Genotype × Environment Interaction and Stability Analysis for Yield in Desi Type Chickpea (*Cicer arietinum* L.)

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ABSTRACT

Background: Chickpea is a member of family fabaceae. Among the pulses it is considered as the third most important pulse. Its unstable performance is still one of the major problems due to G × E interaction. These interactions complicate the selection of stable, high-yielding genotypes, thereby posing challenges for breeding programs aimed at improving yield stability under diverse agro-climatic conditions.

Methods: G × E interaction and stability analysis were carried out in eight different environments with two different dates of sowing at two different locations for total 50 genetically diverse genotypes of desi chickpea.

Result: The pooled analysis of variance shows availability of significant difference among genotypes for all the characters under study. E+ (V × E) found significant for all the characters expect secondary branches/plant and harvest index. Mean squares due to non- linear and linear components of genotype × environment interaction were significant for all the characters under study. V × E were significant for all the characters under study except days to maturity, secondary branches/plant, biological yield/plant, harvest index and grain yield/plant, apart from this Var. × Env. (Linear) were significant for all the characters except secondary branches/ plant and harvest index. Pooled deviation was significant for all the characters except primary branches/plant. Genotypes, ICCV15112, BRC-3, BRC-7, BRC-9, BRC-1047-33, BRC-1009-84, BRC-1048-15, PBC501, SAKI9516 and Phule G13110 were the most stable based on mean seed yield, regression coefficient and deviation from regression and are adapted to the diverse planting condition. Hence, it is concluded that the genotypes ICCV15112, BRC-1047-33, BRC-1009-84, BRC-1048-15, PBC501, BG3043 and PhuleG13110 were found highly stable and adapted to the diverse environments and could be included in the hybridization program.

Key words: Chickpea, G × E interaction, Genetic variability, Grain yield, Stability parameters.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) 2n = 2x = 16, is the third most important food legume belongs to family Fabaceae. It is globally, occupying an area of 14.56 m ha with a production of 14.78 million tons (Mt) (FAOSTAT, 2022). India is the largest producer of chickpea with 72% of area covering about 10.56 million ha and production of 11.17 million tones grain. The present yield level is 1077 kg/ha (Project Coordinator's Report, All India Coordinated Research Project on Chickpea, 2021), which is far below the potential yield (5000 kg/ha) of the crop. Uttar Pradesh is a traditional state for chickpea cultivation covering an area of 501.0 thousand ha with production of 578.66 thousand tones and productivity of 1155 kg/ha while, the area under chickpea cultivation in Bihar is 58.22 thousand hectares with production of 67.19 thousand tons and productivity of 1154 kg/ha (Project Coordinator's Report, All India Coordinated Research Project, Chickpea, 2021). This is only 4% of pulse production of the country. Particular reference to chickpea in Bihar, the area of chickpea has declined from 2.45 lakh in 1975 to 0.58 lakh hectares in 2017 although productivity has increased from 550 kg/ha to 1000 kg/ha during the same period. Highest productivity of 1430 kg/ha was recorded in Bihar state during 2012. The study of genotype × environment interaction in its biometrical aspect is thus important not only from the genetically evolutionary point of view but also it is very relevant to production problems of agriculture in general and to plant breeder in particular (Breese, 1969). The seed yield of chickpea is influenced by many factors including genotype, growing season, geographical site and agronomic practices (Tawaha *et al.,* 2005). The fluctuation in chickpea production may be affected by environmental changes and use of varieties that are not adapted to wide range of environments (Balapure *et al*., 2015). Genotypes are considered to be more adapted or stable if they show low degree of fluctuation in yielding ability under different environments (Dinkar *et al*., 2025). The chickpea production in India can be increased and stabilized by two approaches. The first one is stratification of chickpea growing areas followed by development of suitable varieties for target regions and the second one is development of cultivars with wide

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adaptability for its cultivation in diversified environments. The climatic factors, such as rainfall and temperature change from year to year even in the same region. Therefore, most suitable approach to attain stability would be development of widely adapted varieties with high yield potential. Genotype × environment interaction is the change in relative performance of genotypes across sites (De Lacy *et al*., 1996; Karimizadeh *et al.,* 2021). G × E interaction should be investigated so that the breeder can decide to restructure the program to minimize the interaction effect, or exploit it to produce varieties with specific adaptation to particular environments (Eisemann *et al*., 1990). Eberhart and Russell (1966) model consists of three parameters, (a) mean yield over locations or seasons, (b) regression coefficient and (c) deviation from regression. According to this model a stable variety is one with a regression coefficient of unity (b=1) and a minimum deviation from the regression line (S^2 d=0). Using their definition a breeder would usually desire to develop a variety with high mean yield and satisfying the above requirements for stability (Singh and Narayanan, 2004). Present study was undertaken for estimation of the impact of genotypes environment interaction on grain yield of chickpea and to identify relatively stable genotypes across environments.

