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Development of Climate Resilient Genotypes in Desi Chickpea (*Cicer arietinum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

For development of climate resilient genotypes of chickpea for yield and yield contributing characters the present study was undertaken at Pulses Improvement Project, MPKV, Rahuri during *Rabi* season of 2021-22. The twelve genotypes and four check varieties were evaluated under three different environmental conditions. The data was subjected to ANOVA and Eberthart and Russel model. The analysis of pooled variance showed a significant connection among genotypes, environment (Linear) and genotypes x environment (Linear) almost for all characters except for number of seeds per pod. The genotypes Phule G 181603, Phule G 181609, Phule G 181667,

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Vijay and Phule Vikrant exhibited average stability for grain yield per plant over all three environments. The varieties Digvijay and Phule Vikram was found below average stable so they could be suitable for poor environment and genotypes Phule G 181102 and Phule G 1210-16-1 showed stability under favorable environments.

Keywords: Chickpea; G X E interaction; stability; seed yield.

1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a self-pollinated crop belongs to the family *Fabaceae* of the Tribe *Cicereae*. It is a diploid species with chromosome number 2n=2x=16. The chickpea also known as Bengal gram, Chana and Harbhara in Marathi. Chickpea is classified into two broad types, desi and kabuli. Most of the desi types are small in size, angular in shape with dark seed color and rough seed coat, while kabuli have large beaked seeds with white or beige seed coat color and larger in size with smoother seed coat. Kabuli type chickpea is mostly grown in the temperate regions, while the Desi type chickpea is grown in the semi-arid tropics [1,2]. In any breeding programme, there is need of identification of stable and responsive genotypes across environments which will aid selection of suitable genotypes and varieties for the specific niches. A variety is said to be stable, which can adjust its phenotypic and genotypic status in response to changing environment. Stability analysis is supposed to be one of the genetic parameters responsible for phenotypic stability and adaptation. Therefore, attempt has made in the present study to identify different climate resilient genotypes in chickpea across the three environment conditions.

2. MATERIALS AND METHODS

The sixteen genotypes were evaluated in a Randomized Block Design with three replications for each sowing date (E_1- Early sown rainfed-04/10/2021, E_2- Optimum sown irrigated-15/10/2021, E_3- Late sown-12/12/2021). The gross plot size was 4.00 x 1.80 m (6 rows). The rows were spaced at 30 cm apart with intra plant spacing of 10 cm. A basal dose of 25:50:30 NPK kg/ha was applied at the time of sowing. Stability analysis was performed using the Eberhart and Russell model, revealing significant genotype-environment interactions for yield and yield-contributing traits. According to them, the regression of each variety on an environmental index and a function of square deviation from this regression provide estimates of stability parameters.

For each genotype stability was described by three parameters *viz*., mean performance ($\bar{X}$), regression coefficient (bi) and the squared deviation from the regression (S^2di).
These parameters are defined by using the following model.

$$Yij = \mu + \beta iIj + \delta ij \ (I= 1, 2 \ldots\ldots, t \text{ and } j = 1, 2 \ldots\ldots S)$$

Where,

Yij = Mean of i^{th} genotype in j^{th} environment
μ = Mean of all genotypes over all environments
βi = The regression coefficient of i^{th} genotype on the environmental index, which measures response of genotype to varying environments
Ij = The environment index which is defined as deviation of the mean of all the genotypes at a given environment from the overall mean.
δij = The deviation from regression of the i^{th} genotype of j^{th} environment.

