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RESEARCH ARTICLE

Genotype x Environment interaction analysis of *desi* chickpea (*Cicer arietinum* L.) cultivars using GGE biplot model for Bundelkhand region

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Abstract

Twelve chickpea cultivars were evaluated to identify high-yielding and stable cultivars for the Bundelkhand region of Uttar Pradesh for three consecutive years 2018-2021, at BUAT, Banda. The pooled analysis of variance indicated significant genotype, environment, and genotype × environment interaction effect on all studied traits. Among cultivarsJG 12 was the highest yielding (3566 kg ha^{-1}) cultivar followed by JG 315 (3152 kg ha^{-1}). GGE biplot analysis revealed cultivars G2 (JG 12), G4 (JG 14), G7 (JG 24), G9 (JG 322), G3 (JG 130) and G8 (JG 218) very close to the ideal genotype and have high yield along with stable performance. The identified genotype G12 was identified to be the high-yielding and well-adapted cultivar under climatic conditions of Bundelkhand and may be promoted for commercial cultivation.

Keywords: Chickpea, GGE biplot, G x E interaction, yield potential.

Introduction

Chickpea (*Cicer arietinum* L.) is an important food legume crop, cultivated on arid to semi-arid agroecology. During 2021-22 in India, chickpea was cultivated on a 10.91 m ha area with a total production and productivity of 13.75 mt and 12.6 quintals per hectare (DAC 2023, MOAF & W GoI). In India, Madhya Pradesh is the largest chickpea-producing state, accounting for 25.97% of the national production, while Uttar Pradesh contributes 5.64%. More than 80% of the chickpea cultivation area in Uttar Pradesh is concentrated in seven districts of the Bundelkhand region. Farmers of UP Bundelkhand region are mainly growing desi chickpea cultivars but yield is very low as compared to improved varieties. Therefore, it is important to test improved, newly released cultivars and also to popularize cultivars that show superior performance and yield stability in this region. In the present study, 12 desi commercial cultivars of chickpea, of which 11 were procured from Jawaharlal Nehru Krishi Vishwa Vidyalaya (JNKVV), Jabalpur, Madhya Pradesh, along with one local check Radhey, were evaluated for productivity and stability under Bundelkhand climatic conditions. The selected varieties are widely cultivated in Madhya Pradesh having a similar climate to the Bundelkhand region of Uttar Pradesh. Radhey is a long-duration, tall, heat-tolerant, wilt-susceptible variety, but it is preferred by farmers since 1968. The present investigation was carried out in randomized complete block design (RCBD) with two replications over three consecutive years (2018-2021), during *rabi* at the Experimental Research Farm of Banda University of Agriculture and Technology, Banda, Uttar Pradesh, India. The experiment was sown with a precision plot drill in a 4-row plot of 4m length while maintaining a plant-to-plant distance of 10 cm. Seven key agro-morphological traits *viz*., days to 50% flowering (DTF), days to maturity (DTM), plant height (PH), number of primary branches (NPB), pod plant^{-1} (PPP), seed index (SI) and seed yield (SY) kg ha^{-1} were recorded at flowering, maturity and at a post-harvest stage

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Table 1. Analysis of variance of seven quantitative traits in chickpea cultivars

Source of variation	Df	DTF	DTM	PH	NPB	PPP	SI	SY
Environment (E)	2	71.26***	151.75***	1221.46***	20.18***	809.28***	28.03***	2335712***
Genotypes (G)	11	82.95***	22.64***	162.51***	0.56	341.82***	112.39***	1115922***
Interaction (G×E)	22	33.32***	13.14**	27.43	0.8	126.53**	6.54***	214571.6***
Error	33	10.37	7.34	18.74	0.53	71.16	1.83	42421.2

*Significant at 0.1,**significant at 0.05 and ***significant at 0.001,

of the crop. The analysis of variance was performed with the CPCS1 package. The package PB tools were used for GGE biplot analyses (Sales et al. 2013). The GGE interaction provides the purposeful interpretation of knowledge and separates the significant and interaction effects (Yan and Kang 2003). The GGE biplot was used to graphically analyze the data to identify stable and adaptive genotypes based on the G×E interaction(Yan and Tinker 2006). The biplots were generated from the first two PCAs without scaling, centering and singular value partitioning (SVP).

The pooled analysis of variance indicated that the genotype, environment and the genotype × environment interaction had a significant ($p < 0.05$) influence on the DTF, DTM, PPP, SI and SY, whereas non-significant variation was observed only for NPB and PH (Table 1).