MATERIALS AND METHODS

The experiment was conducted under two sowing environments, namely normal and late sowing, at SHUATS, Prayagraj and BAU, Sabour during *Rabi* 2019-20 and *Rabi* 2020-21. At SHUATS, Prayagraj, normal sowing was undertaken on 06 November 2019 and 16 November 2020, while late sowing was carried out on 15 December 2019 and 10 December 2020. At BAU, Sabour, normal sowing was performed on 12 November 2019 and 17 November 2020, whereas late sowing was done on 13 December 2019 and 08 December 2020 during the respective crop seasons.

Data were gathered on days to maturity, plant height (cm), number of primary and secondary branches per plant, number of effective pods per plant, biological yield per plant (g), harvest index (%), 100-Seed weight (g) and seed yield per plant.

Five randomly chosen plants were used to estimate all these characters. Three replications of the genotypes were used in a randomized block design. Before performing the combined analysis, a separate analysis of variance for seed yield and its component was conducted for each season. The genetic parameters and broad-sense heritability were estimated as suggested by Burton (1952). The G × E interaction and stability parameters were statistically analyzed using the models developed by Eberhart and Russell (1966).

RESULTS AND DISCUSSION

Coefficient of variability, heritability and genetic advance

A wide range of variability was observed for yield and yield attributing traits. The pooled analysis showed that grain yield per plant (15.38% and 11.84%), biological yield per plant (14.92% and 13.52%), effective pods per plant (20.00% and 16.59%), primary branches/plant (19.93% and 19.19%) and secondary branches per plant (17.78% and 16.70%) had moderate phenotypic and genotypic coefficient of variation, while other traits showed low coefficients of variation (Table 1). These results were in accordance with the result of Khan *et al.* (2011) and Babbar *et al.* (2012). Pooled estimations from the current study show that the percentage of heritability was higher for all traits (Table 1). For primary branches per plant, secondary branches per plant, effective pods per plant and biological yield per plant, demonstrated high heritability coupled with high genetic advancement as a percentage of mean. Similar results were also reported by Kumar *et al.* (2017); Babbar and Tiwari (2018); Saini *et al.* (2020) and Devi *et al.* (2021).

Stability analysis

The stability parameters-mean (X), regression coefficient (β_1) and deviation from regression (S^2d_i)-were estimated for all traits. The partitioned analysis of variance (Table 2) revealed highly significant differences for genotype,

Table 1: Pooled estimates of genetic parameters for eight quantitative characters in fifty genotypes of chickpea.

Characters	σ^2g	σ^2p	GCV	PCV	h^2bs %	GA	GA as % of mean
DM	10.82	11.54	2.83	2.92	93.80	6.56	5.64
PH	22.20	23.57	9.98	10.28	94.21	9.42	19.95
NPBP	0.12	0.13	19.19	19.93	92.71	0.69	38.06
NSBP	0.66	0.75	16.70	17.78	88.25	1.58	32.33
EPP	15.48	22.50	16.59	20.00	68.88	6.72	28.35
BY	6.07	7.40	13.52	14.92	82.02	4.60	25.22
HI	7.52	9.38	8.13	9.08	80.18	5.06	15.00
GYP	0.53	0.89	11.84	15.38	60.27	1.15	18.78

σ^2g= Genotypic variances, σ^2p= Phenotypic variances, GCV= Genotypic coefficient of variation, PCV= Phenotypic coefficient of variation, h^2bs= Heritability in broad sense and GA= Genetic advance, DM= Days to maturity, PH= Plant height, NPBP= No. of primary branches per plant, NSBP= No. of secondary branches/plant, EPP= Effective pods per plant, BY= Biological yield per plant, HI= Harvest index, GYP= Grain yield per plant.