2.1 The Stability Parameters

a. The regression coefficient (bi) is described as under

$$bi = \sum_j Yij \ Ij / \sum_j I^2 j$$

Where,

$\sum_j Yij\ Ij$ is the sum of products

$\sum_j I^2 j$ is the sum of squares of environmental index

b. Mean square deviation (S^2di) from linear regression is calculated as

$$S^2di = \frac{\sum_j \delta^2 ij}{(S-2)} - \frac{S^2e}{r}$$

Table 1. List of chickpea genotypes with their pedigree used for the present study

Sr. No.	Genotypes	Pedigree	Sr. No.	Genotypes	Pedigree
1.	Phule G 181102	Genesis 836/JG 11	9.	Phule G 1221-2-1	ICCV 10107 x WR 315
2.	Phule G 181117	ICCV 96029/ICC 16644/JG 11	10.	Phule G 1221-2-6	ICCV 10107 x WR 315
3.	Phule G 181603	ICC 4958 TM / ICCV 97105	11.	Phule G 1210-16-1	Phule G 07102 x ICCV 10107
4.	Phule G 181608	JG 130/ ICCV 11601	12.	Phule G 1210-16-12	Phule G 07102 x ICCV 10107
5.	Phule G 181609	ICCV 97105 / ICCV 11601	13.	Vijay (Check)	P 1270 x Annigeri
6.	Phule G 181667	JAKI 9218 x ICCV 11601	14.	Digvijay (Check)	Phule G 91028 x Bheema
7.	Phule G 181674	Genesis 836/GG2/ICC 4958 TM/JG 11	15.	Phule Vikram (Check)	ICCV 10 x ICCL 87322
8.	Phule G 1216-10-17	GJG 0907 x ICCV 92944	16.	Phule Vikrant (Check)	Digvijay x WCG 2000-2

Where,

$$\sum_j \delta^2 ij = \sum_j Y^2 ij - \left(\frac{Y^2 i}{t} - \frac{(\sum_j Yij \cdot Ij)^2}{\sum_j Ij} \right)$$

and

S^2e = The estimate of pooled error
t = Number of genotypes
S = Number of environments

3. RESULTS AND DISCUSSION

3.1 Pooled Analysis of Variance

The analysis of variance representing the mean sum of squares due to different sources of variation as per Eberhart and Russell [3] for the five characters is presented in Table 3. The G X E interactions against pooled error were significant for fruiting branches per plant, number pods per plant, 100 seed weight, seeds per pod and seed yield per plant. Thus, the performance of genotypes across various three environmental conditions and sowing dates was affected by the environments created by sowing genotypes in various sowing windows. Therefore, the performance of the genotypes was subjected to regression analysis to arrive at extent of Genotype and Environment interaction. The characters which exhibited significant G X E are further subjected to stability analysis as per the model proposed by Eberhart and Russell [3].

Pooled analysis of variance over three different environments showed that genotypes differed significantly for all characters when tested against G X E interaction, pooled deviation and pooled error indicating the presence of genotypic variation in the studied material. The variance due to environments + (genotype x environments) were significant for all characters indicating considerable interactions of genotypes with environment and also the distinct nature of environment and genotype x environment interactions in phenotypic expression.

Further, partitioning of the environments + (genotype x environments) component into environment (linear) revealed the significance of environment (linear) for all the traits when tested against pooled deviation and pooled error indicating that macro-environmental differences were present under all three environments studied. The higher magnitude of mean sum of squares for environment (linear), compared to genotype x environments (linear) indicated that linear response of environment accounted for major part of the total variation for all the traits studied and might be responsible for high adaptation of the genotypes in relation to yield and other traits. Therefore, prediction of performance of the genotypes over environment is expected to be possible for the traits studied in the present investigation.

The mean squares due to G x E (linear) were significant for all the traits except seeds per pod when tested against pooled deviation and pooled error indicating the predictability of the performance of genotypes over environments. Similarly, variance due to G x E (non-linear) interaction was significant for all the traits studied. This indicated differential response of genotypes in expression of characters to varying environment. The mean squares for pooled deviation (non-linear) were also significant for all the traits indicating that both linear and non-linear components contributed to the genotype x environment interaction duly indicating that the predictable as well as unpredictable components were involved in differential response of the genotypes for stability for the above traits.