Bartlett test indicated the non-homogeneity of variance among 12 cultivars for seven quantitative traits (Table 2). Cultivar exhibited variations for PPP ranging from 28 (JG 218) to 58 (JG 16) and 42 was the average. SI varied from 14.29 to 13.53 (JG 36) to 26.06g (JG 24), with an average of 18.64g. The cultivar JG 12 produced the highest yield, 3566 kg ha^{-1} over three years, while check Radhey had a minimum (1970 kg ha^{-1}). Cultivar JG 12, expressed medium height phenology with good PPP, started flowering in 73 days and took 126 days to mature which is earlier than local check Radhey, 83 days DTF, 132 days DTM. The cultivar JG 315 was the second-best performer with 3152 kg ha^{-1} and had similar phenological and yield-contributing traits to JG 12 cultivars. Whereas the genotype JG 36 was found stable with the high yielding ability which showed a stable performance during all the growing seasons. The test cultivar's yield performance was stable in all the growing seasons and productivity was greater than the UP state average productivity of 1272 kg ha^{-1} (2018-19). Therefore, the test genotypes performed better than the existing cultivars of chickpeas grown by farmers. Three genotypes, JG 130, JG 315 and JG 412 were found to have early flowering coupled with fast grain filling that had the maximum PPP and also had a high SY. The short-duration genotypes with stable yield give better performance under rainfed conditions because the early genotypes had short growth periods and matured before the stress occurred.

The GGE biplot analysis was used to identify the best-performing cultivar over the three-year evaluation. In the biplot, cultivars G4 (JG-14), G7 (JG-24), G10 (JG-36) and G9 (JG-322) located near the center showed stable performance with lower G×E interaction for yield than cultivars located far from the center of the circle (Fig. 1). The genotypes that performed well in each environment can be predicted with the help of the 'Which won where' feature of the GGE biplot(Yan and Tinker 2006). The pentagon has four genotypes such as G12 (Radhey), G2 (JG-12), G11 (JG-412) and G8 (JG-315) at the vertex and the longest distance to the origin, which are responsive to environmental fluctuation and highly adapted genotypes (Fig. 2). The GGE biplot analysis allows advantage-based discriminative ability and representativeness of the environment (Yan et al. 2007). The ideal genotype G2 (JG-12) is stable as it is projected to be very close to the ideal genotype with the highest yield and stable performance in all environments. The promising cultivars G4 (JG-14), G7 (JG-24), G9 (JG-322), G3 (JG-130) and G6 (JG-218) are very close to ideal grain yield performance. These cultivars have high-yield performance and stability across the three environments. However, low-yielding genotypes G12 (Radhey) and G11 (JG-412) are poor performers and unstable projected far away from the ideal cultivar. The cultivars G1 (JG-11), G5 (JG-16), and G10 (JG-36) are stable but have poor yields across environments (Fig. 3). The GGE biplot showed the effects of environment (E) and genotypic environmental interaction (G×E) on the performance of genotypes among these environments

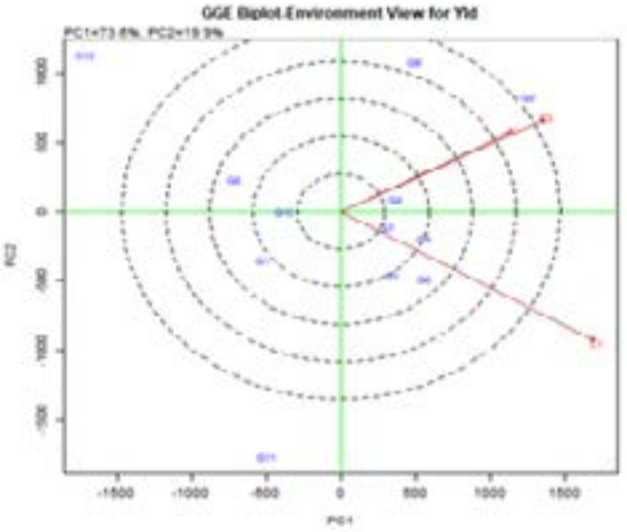

Fig. 1. GGE-biplot showing relationship among test environments for seed yield

Table 2. Tukey's pairwise mean comparison of 12 desi chickpea genotypes

Genotypes	Genotype Code	DTF	DTM	PH	NPB	PPP	SI	SY
JG-11	G1	75^{ab}	128^{bc}	47.50^{c}	4^{a}	30^{b}	22.68^{ab}	2547^{i}
JG-12	G2	74^{ab}	126^{bc}	58.25^{abc}	4^{a}	45^{ab}	16.12^{cd}	3566^{a}
JG-130	G3	73^{ab}	127^{bc}	55.25^{abc}	4^{a}	37^{ab}	22.17^{ab}	3016^{f}
JG-14	G4	68^{b}	125^{c}	$60.00a^{bc}$	3^{a}	49^{ab}	25.68^{a}	3038^{e}
JG-16	G5	77^{ab}	127^{bc}	50.00^{bc}	3^{a}	58^{a}	14.86^{d}	2454^{k}
JG-218	G6	75^{ab}	127^{bc}	58.25^{abc}	4^{a}	28^{b}	16.75^{cd}	3144^{c}
JG-24	G7	75^{ab}	126^{bc}	64.75^{a}	3^{a}	35^{ab}	26.06^{a}	3005^{g}
JG-315	G8	73^{b}	126^{bc}	57.50^{abc}	3^{a}	48^{ab}	15.18^{d}	3152^{b}
JG-322	G9	74^{ab}	126^{bc}	54.75^{abc}	3^{a}	52^{ab}	14.29^{d}	3135^{d}
JG-36	G10	77^{ab}	129^{b}	56.25^{abc}	4^{a}	42^{ab}	13.53^{d}	2646^{h}
JG-412	G11	73^{b}	126^{c}	58.00^{abc}	3^{a}	47^{ab}	19.53^{bc}	2500^{j}
Radhey	G12	83^{a}	132^{a}	63.25^{ab}	3^{a}	32^{ab}	16.88^{cd}	1970^{l}
GM		74 ± 0.74	127 ± 0.71	56.98 ± 1.08	3 ± 0.2	42 ± 1.8	18.64 ± 0.67	2788 ± 87.84
Max.		85	132	77	7	68	30.37	3566
Min.		60	125	42	2	14	12	1970
CV (%)		6.91	3.86	13.14	40.37	29.8	25.04	21.83
SD		5.15	4.89	7.48	1.36	12.46	4.67	608.60
Bartlett Test		24.96*	21.97*	22.36*	22.53*	15.73*	45.91*	10.23*