environment (linear), pooled deviations, Environment + (Genotype × Environment) and Genotype × Environment (linear). Most traits exhibited significant deviations from linearity, suggesting strong environmental influence on their expression, consistent with Eberhart and Russell (1966). The ANOVA indicated significant genotypic differences across all traits over environments. Variance due to Environment + (Genotype × Environment) was highly significant for most traits, except secondary branches per plant and harvest index, when tested against pooled error. The Genotype × Environment interaction was also highly significant for most traits, except days to maturity, secondary branches per plant, biological yield per plant, harvest index and grain yield per plant. The mean square due to environment (linear) was highly significant for all traits, indicating that a large proportion of variation was explained by linear regression. Genotype × Environment (linear) effects were significant for most traits, except secondary branches per plant and harvest index, suggesting predictable performance. Pooled deviation mean squares were significant for all traits except primary branches per plant, indicating the importance of non-linear (unpredictable) components in Genotype × Environment interaction. Thus, both linear and non-linear components contribute to stability assessment. These findings are in agreement with earlier reports by Shivani and Sreelakshmi (2015); Sharma *et al.* (2017); Yadav *et al.* (2014) and Babbar and Tiwari (2018).

The genotypes had regression coefficient lesser than unity coupled with mean values less to grand mean revealed that above average stability of genotypes (Table 3 and 4).

Eberhart and Russell (1966) emphasized the need of considering both linear (bi) and non linear (S^2d_i) components of G × E interaction in judging the stability of genotypes. An ideal genotype is defined as, one possessing high mean performance, with regression coefficient around unity (bi=1) and deviation from regression (S^2d_i) close to zero. The stability parameters for fifty genotypes have been given in the Table 3 and 4. An overall study of stability parameters revealed that not a single genotype was ideally stable for all the characters. The stability parameters for seed yield per plant showed that five genotypes ICCV15112, BRC-1047-33, BRC-1009-84, BRC-1048-15, PBC501, BG3043 and PhuleG13110 were stable over the eight environments. Out of these the genotype ICCV15112 having highest grain yield per plant, bi=1 (unity) and S^2d_i=0 and is found the best stable a for grain yield per plant along with other yield contributing traits like number of primary branches per plant and number of secondary branches per plant for over all eight environments. The genotypes BRC-3, BRC-7, BRC-9, PhuleG13110, H12-62, SAKI9516 and PG186 had regression coefficient lesser than unity coupled with mean values less to grand mean revealed above average stability of these genotypes for grain yield per plant. The genotypes BRC 1047, PBC 501, BG3043, GCP 105 and KWR 108 had the regression

Table 2: Pooled analysis of variance of eight characters for G × E interaction in chickpea.

Source of variation	d. f.	DM	PH	NPBP	NSBP	EPP	BY	HI	GYP
Rep. within environments	1	2.10	4.48	0.04**	0.006	0.21	1.51	1.31	0.24
Varieties	49	88.49**	181.26**	1.00**	5.54**	142.57**	52.12**	65.13**	5.17**
Env. + (Var. × Env.)	350	144.38**	48.80**	0.02**	0.09	88.47**	38.56**	6.35	4.37**
Environments	7	6923.30**	1660.04**	0.02*	0.35**	2861.23**	1593.09**	31.01**	192.02**
Var. × Env.	343	6.03	15.92**	0.02**	0.09	31.88**	6.83	5.84	0.54
Environments (Linear)	1	48463.11**	11620.29**	0.17**	2.46**	20028.60**	11151.65**	217.08**	1344.16**
Var. × Env. (Linear)	49	9.87**	45.41**	0.09**	0.04	81.95**	10.34**	5.62	0.89**
Pooled deviation	300	5.28**	10.78**	0.01	0.09**	23.06**	6.13**	5.76**	0.48**
Pooled error	784	2.02	3.47	0.01	0.05	2.78	0.67	1.26	0.16
Total	399	137.51	65.06	0.14	0.76	95.11	40.22	13.56	4.47

*, ** Significant at 5% and 1% levels of significance, respectively, DM= Days to maturity, PH= Plant height, NPBP= No. of primary branches per plant, NSBP= No. of secondary branches/plant, EPP= Effective pods per plant, BY= Biological yield per plant, HI= Harvest index, GYP= Grain yield per plant.

Table 3: Estimation of stability parameters of fifty chickpea for days to maturity, grain yield per plant, plant height and number of primary branches per plant.