The variation due to G X E interaction and linear components was observed by Singh and Mishra [4], demonstrating similar observations regarding the proportion of interaction between G and E through linear regression (bi) in environmental indices. These finding was in the line with observations from Deshmukh et al. [5], Sirohi et al. [6], Rao and Rao [7], Rao [8], Karpe [9], Varma [10], Desai [11] and Hanamantagouda K [12]. The significance of genotypes and G X E (Linear) components emphasized that genotypes differing slightly from the regression line of unit slope could be identified. Accordingly, these linear responses, namely bi=1, bi > 1 and bi < 1, were generally observed.

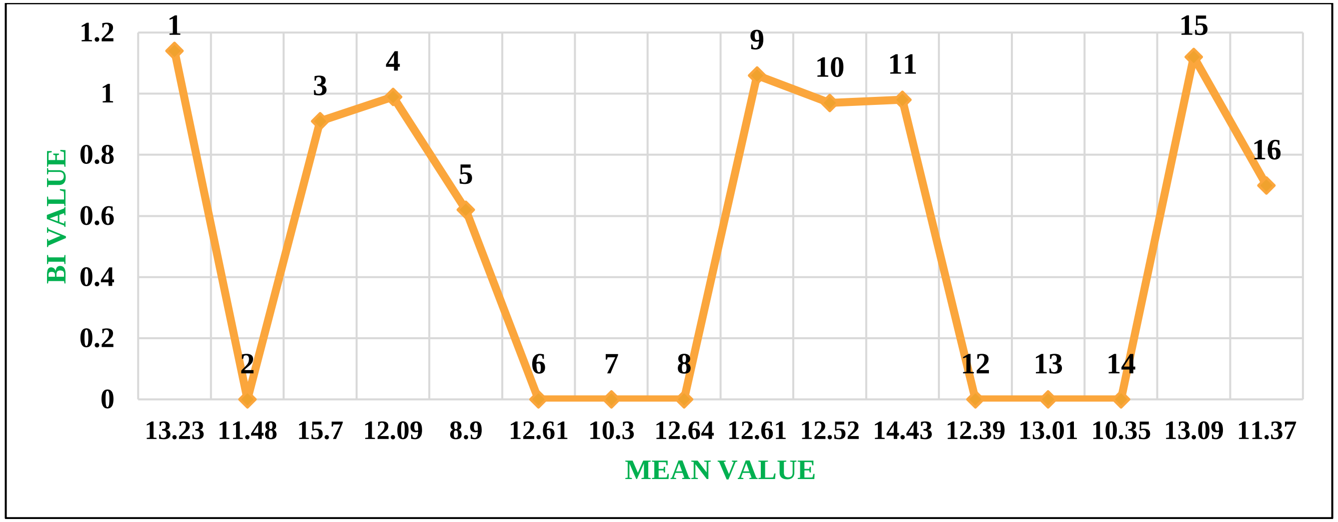

Fig. 1. Relation of number of fruiting branches per plant with stability

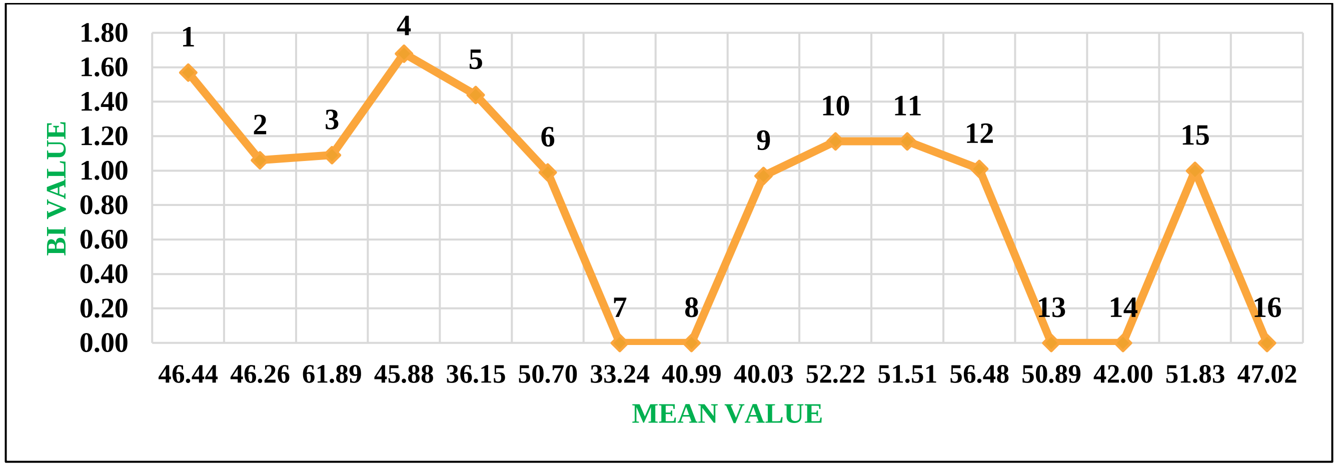

Fig. 2. Relation of number of pods per plant with stability