GM = General mean; CV = Coefficient of variance; SD = Standard deviation; LSD = Least significant difference; * non-homogenous variance

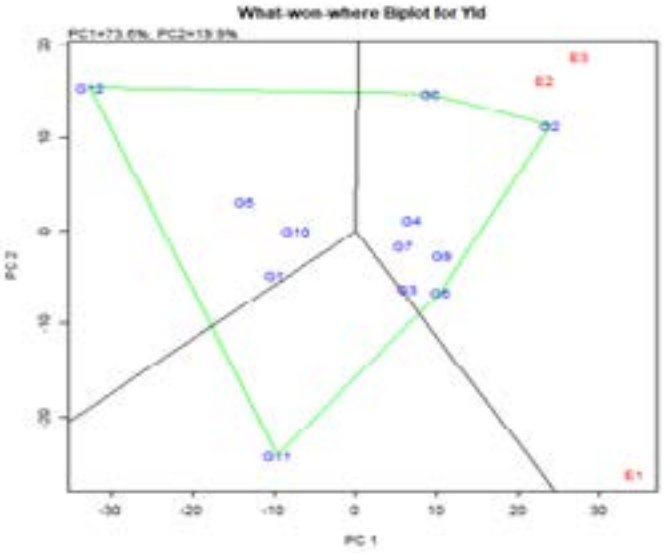

Fig. 2. GGE-biplot showing "which won where" pattern for cultivars and environment

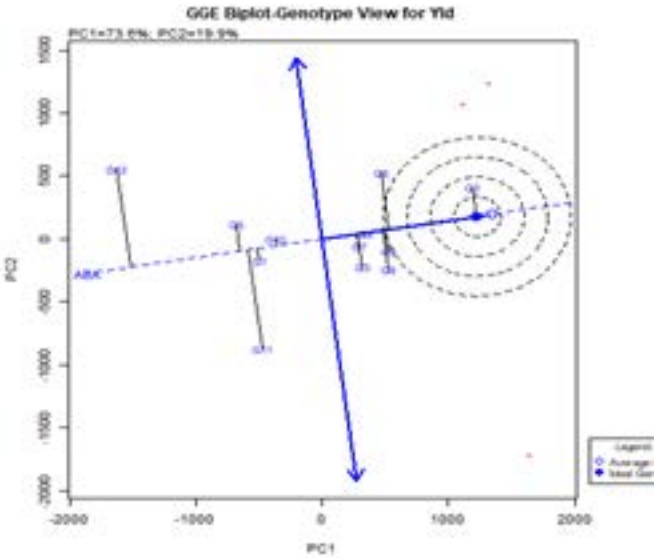

Fig. 3. Identification of stable and ideal cultivar over three environments

and allows the selection of stable genotypes with better yield. The cultivars G2 (JG-12), G10 (JG-36), and G4 (JG-14) had a high stable yielding ability over the environments and were found to fit in the existing crop rotation under rainfed cultivation.

The study found that JG 12 (3566 kg ha-1) was the highest-yielding cultivar in the Bundelkhand region, followed by JG 315 (3152 kg ha^{-1}). Other cultivars, including G2 (JG 12), G4 (JG 14), G7 (JG 24), G9 (JG 322), G3 (JG 130) and G6 (JG 218), were close to the ideal genotype and had high-yielding along with stable performance. G12 (Radhey), the high-yielding and well-adapted cultivar, is recommended for commercial cultivation in the region. Therefore, the

cultivar performed well across environments and would be recommended for cultivation in the Bundelkhand region.

Authors' contribution

The conceptualization of research (HK, MK, GSP); Designing of the experiments (HK, GSP, MK); Contribution of the experimental materials (GSP); Execution of field experiments and data collection (AK, HK); Analysis of data and interpretation (HK,A); Preparation of the manuscript (VG, HK).

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