Genotypes	DM			GYP (g)			PH (cm)			NPBP		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
GL29098	123.042	0.934	1.286	4.740	0.675	0.445**	52.000	1.847*	18.042**	1.495	0.958	-0.007
JG24	120.917	1.002	3.929**	6.229	1.075	0.528**	59.542	1.544**	-1.429	1.752	1.092	-0.004
JG74315-14	115.708	1.129	1.744	5.279	0.947	0.274*	46.208	2.019**	10.417**	2.002	4.149	0.008
Sabour Chan.-1	119.542	1.039	-0.713	9.065	1.130	0.589**	52.167	1.674**	1.775	2.418	0.434	0.009
BRC-2	118.958	1.105	7.388**	5.633	0.839	0.232*	49.292	0.925	1.725	1.886	-3.175	-0.001
BRC-3	117.458	0.961	7.434**	5.734	0.829	0.031	48.875	0.504	8.479**	2.088	9.935**	-0.002
BRC-4	116.792	0.992	1.466	6.463	0.951	0.242*	43.167	1.203	-0.841	2.036	9.295**	0.002
BRC-5	118.042	0.931	0.370	5.359	0.825	0.477**	50.792	1.642*	6.605**	2.409	12.018*	0.032**
BRC-1009-84	115.625	1.102	5.126**	6.465	0.821	0.077	47.500	-0.150**	14.346**	2.356	5.036	0.013*
BRC-1047-33	115.542	1.220	6.368**	6.915	1.260	0.152	49.458	0.788	3.759	1.672	0.915	-0.006
Udai	118.625	0.949	1.740	6.305	1.352*	0.304**	42.458	1.270	3.791	1.560	2.510	-0.008
NDG14-24	112.667	1.183	4.457 **	6.971	0.897	1.326**	42.875	0.344*	8.786**	1.687	5.635*	-0.004
IPC2012-98	116.167	1.074	2.062	5.792	0.853	0.206*	50.667	1.070	15.558**	1.343	-4.990	0.020**
NBeG507	114.625	1.062	11.638**	6.578	0.823	0.555**	47.583	0.252*	9.629**	2.987	10.566*	0.018*
BG3067	119.417	1.150*	-0.388	6.390	0.746	0.433**	52.167	0.498*	2.522	1.440	-0.810**	-0.010
IPC2012-49	120.042	1.040	5.083 **	6.135	1.298	0.456**	56.125	0.941	0.318	2.139	1.492	-0.009
BRC-6	116.167	1.085	2.089	6.144	0.809	0.916**	48.625	1.360	15.897**	1.973	2.257	-0.007
BRC-7	116.875	1.045	-0.734	5.030	0.954	0.030	47.917	1.476**	-0.362	1.810	2.730*	-0.001
BRC-8	116.125	0.928	2.128	5.364	1.053	0.292**	55.875	1.001	10.347**	1.680	1.883	-0.008
BRC-9	120.458	0.936	0.037	5.862	0.799	0.137	47.708	0.202**	5.769*	1.934	-0.853	-0.006
PhuleG13110	111.125	1.173	2.856 *	6.075	0.961	0.112	48.750	1.411	6.552**	1.883	-12.222**	0.030**
CSJ887	116.083	0.923	4.867 **	5.489	1.324*	0.113	43.083	0.831	2.637	1.431	1.477	-0.011
BG3068	116.833	0.758**	-0.408	6.278	1.229	0.650**	40.708	0.753	8.619**	1.500	1.020	-0.010
H12-55	115.292	1.132*	0.432	6.263	0.590*	0.224*	43.042	0.888	9.383**	1.716	1.279	-0.009
GNG2304	115.292	0.953	2.646 *	6.016	1.115	0.492**	43.000	0.421	10.678**	1.586	4.883**	-0.009
GNG2299	116.292	0.985	3.208 *	5.838	1.335*	0.236*	48.417	1.256	2.076	1.947	-6.600**	-0.005
H12-62	115.542	0.945	0.935	4.766	0.915	-0.030	49.625	1.166	26.035**	1.667	-8.433**	0.002
GL12003	117.542	1.024	5.142 **	5.440	1.220*	-0.023	53.625	1.501*	2.985	1.585	-7.358*	0.017*
PBC501	108.833	0.831	9.302**	6.387	1.100	-0.019	37.875	0.964	0.070	2.377	8.658**	-0.003
GNG469	117.042	1.041	0.657	6.721	0.865	0.334**	49.250	0.891	0.004	1.683	-8.326**	-0.005
BRC-1048-15	107.042	1.013	6.439**	6.410	1.084	0.138	36.292	0.586	24.801**	1.658	1.827	-0.005
BRC-1055-155	114.667	1.148	1.795	7.068	1.252	0.311**	44.500	1.108	13.994**	1.528	0.250	-0.006
BRC-1058-16	104.958	1.050	8.185**	7.208	1.102	0.750**	46.292	1.455	10.832**	1.634	0.722	-0.006
BG3043	116.500	0.991	6.897**	6.169	1.206	0.040	38.792	1.333	13.863**	2.283	7.228**	-0.003
DCP92-3	119.500	0.921	-0.519	5.085	0.782*	0.009	42.417	0.698	2.237	1.428	-8.773**	0.007
IPC2010-62	118.083	0.990	1.226	6.237	0.812	0.325**	45.417	1.005	0.186	2.205	-3.356**	-0.008