Table 2. Estimates of environment index (Ij) under different environments

Sr. No.	Characters	Environmental index (Ij)		
		E_1	E_2	E_3
1.	Fruiting branches per plant (No.)	-1.00	4.30	-3.30
2.	Pods per plant (No.)	-0.65	10.05	-9.40
3.	Seeds per pod (No.)	-0.02	0.09	-0.07
4.	100 seed weight (g)	-0.08	0.96	-0.88
5.	Seed yield per plant (g)	-0.83	3.20	-2.37

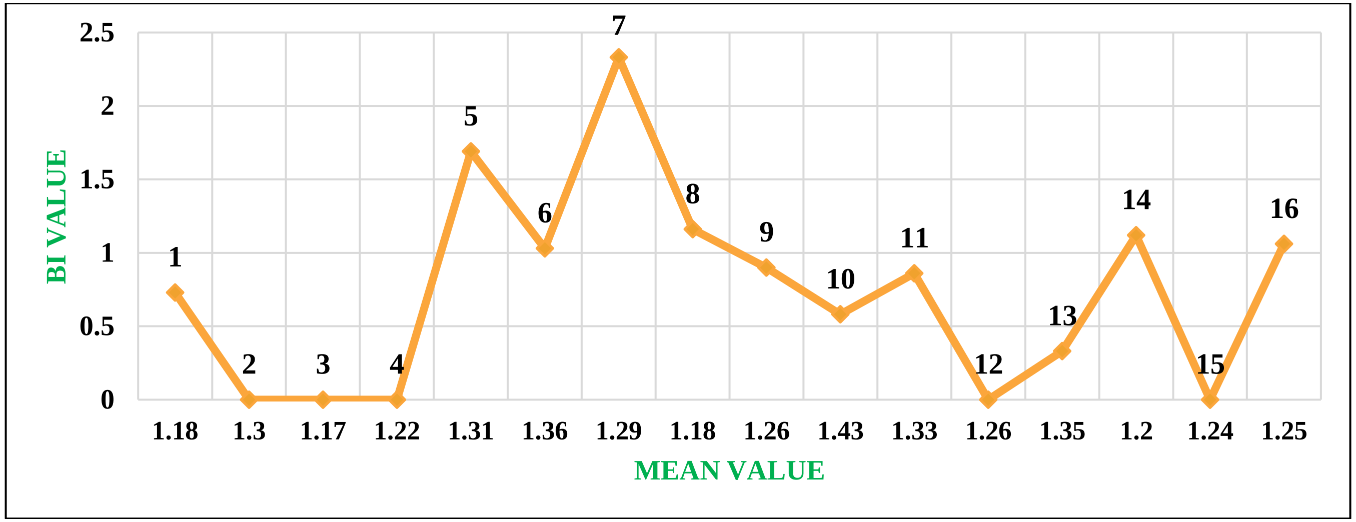

Fig. 3. Relation of number of seeds per pod with stability

List 1. Chickpea genotypes

1.	Phule G 181102	**7.**	Phule G 181674	**13.**	Vijay (Check)
2.	Phule G 181117	**8.**	Phule G 1216-10-17	**14.**	Digvijay (Check)
3.	Phule G 181603	**9.**	Phule G 1221-2-1	**15.**	Phule Vikram (Check)
4.	Phule G 181608	**10.**	Phule G 1221-2-6	**16.**	Phule Vikrant (Check)
5.	Phule G 181609	**11.**	Phule G 1210-16-1		
6.	Phule G 181667	**12.**	Phule G 1210-16-12		

