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Stability analysis of chickpea (*Cicer arietinum* L) genotypes for major quantitative traits

RD KAMBLE[1*], DB LAD[1], AA BHAGAT[2], LS SHITOLE[1], SA ANARASE[1], SV KHONDE[1] and AS NAPHADE[1]

[1]Department of Botany, [2]Department of Agricultural Economics
College of Agriculture (MPKV), Shivajinagar, Pune 411005 Maharashtra, India
[*]Email for correspondence: rutujakamble046@gmail.com

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ABSTRACT

A study was conducted to evaluate the stability and performance of 16 chickpea genotypes across three different sowing environments in Pune, Maharashtra. The research utilized a randomized block design and analyzed five key traits. The results confirmed a significant genotype × environment (G × E) interaction for all traits, indicating that genotypes performed differently depending on the sowing date. The earliest sowing date (20 October) proved to be the most favourable environment, leading to the best overall growth and yield. The analysis successfully identified several genotypes with average stability, meaning they were well-suited for a range of environments. Specifically, Phule Vikram, PG-1609-4-19 and PG-1628-15-13 were found to be stable, high-yielding genotypes. The study also identified genotypes with unpredictable performance and one (PG-211110) with above-average stability, making it ideal for less favourable conditions. These findings provide valuable information for breeders and farmers seeking to select stable, high-yielding chickpea varieties adapted to diverse environments.

Keywords: Chickpea; genotypes; stability analysis; sowing dates; G × E interaction; yield

INTRODUCTION

Pulses are the backbone of Indian agriculture because they provide food, heal the land, protect the environment and support the livelihoods of farmers. They are a quiet, but powerful, force that ensures the health and well-being of the nation (Dixit et al 2024). In dry, arid regions, pulses are often the most successful crop. They thrive in these challenging environments because they don't need much water or a lot of a farmer's attention. Pulses are incredibly resilient, able to withstand long periods of drought. This makes them a more reliable choice than other crops, which often struggle to survive in the harsh, fragile climates of these areas (Singh et al 2009). Pulses are considered as soil ameliorant in view of their unique ability of fixing atmospheric nitrogen through activities of *Rhizobia*. Being nutritionally complementary to cereals in their pattern and profile of amino acids, legumes are a nutritional powerhouse. They're packed with good stuff like fiber, protein and a bunch of essential vitamins and minerals, including iron, magnesium and zinc. They're naturally low in fat, have almost no saturated fat and contain zero cholesterol, since they come from plants. They're basically a nutritional all-star, a simple food with huge benefits (Polak et al 2015).

Chickpea (*Cicer arietinum* L) is the third-largest food legume produced worldwide, after *Pisum sativum* L (field pea) and *Phaseolus vulgaris* L (common bean) (Rasheed et al 2021, Grasso et al 2022). It is grown mainly in the arid and semi-arid regions of the world (Chetariya et al 2023). It is commonly known as gram, Chana, Bengal gram and Garbanzo bean. Desi chickpeas are small and angular with rough brown to yellow testas, while Kabuli types are relatively large, plump and with smooth cream coloured testas (Desai et al 2016). India is the largest producer of chickpea followed by Pakistan, Turkey and Iran (Sharma et al 2020). According to the third advance estimates released by the Ministry of Agriculture and Farmers' Welfare, Government of India, 2025, chickpea production in India during the 2024 season was projected 11.345 million tonnes. An overview of the anticipated chickpea output for major Indian states in the marketing year 2025-26 revealed Maharashtra to lead production with approximately 3.06 million tonnes (Anon 2025).

Chickpea is a major food legume of India that is well adapted to rainfed conditions and grows very well on marginal lands which are characterized by poor fertility (Chaturvedi et al 2013). The fluctuation in chickpea production may be attributed to environmental changes and use of varieties that are not adapted to wide range of diversified environments. Genotypes are considered to be more adapted or stable if they show low degree of fluctuation in yielding ability under different environments (Bakhsh et al 2011). Therefore, these investigations were conducted to discover stable genotypes with high yield by using Eberhart and Russell (1966) model.

MATERIAL and METHODS

The field experiment was conducted during the 2023 rabi season at the Zonal Agricultural Research Station at Ganeshkhind, Pune, Maharashtra. The study used a randomized block design with three replications and evaluated the performance of 16 chickpea genotypes under three different sowing dates: 20 October, 10 November and 30 November 2023.