Table 3: Continue..

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GNG2215	119.708	0.835	3.863**	7.066	1.171	1.010**	49.458	0.903	5.626*	1.580	-5.305*	0.001
GNG2207	117.500	0.891	3.280*	6.085	0.991	0.202*	46.208	1.012	8.702**	1.975	10.161**	0.009
PG170	115.042	0.900	1.839	5.979	1.103	0.199*	56.375	1.556	11.068**	1.656	-0.268	-0.008
BRC-1074-183	114.625	1.035	7.723**	6.392	0.943	0.640**	48.208	0.719	29.222**	1.462	1.114	-0.006
BRC-1082-137	115.083	1.068	-0.045	7.186	0.896	0.477**	44.417	0.505	10.239**	1.365	0.738	-0.008
BRC-1084-127	115.500	1.030	-0.929	7.206	1.036	0.642**	45.250	1.375	6.452**	1.549	-2.107*	-0.006
BRC-1104-164	118.375	1.042	-0.167	6.160	1.075	0.299**	49.208	1.038	10.432**	1.775	1.696	-0.006
GNG2264	115.542	1.036	11.881**	6.513	0.997	0.693**	49.417	1.185	2.467	1.314	1.075	-0.010
SAKI9516	115.958	0.917	3.919**	5.792	0.988	0.031	40.708	0.786	0.871	1.300	-0.692	-0.009
ICCV15112	114.708	0.795	7.761**	7.277	1.008	0.004	47.333	1.098	6.954**	2.337	3.914	-0.004
PG186 (NC)	120.208	0.925	1.380	4.859	0.846	0.066	45.333	0.710	1.379	1.753	0.220	0.044**
BG372 (NC)	119.917	0.955	2.067	4.848	0.854	0.225*	48.000	0.613*	-0.905	1.760	2.199	0.039**
GCP105 (NC)	114.708	0.876	3.608 *	5.312	1.103	0.149	43.917	0.905	1.592	1.978	2.419	0.006
KWR108 (NC)	119.958	0.953	0.828	5.597	1.162	-0.034	45.458	0.917	0.510	2.108	1.485	0.001
Population mean	116.405			6.124			47.228			1.814		
SE(m)	0.90			0.261			1.241			0.041		
Bi Mean		1.00			1.000			1.000			1.000	
SE Bi		0.10			0.133			0.215			1.865	

*, ** Significant at 5% and 1% levels of significance, respectively; DM= Days to maturity, PH= Plant height, NPBP= No. of primary branches per plant, GYP= Grain yield per plant.

Table 4: Estimation of stability parameters of fifty chickpea genotypes for number of secondary branches per plant, effective pods per plant, biological yield per plant and harvest index.