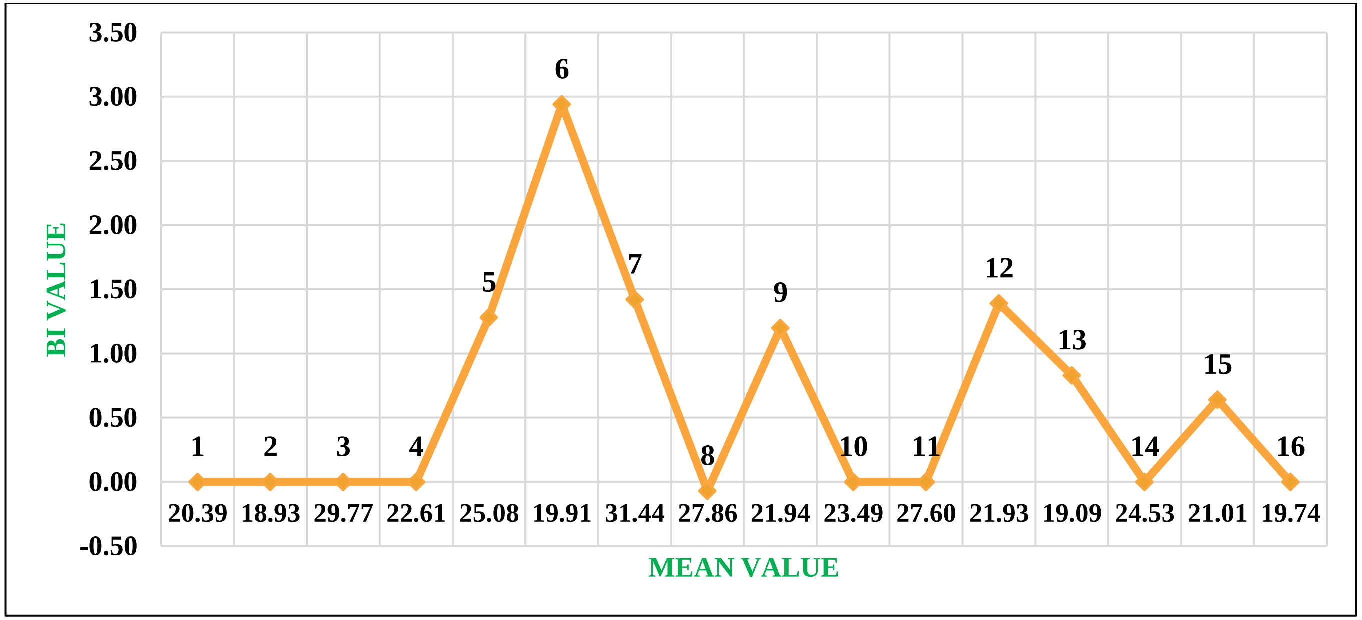

Fig. 4. Relation of 100 seed weight (g) with stability

Table 3. Pooled ANOVA (Mean sum of squares) for different traits over the environments in Chickpea

Sr. No.	Sources	G	E	G × E	E + G × E	E (L)	G × E(L)	PD (Pooled deviation)	PE (Pooled error)
	DF	15	2	30	32	1	15	16	90
1	Fruiting branches perplant (No.)	7.89++**##	243.24++**##	1.99##	17.07++**##	486.48**##	2.66*##	1.24##	0.35
2	Pods per plant (No)	166.01++**##	1518.42++**##	29.99##	123.02++**#	3063.85**##	28.24##	29.76##	4.49
3	Seeds per pod (No.)	0.02##	0.11++**#	0.01##	0.02##	0.22**##	0.01	0.02##	0.01
4	100 seed weight (g)	46.13++**##	13.58++**##	1.16##	1.71+**##	27.16**##	1.16##	0.63#	0.30
5	Seed yield per plant (g)	7.12++**##	132.08++**##	1.74##	9.89++**##	264.17**##	2.66*##	0.77#	0.41