The genotypes were assessed for five key traits: days to 50 per cent flowering, days to maturity, plant height, plant spread and seed yield per plant. Observations for these traits were recorded from five randomly selected plants in each plot. Standard cultural practices, including a recommended fertilizer dose and a spacing of 30 cm × 10 cm, were followed. Data were analyzed using the analysis of variance procedure by Panse and Sukhatme (1985). Stability analysis was performed using the Eberhart and Russell (1966) model to identify the most stable chickpea genotypes.

RESULTS and DISCUSSION

Analysis of variance

Based on the analysis of variance data in Table 1, it is clear that the pooled analysis confirmed that both genotypes and environments were highly significant for all traits studied. This highlights the strong influence of both genetic and environmental factors on trait expression. The genotype × environment (G × E) interaction was also significant for all traits, when tested against the pooled error, except plant spread, suggesting that the performance of the genotypes was not consistent across environments.

The linear component of the environment was highly significant for all traits, confirming that the three sowing environments had a strong and predictable influence. Similarly, the genotype × environment (linear) interaction was significant for all traits except plant spread, when tested against pooled error, which means the performance of genotypes across environments could be reliably predicted for those traits. However, the pooled deviation was also significant for days to 50 per cent flowering, days to maturity and seed yield per plant, revealing that the performance of some genotypes for these three traits could not be consistently predicted.

Estimates of environmental indices

The environmental index (Ij) estimates provided in Table 2 demonstrate marked differences among the three sowing environments. Environment E1 (20 October sowing) consistently showed positive indices for all the traits studied viz days to 50 per cent flowering (5.78), days to maturity (8.18), plant height (3.24), plant spread (4.47) and seed yield per plant (2.60). These positive values strongly indicate that E1 offered highly favourable growing conditions, contributing to better crop growth, development and productivity. On the other hand, Environment E2 (sowing date 10 November) exerted a moderately favourable effect, as reflected in its marginally positive indices for days to maturity (0.18), plant height (0.32) and seed yield per plant (0.36), while it did not significantly enhance other traits. Environment E3, however, failed to provide favourable conditions for any of the characters studied, indicating that late sowing (30 November) was not conducive for optimal growth and yield performance. Taken together, these findings highlight that the early sowing date, particularly 20 October (E1), is the most advantageous for maximizing productivity and ensuring favourable expression of major quantitative traits in chickpea.

Stability analysis

To interpret the G × E interaction and assess stability, the Eberhart and Russell (1966) model was employed. This model evaluates stability on the basis of three parameters: the mean performance of the genotype, the regression coefficient (bi) and the

Table 1. Pooled analysis of variance for the characters studied in chickpea

Source	Mean square							
	Genotype (15)	Environment (2)	G × E (30)	E + (G × E) (32)	E (L) (1)	G × E (L) (15)	Pooled deviation (16)	Pooled error (90)
Days to 50% flowering	12.152+	483.100++	4.786##	34.681**##	966.200**##	4.802##	4.472##	1.320
Days to maturity	67.605+	1093.886++	30.030##	96.521**##	2187.771**##	36.944##	21.671##	1.254
Plant height (cm)	19.387++	186.179++	2.691##	14.159**##	372.358**##	3.677##	1.598	1.274
Plant spread (cm)	46.160++	265.753++	5.773*	22.022**##	531.507**##	9.448**	1.967	6.285
Seed yield/plant (g)	5.030++	124.882++	1.517##	9.227**##	249.764**##	1.337##	1.590##	0.272

+Significant at 5% LoS tested against G × E, ++Significant at 1% LoS tested against G × E, *Significant at 5% LoS tested against pooled deviation (PD), **Significant at 1% LoS tested against PD, #Significant at 5% LoS tested against pooled error (PE), ##Significant at 1% LoS tested against PE, Values in the parentheses show degrees of freedom

Table 2. Estimation of environment index (Ij) under different dates of sowing in chickpea

Character	Environmental index (Ij)		
	E1	E2	E3
Days to 50% flowering	5.78	–0.62	–5.16
Days to maturity	8.18	0.18	–8.36
Plant height	3.24	0.32	–3.56
Plant spread	4.47	–0.97	–3.51
Seed yield/plant	2.60	0.36	–2.96

E1: 20 October sowing, E2: 10 November sowing, E3: 30 November sowing

deviation from regression (S^2di). The model emphasizes evaluation under diverse environments to generate reliable information on genotype stability.