Genotype	NSBP			EPP			BY (g)			HI (%)		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	Bi	S^2di
GL29098	4.891	1.589	0.120**	18.999	0.941	8.829**	16.213	0.918	13.172**	29.729	1.182	3.710**
JG24	4.169	0.738	0.041	20.972	1.302	147.421**	18.996	1.087	5.303**	32.555	1.221	-0.383
JG74315-14	3.902	-0.779	0.097**	16.455	0.647*	4.643*	14.626	1.116	6.977**	37.453	-1.467	17.220**
Sabour Chan.-1	7.173	0.979	-0.014	38.786	1.920*	26.926**	24.683	1.195	11.558**	37.034	1.019	3.505**
BRC-2	4.790	1.411	-0.016	20.002	0.256**	5.363**	17.876	0.894	2.517**	31.369	0.481	2.429**
BRC-3	5.788	0.595	0.157**	18.432	1.100	0.924	17.315	0.945	1.875**	33.336	0.250	1.082
BRC-4	5.565	2.455	0.011	22.976	1.008	7.964**	21.708	1.132	5.890**	29.837	0.591	2.906**
BRC-5	3.588	0.050	-0.021	18.188	0.774	27.651**	19.147	0.899	12.208**	27.904	2.208	3.282**
BRC-1009-84	4.396	0.709	-0.015	21.723	0.496**	1.264	20.118	0.930	2.058**	32.250	-0.338	2.395**
BRC-1047-33	5.360	1.007	0.038	20.592	0.588*	5.410**	20.775	1.338*	1.718**	33.307	-0.100	-0.127
Udai	4.527	1.190	-0.019	22.400	0.689**	-1.957	20.832	1.742**	7.484**	31.088	0.111	9.021**
NDG14-24	5.991	0.026	0.007	21.960	0.209**	-0.236	18.228	0.634	9.994**	37.859	3.277*	2.467**
IPC2012-98	5.153	1.228	-0.010	25.806	0.540*	6.507**	15.965	0.676	3.377**	35.867	1.937	2.611**
NBeG507	6.614	1.631	0.028	20.830	0.080**	2.635	22.721	1.165	5.850**	29.181	-0.515	2.151*
BG3067	4.280	1.679	0.012	19.512	0.552	12.134**	21.369	0.775	8.778**	29.939	1.868	4.217**

Table 4: Continue..

Table 4: Continue..

IPC2012-49	5.574	2.069	-0.009	20.955	0.823	13.179**	17.170	1.039	5.723**	34.863	3.514	6.653**
BRC-6	4.215	0.346	-0.025	21.487	0.687	20.226**	16.413	0.745	8.019**	37.429	-0.540	2.775**
BRC-7	3.747	0.207	-0.036	23.394	0.974	9.931**	13.139	0.883	0.860*	38.298	1.609	2.030*
BRC-8	3.859	0.726	-0.037	29.093	1.342	20.641**	16.041	1.117	0.832*	33.497	1.797	1.848*
BRC-9	4.641	1.199	-0.027	21.761	0.502*	4.961*	19.096	0.914	1.179*	30.675	-0.328	2.258*
PhuleG13110	4.971	1.051	0.479**	23.565	1.052	4.740*	16.873	0.894	3.412**	35.910	1.195	1.202
CSJ887	3.826	0.584	-0.026	27.975	1.545	50.258**	16.535	1.383*	4.681**	33.127	1.443	1.586*
BG3068	4.919	0.013	0.116**	33.579	2.199*	82.624**	19.030	1.294*	2.330**	32.931	-0.209	7.000**
H12-55	4.542	1.449	-0.036	28.665	1.342	16.199**	20.085	0.668	5.158**	31.240	0.273	2.574**
GNG2304	4.505	1.504	-0.020	26.167	1.350	6.188**	17.625	1.132	5.191**	34.113	1.725	1.080
GNG2299	4.433	0.945	0.030	20.889	1.060	0.201	18.216	1.312	4.853**	31.518	1.479	5.285**
H12-62	5.718	0.845	0.107**	28.948	1.039	17.188**	16.185	1.250	2.408**	30.402	-1.236	14.047**
GL12003	4.009	0.459	-0.033	20.095	0.772	4.845**	16.725	1.206	4.558**	32.184	1.346	7.101**
PBC501	5.815	0.776	0.014	26.887	1.182	16.439**	17.781	1.068	2.486**	36.105	2.596	3.847**
GNG469	4.985	0.845	-0.013	29.462	1.661*	11.741**	18.428	0.788	10.050**	36.753	0.316	11.712**
BRC-1048-15	3.682	0.814	-0.039	20.980	0.643*	3.653**	17.135	1.095	2.658**	37.767	-0.084	4.428**
BRC-1055-155	4.296	1.365	-0.042	22.614	0.624**	0.613	21.753	1.257	3.874**	32.260	0.897	2.308**
BRC-1058-16	3.865	1.298	-0.040	27.909	1.469	57.934**	23.999	1.024	11.925**	29.679	1.590	6.815**
BG3043	6.308	2.332	0.026	21.139	0.733	2.980	19.072	1.152	7.567**	31.995	2.359	6.845**
DCP92-3	5.727	1.669	-0.013	24.099	0.612	9.456**	14.818	0.770*	0.467	34.214	1.337	4.357**
IPC2010-62	6.460	1.387	0.003	23.647	1.261	28.230**	16.935	0.844	2.632**	37.058	0.877	4.175**
GNG2215	4.530	1.319	-0.040	24.551	1.441	65.186**	18.050	0.998	15.340**	39.361	0.092	6.066**
GNG2207	5.104	1.159	0.344**	21.726	1.245	12.836**	15.774	0.720*	2.184**	38.010	2.480	5.369**
PG170	5.280	1.075	-0.038	26.457	0.653	13.365**	17.523	0.826	5.301**	33.359	2.367	10.712**
BRC-1074-183	4.209	0.688	-0.021	26.556	1.723	116.900**	18.319	0.910	5.712**	34.766	1.074	1.505*
BRC-1082-137	4.555	1.009	-0.015	25.684	1.182	10.217**	22.322	0.945	2.868**	32.173	1.059	3.839**
BRC-1084-127	5.218	0.800	-0.036	29.069	1.617	52.679**	21.159	0.924	17.920**	33.989	-0.312	6.305**
BRC-1104-164	4.595	1.276	0.136**	17.773	0.677*	0.510	15.703	0.801	2.946**	38.647	1.022	5.882**
GNG2264	3.753	0.997	-0.026	23.121	0.741	6.490**	20.086	0.788	16.359**	32.214	1.450	11.164**
SAKI9516	4.887	0.799	0.365**	26.366	1.287	6.503**	17.332	0.985	0.604	33.242	1.041	3.292**
ICCV15112	5.782	1.342	0.028	26.751	1.454	13.620**	20.099	0.934	3.331**	36.420	0.862	7.262**
PG186 (NC)	4.735	-2.453	0.270**	20.989	1.007	23.381**	14.243	0.785	2.101**	33.799	1.569	2.266*
BG372 (NC)	4.425	3.547	0.482**	22.123	1.410*	2.537	15.045	0.952	2.606**	32.421	-0.984	3.523**
GCP105 (NC)	5.087	1.232	0.228**	20.429	0.533	38.758**	16.484	1.075	3.052**	31.726	3.098**	0.036
KWR108 (NC)	5.406	0.821	-0.034	23.036	1.054	15.878**	15.720	1.079	2.008**	35.405	1.502	1.671*
Population mean	4.877			23.711			18.230			33.725		
SE (m)	0.115			1.815			0.935			0.907		
Bi mean		1.000			1.000			1.000			1.000	
SE Bi		1.375			0.240			0.166			1.152	