+, ++ = Significant at 5 and 1 % level of significance, respectively against G x E

**, ** = Significant at 5 and 1% level of significance, respectively against the pooled deviation (PD)#, ## = Significant at 5 and 1% level of significance, respectively against the pooled error (PE)*

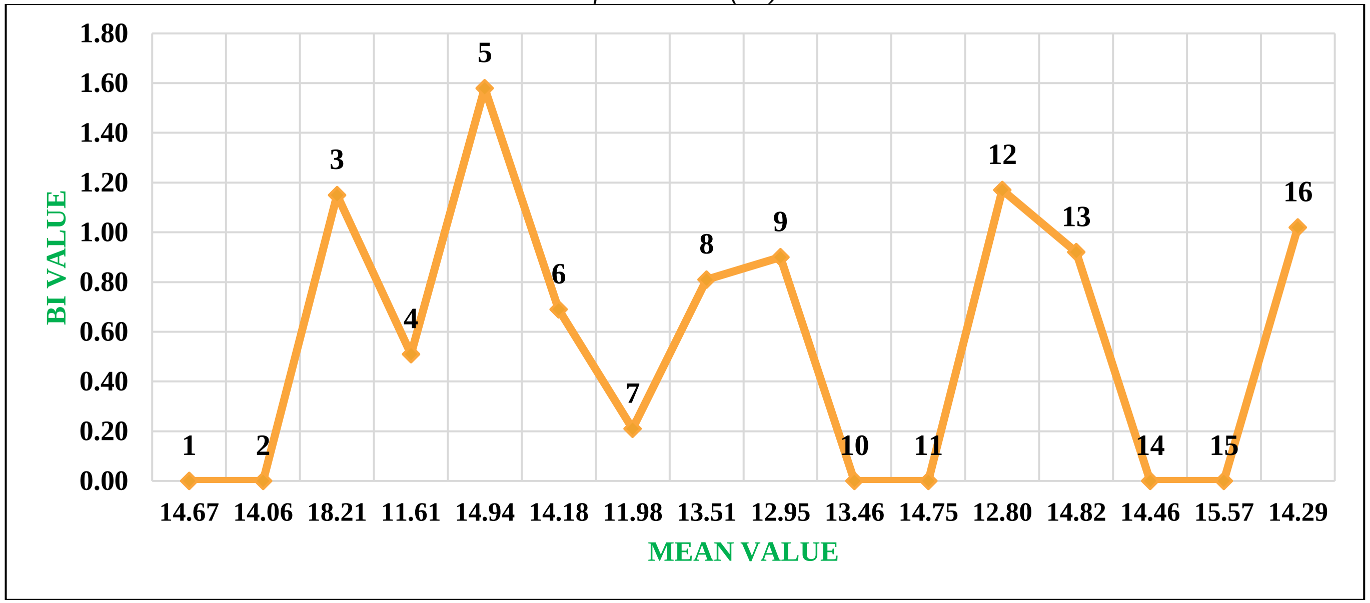

Fig. 5. Relation of seed yield per plant (g) with stability

Table 4. Mean and stability parameters of different genotypes in three environments