A genotype is considered stable across environments when it records a mean higher than the population average, a non-significant regression coefficient (bi) close to unity and a non-significant deviation from regression. Genotypes with above-average mean, significant regression coefficients less than unity (bi <1) and non-significant deviations from regression are regarded as having above-average stability and are better suited for stress or poor environments. In contrast, genotypes with above-average mean, significant regression coefficients greater than unity (bi >1) and non-significant deviations from regression are classified as having below-average stability, indicating their suitability for favourable or rich environments. However, when the deviation from regression is significant, irrespective of the value of the regression coefficient, the genotype is considered unstable or unpredictable across environments.

Table 3 presents the mean performance of genotypes across the three environments, together with their regression coefficients (bi) and deviations from regression (S^2di), as analyzed using the Eberhart and Russell (1966) model for the traits under study.

Days to 50 per cent flowering: The genotypes Narayangaon Local (49.44 days), C-2272 (54.56 days), PG-1628-15-13 (55.11 days), PG-211110 (52.78 days), PG-1623-3-4 (55.00 days) and Phule Vikram (55.33 days) exhibited average stability with mean values higher than population mean (earlier than mean) and non-significant regression coefficient close to unity (bi = 0.81, 0.79, 1.07, 0.85, 0.82 and 0.93 respectively) and non-significant deviation from regression, indicating their suitability for all three environments. Genotypes Karad Local, Jaki-Mahabeej, ICCX-171060 and PG-

Table 3. Stability attributes (mean, bi, S^2di) for the characters studied in chickpea

Genotype	Days to 50% flowering			Days to maturity			Plant height			Plant spread			Seed yield/plant		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
Karad Local	55.89	0.82	6.57*	104.39	0.92	–1.19	43.80	0.68	–2.20	43.80	0.86	–6.54	12.56	0.66	0.11
Narayangaon Local	49.44	0.81	0.36	111.11	1.60	26.05**	41.93	0.80	–1.95	38.71	1.13	–6.19	12.67	1.43	6.46**
Jaki-Mahabeej	56.11	0.88	5.36*	109.44	1.49	–0.64	43.69	1.53	–1.66	40.76	1.65	–2.42	12.19	0.47	1.23*
PG-1620-7-6	58.33	1.09	–0.64	105.44	1.15	–1.05	48.29	1.76	–1.60	31.01	0.39	–6.47	11.03	1.05	0.85
ICCX-171060	57.00	1.41	28.82**	104.11	1.07	–1.07	47.56	0.63	–0.66	38.36	2.05	2.29	10.27	0.51	2.66**
PG-1609-4-19	56.89	1.31	5.21*	102.89	0.89	–0.99	48.93	0.81	–0.37	39.29	0.33	–5.63	14.23	1.06	0.18
C-2272	54.56	0.79	–1.22	103.67	1.14	8.50**	46.80	1.75	–0.24	44.82	1.24	–4.38	12.23	1.00	1.49*
PG-1628-15-13	55.11	1.07	2.32	111.44	1.05	119.53**	46.47	1.14	–0.02	41.47	0.71	–6.36	13.52	1.32	0.80
PG-1616-5-6	54.89	0.53	1.80	109.67	2.03	42.08**	48.69	0.70	4.90	45.27	0.92	–6.14	13.18	1.04	1.06*
PG-1517-1-8	56.56	0.91	–1.15	104.89	0.86	26.38**	45.49	0.89	–1.70	37.44	1.65	–5.59	13.69	1.14	–0.08
PG-211110	52.78	0.85	–1.31	104.42	–0.19	16.01**	49.96	0.72*	–2.29	44.24	0.69	–5.24	14.19	1.27	1.16*
PG-1623-3-4	55.00	0.82	–1.28	109.55	1.33	1.54	46.11	0.91	0.64	42.62	0.91	–6.12	13.28	0.84	1.35*
PG-1521-12-2	56.67	1.09	2.84	98.14	0.24	20.63**	49.33	1.24	–2.12	40.20	1.79	–6.30	11.78	1.41	–0.11
ICCX-171028	55.67	1.70	1.18	105.00	0.80	56.23**	48.33	0.75	0.22	40.09	0.59	2.12	13.63	0.74	4.17**
Phule Vikram	55.33	0.93	–0.07	103.44	0.61	16.59**	51.60	1.21	–2.19	34.82	0.51	–6.45	15.49	0.97	–0.14
Digvijay	55.67	1.00	1.58	111.11	1.03	–1.20	45.98	0.48	0.13	44.31	0.57	–3.94	13.66	1.09	–0.28
Mean	55.37	1		106.17	1		47.06	1		40.45	1		12.98	1	