*, ** Significant at 5% and 1% levels of significance, respectively; NSBP= No. of Secondary branches/plant, EPP= Effective pods per plant, BY= Biological yield per plant, HI= Harvest index.

coefficient above unity and also with very low mean values over the environment indicating below average stability. These genotypes were found stable for grain yield per plant in unfavorable environment. The genotypes namely, Sabour chana-1, BRC1055-155, BRC1058-16, GNG2215, BRC1082-137, BRC1084-127, ICCV15112, GNG469, NDG14-24 and BRC1047-33 had the regression coefficients greater than one coupled with high mean values indicating specific adaptation of these genotypes for exploitation of character for grain yield per plant. Stability in the seed yield was earlier reported by many workers (Arshad *et al.,* 2003; Prakash *et al*., 2006; Abbas *et al.,* 2008) by using stability analysis identified some stable chickpea genotypes for different environments. 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.

CONCLUSION

High yielding genotypes BRC-3, BRC 1009-84, BRC-7, BRC-9, Phule G13110, SAKI9516 and PG 186 were clearly stable with regard to the majority of the yield-attributing traits, suggesting that the stability of these traits may be the cause of the observed grain yield. The aforementioned findings have made it possible to cultivate chickpeas in double cropping (after rice) under very late planting conditions. Additionally, it was determined that the genotypes ICCV15112, BRC-1047-33, BRC-1009-84, BRC-1048-15, PBC501, BG3043 and PhuleG13110 were the most stable and suited to the various environments. As a result, they could be incorporated into the hybridization program to converge the stability characteristics of grain yield in order to create stable cultivars that are multi-environment adapted.

Conflict of interest

All authors declare that they have no conflicts of interest.

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