Sr. No.	Genotypes	Fruiting branches per plant (No.)			Pods per plant (No.)			Seeds of pod (No.)		
		$\overline{X}$	bi	S^2di	$\overline{X}$	bi	S^2di	$\overline{X}$	bi	S^2di
1.	Phule G 181102	13.23	1.14	0.57	46.44	1.57	89.70**	1.18	0.73	0.01
2.	Phule G 181117	11.48	1.35*	0.40	46.26	1.06	0.19	1.30	1.43**	-0.01
3.	Phule G 181603	15.70	0.91	-0.23	61.89	1.09	-2.48	1.17	-0.28**	-0.01
4.	Phule G 181608	12.09	0.99	0.11	45.88	1.68	106.34**	1.22	0.90**	-0.01
5.	Phule G 181609	8.90	0.62	0.06	36.15	1.44	139.11**	1.31	1.69	0.01
6.	Phule G 181667	12.61	1.45**	0.48	50.70	0.99	9.54	1.36	1.03	0.00
7.	Phule G 181674	10.30	1.50**	0.65	33.24	0.82**	-3.86	1.29	2.33	0.01
8.	Phule G 1216-10-17	12.64	1.26**	-0.35	40.99	0.16**	7.13	1.18	1.16	-0.01
9.	Phule G 1221-2-1	12.61	1.06	0.01	40.03	0.97	-3.95	1.26	0.90	0.02*
10.	Phule G 1221-2-6	12.52	0.97	7.44**	52.22	1.17	25.48**	1.43	0.58	0.07**
11.	Phule G 1210-16-1	14.43	0.98	1.63*	51.51	1.17	34.58**	1.33	0.86	0.00
12.	Phule G 1210-16-12	12.39	0.58**	-0.23	56.48	1.01	8.65	1.26	0.42**	-0.01
13.	Vijay (Ch)	13.01	0.77**	-0.29	50.89	0.61*	0.01	1.35	0.33	0.08**
14.	Digvijay (Ch)	10.35	0.60**	-0.21	42.00	0.60**	-3.71	1.20	1.12	0.00
15.	Phule Vikram (Ch)	13.09	1.12	1.94*	51.83	1.00	1.95	1.24	1.74**	-0.01
16.	Phule Vikrant (Ch)	11.37	0.70	2.26**	47.02	0.66**	-4.39	1.25	1.06	0.00
	Mean	**12.29**			**47.10**			**1.27**		
	S.E.±		**0.20**			**0.40**			**1.05**	

**, ** = Significant at 5 and 1% level of significance, respectively*

Table 5. Mean and stability parameters of different genotypes in three environments

Sr. No.	Genotypes	100 seed weight (g)			Seed yield per plant (g)		
		$\overline{X}$	bi	S^2di	$\overline{X}$	bi	S^2di
1.	Phule G 181102	20.39	2.24**	0.38	14.67	1.43**	0.01
2.	Phule G 181117	18.93	-0.24**	-0.21	14.06	1.25**	-0.35
3.	Phule G 181603	29.77	0.56**	-0.29	18.21	1.15	-0.26
4.	Phule G 181608	22.61	0.45**	-0.30	11.61	0.51	-0.39
5.	Phule G 181609	25.08	1.28	0.05	14.94	1.58	-0.25
6.	Phule G 181667	19.91	2.94	2.54**	14.18	0.69	0.49
7.	Phule G 181674	31.44	1.42	1.65*	11.98	0.21	3.16**
8.	Phule G 1216-10-17	27.86	-0.07	2.84**	13.51	0.81	0.72
9.	Phule G 1221-2-1	21.94	1.20	-0.21	12.95	0.90	2.63**
10.	Phule G 1221-2-6	23.49	0.87**	-0.30	13.46	1.18**	-0.25
11.	Phule G 1210-16-1	27.60	1.67**	-0.22	14.75	1.74**	-0.24
12.	Phule G 1210-16-12	21.93	1.39	0.10	12.80	1.17	0.97
13.	Vijay (Ch)	19.09	0.83	-0.21	14.82	0.92	0.06
14.	Digvijay (Ch)	24.53	0.26**	-0.26	14.46	0.59*	0.09
15.	Phule Vikram (Ch)	21.01	0.64	-0.01	15.57	0.86*	-0.36
16.	Phule Vikrant (Ch)	19.74	0.57**	-0.27	14.29	1.02	-0.25
	Mean	**23.46**			**14.14**		
	S.E.±		**0.61**			**0.22**	

**, ** = Significant at 5 and 1% level of significance, respectively*

Table 6. Nature of stability of chickpea genotypes under early sown rainfed, optimum sown irrigated and late sown conditions

