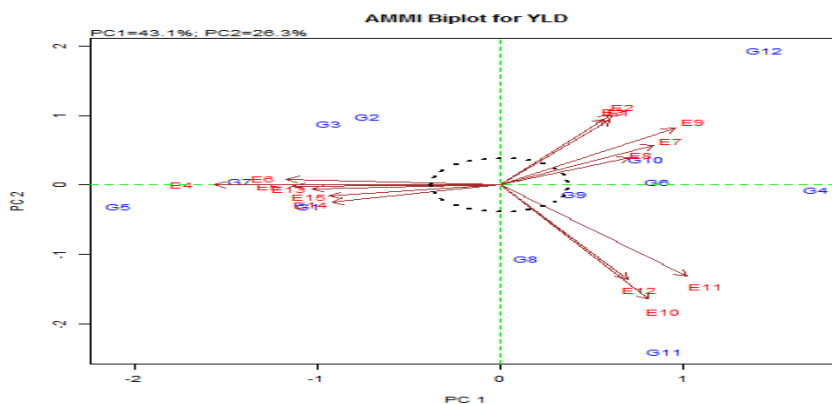
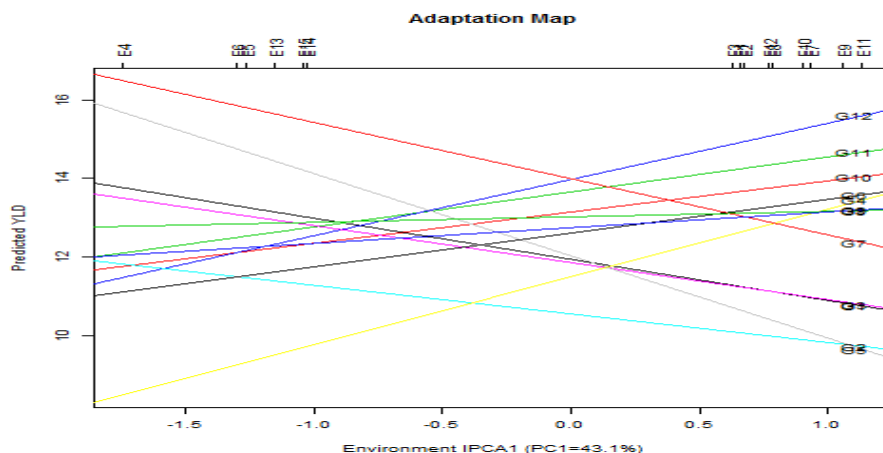


Fig.3 Yield responses of best adapted chickpea varieties from the AMMI 2 model for Chhattisgarh state



The rank in such environments is likely to be quite variable, thus making it difficult for recommendations of varieties. Further the environment E4, E5, E6, E10, E11, E12, E13, E14 and E5 were the highest yielding and highly interacting, hence are most suitable only for the specifically adapted varieties (Alberts 2004, Adguna 2007, Anandan *et al.*, 2009, crossa 1990, Zobel *et al.*, 1988 and Annichiarico 2002).

AMMI 2 bi-plot

The IPCA 1 versus IPCA 2 bi-plot (i.e. AMMI 2 bi-plot) (Fig. 2) explain the magnitude of interaction of each variety and environment (Yan *et al.*, 1998; Cornelius *et al.*, 1996). The varieties and environments those were farthest from the origin being more responsive. Varieties and environments that fall into the same sector interact positively; negatively if they fall into opposite sectors. A variety showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or an agro-management condition of the specific environment and therefore best suited to that environment. AMMI analysis permits estimation of interaction effect of a variety in each environment and it helps to identify

varieties best suited for specific environmental conditions.

However, for the AMMI 2 model, IPCA2 scores was considered in interpreting GEI that captured 26.30% of the interaction sum of squares. A bi-plot is generated using genotypic and environmental scores of the first two AMMI components. Furthermore, when IPCA1 were plotted against IPCA 2, pointed out that the closer the varieties score to the center of the bi-plot (Fig. 2), the more stable. Figure 3 showed the AMMI 2 bi-plot for yield. The IPCA 1 component accounted for 43.1% of G×E interaction, while IPCA 2 accounted for only 26.30 % (Table 1). Distribution of variety points in the AMMI 2 bi-plot revealed that the varieties, JG-226 (G9), JG-63 (G6), and Vaibhav (G10) scattered close to the origin, indicating minimal interaction of these varieties with environments. The remaining 8 varieties scattered away from the origin in the bi-plot indicating that the varieties were more sensitive to environmental interactive forces. Interaction of varieties with specific environmental conditions was judged by projection of variety points on to environment spokes. On these basis, the varieties JG-11 (G3), JG-6 (G2) and JG-74 (G7) have positive

interaction with environments E4 and E6, hence exhibited specific adaptation with environments. Varieties Vijay (G1) and JG-16 (G5) displayed positive interaction with environments E5, E13, E14 and E15. Varieties JG-14 (G4), JG-226 (G9), JG-130 (G8) and JAKI-9218 (G11) indicated specific adaptability and positive interaction with environments E10, E11 and E12. The accessions JG-63 (G6), Vaibhav (G10) and Vishal (G12) showed specific adaptability and positive interaction with environments E7, E8, E9, E1, E3 and E2.

Adaptation of the promising varieties according to the AMMI 2 model using map

AMMI models can also be constructed for maps of the best adapted varieties by evacuate yield estimated. There was no need to consider the environments main effects since these moves all the yield lines up or down the yield axis together, and we only interested in seeing the top lines at each environment (Alberts, 2004).

The predicted yields of the chickpea varieties over the range of environment, IPCA1 score had been plotted for the chickpea data in figure 3. The figure showed that the three groups of varieties: varieties that respond positively to IPCA1 are Vishal (G12), JAKI-9218 (G11), Vaibhav (G10), JG-74 (G7) and JG-130 (G8); varieties that respond negatively to IPCA1 are JG -11 (G3) and JG-6 (G2), and non-responsive varieties to IPCA1 are JG-16 (G5), JG-63 (G6) and JG-226 (G9). This can also be seen from the sign of the IPCA1 scores. Best adapted varieties were those for which the response line was higher over the interval of IPCA1 scores. JG-63 (G6) is never highest and so there is always a better choice. The intervals of adaptation for the other varieties were the same as those computed from AMMI bi-plot.

In conclusion, the article goes well beyond a description of AMMI however, giving a carefully reasoned analysis of the nature of prediction and of selection, finally claiming that the adoption of the practices described would result in an annual improvement in state crop yields of around an extra 0.4% per year for negligible increase in research costs. The techniques described are heavily dependent on computing power. AMMI requires an interactive process, and finding the degrees of freedom and the prediction accuracy require repeated re-sampling of subsets of the experimental data. It is clearly showing the adaptation of chickpea varieties to environments and can be used to identify the superior varieties in relation with the environments and years.

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