Sr. No.	Characters	Genotypes showing stability		
		Average stability (Suitable for all environments)	Above average stability (bi<1) (Suitable for poor environment)	Below average stability (bi>1) (Suitable for rich environment)
1.	Fruiting branches per plant (No.)	Phule G 181102 Phule G 181603 Phule G 1221-2-1	Phule G 1210-16-12 Vijay	Phule G 181667 Phule G 1216-10-17
2.	Pods per plant (No.)	Phule G 181603 Phule G 181667 Phule G 1210-16-12 Phule Vikram	Vijay	-
3.	Seeds per pod (No.)	Phule G 181609 Phule G 181667 Phule G 181674 Phule G 1210-16-1	-	Phule G 181117
4.	100 seed weight (g)	Phule G 181603 Phule G 181609 Phule G 1221-2-6 Vijay	-	Phule G 1210-16-1
5.	Seed yield per plant (g)	Phule G 181603 Phule G 181609 Phule G 181667 Vijay Phule Vikrant	Digvijay Phule Vikram	Phule G 181102 Phule G 1210-16-1

3.2 Estimates of Environmental Indices

The estimation of environmental indices for five characters among the present study showed that E_2 (15 October 2021) revealed that positive and maximum environmental indices for nearly all the important yield contributing characters *viz*., fruiting branches per plant, pods per plant, number of seeds per pod, 100 seed weight and seed yield per plant.

3.3 Stability Parameters for Individual Characters

The stability parameters assessed for diverse traits (Tables 4,5) facilitate to recognize genotypes with overall and specific adaptation.

Among the 16 genotypes studied, the genotypes Phule G 181603, Phule G 181609, Phule G 181667, Vijay and Phule Vikrant was observed average stability, the genotypes Digvijay and Phule Vikram showed above average stability and the genotypes Phule G 181102 and Phule G 1210-16-1 showed below-average stability for seed yield per plant. For number of fruiting branches per plant, the genotypes Phule G 181102, Phule G 181603, Phule G 1221-2-1 showed average stability, the genotypes Phule G 1210-16-12 and Vijay showed above average stability and the genotypes Phule G 181667 and Phule G 1216-10-17 showed below average stability. The genotypes Phule G 181603, Phule G 181667, Phule G 1210-16-12 and Phule Vikram showed average stability, the genotype Vijay recorded above average stability and no genotype recorded below average stability for number of pods per plant. The genotypes Phule G 181609, Phule G 181667, Phule G 181674 and Phule G 1210-16-1 showed average stability, no genotype recorded above average stability and the genotype Phule G 181117 recorded below average stability for number of seeds per pod. The genotypes Phule G 181603, Phule G 181609, Phule G 1221-2-6 and Vijay were observed average stability, no genotype recorded above average stability and the genotype Phule G 1210-16-1 demonstrated below average stability for 100 seed weight.

None of the genotypes found stable for all the characters. Optimum sown irrigated condition *i.e.*, an environment E_2 *i.e.*, sowing of chickpea on 15th October was most favorable for expression of most of the characters including seed yield. Mehra and Ramanujan [13], Sharma and Maloo [14], Singh et al. [15], Popalghat et al. [16], Sirohi et al. [6], Chaudhary and Haque [17], Desai et al. [11], Tolgya et al. [18], Varma et al. [10] and Hanamantagouda [12] reported similar results in chickpea.

4. CONCLUSION

This study observed substantial genotype-environment interaction for yield and yield contributing characters of chickpea. Considering the mean yield performance, the genotypes Phule G 181603, Phule G 181609, Phule 181667, Vijay and Phule Vikrant recorded average stable performance. These genotypes can be used to develop climate resilient genotypes which would be suitable to grow under different sown conditions. The varieties Digvijay and Phule Vikram was found below average stable so they could be suitable for poor environment. Also genotype Phule G 121102 and Phule G 1210-16-1 was found below average stable so it would be suitable for to develop variety which is suitable for rich environmental conditions after multilocation trial for three or more years for stable performance.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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