1609-4-19 showed significant deviation from regression (6.57, 5.36, 28.82 and 5.21 respectively) hence, they were unstable. Pooled analysis of variance revealed significant variation in the genotypes and environments when tested against G x E. The linear and non-linear G x E interactions were found to be significant when tested against pooled error. The equivalent results were also observed by Dhopre et al (2022), Tiwari et al (2022), Chetariya et al (2023), Jayalakshmi et al (2024) and Mahto et al (2024) in their stability study in chickpea.

Days to maturity: The genotypes Karad Local (104.39), PG-1620-7-6 (105.44), ICCX-171060 (104.11) and PG-1609-4-19 (102.89) showed average stability, with mean values higher (earlier) than the population mean (106.17), indicating earlier maturity with non-significant regression coefficients (bi = 0.92, 1.15, 1.07 and 0.89 respectively) close to unity and the deviations from regression were also non-significant, suggesting that these genotypes are well-suited for growth in all three environments. The genotypes Narayangaon Local, C-2272, PG-1628-15-13, PG-1616-5-6, PG-1517-1-8, PG-211110, PG-1521-12-2, ICCX-171028 and Phule Vikram had significant deviation from regression (26.05, 8.50, 119.53, 42.08, 26.38, 16.01, 20.63, 56.23 and 16.59 respectively) indicating the unpredictable nature of genotypes for this trait. The pooled analysis of variance showed significant variation in the genotypes and environments when tested against G x E. When compared to pooled error, the linear and non-linear components of G x E interaction were significant. Dhopre et al (2022), Tiwari et al (2022), Chetariya et al (2023), Jayalakshmi et al (2024) and Mahto et al (2024) observed similar results.

Plant height and plant spread: For plant height, the genotypes PG-1609-4-19 (48.93 cm), PG-1616-5-6 (48.69 cm), PG-1521-12-2 (49.33 cm), ICCX-171028 (48.33 cm) and Phule Vikram (51.60 cm) exhibited mean values greater than the population mean, with non-significant regression coefficients (bi = 0.81, 0.70, 1.24, 0.75 and 1.21 respectively) close to unity and non-significant deviations from regression, indicating average stability ie suitable for all the environments. Genotype PG-211110 (49.96 cm) exhibited high mean value and significant regression coefficient (bi = 0.72) less than unity, with non-significant S^2di, indicating that it is stable in poor environments ie it has above average stability. The pooled analysis of variance for plant height showed that the environments and genotypes were significant

Table 4. Nature of stability of chickpea genotypes under three different environments

Character	Nature of stability	
	Average stability (suitable for all environments)	Above average stability (suitable for poor/stress environments)
Days to 50% flowering	Narayangaon Local, C-2272, PG-1628-15-13, PG-211110, PG-1623-3-4, Phule Vikram	-
Days to maturity	Karad Local, PG-1620-7-6, ICCX-171060, PG-1609-4-19	-
Plant height	PG-1609-4-19, PG-1616-5-6, PG-1521-12-2, ICCX-171028, Phule Vikram	PG-211110
Plant spread	Karad Local, C-2272, PG-1628-15-13, PG-1616-5-6, PG-1623-3-4	-
Seed yield/plant	PG-1609-4-19, PG-1628-15-13, PG-1517-1-8, Phule Vikram, Digvijay	-

when tested against G × E. Both the linear and non-linear components of G × E interaction were significant when tested against pooled error. For plant spread, both the linear and non-linear components of G × E interaction were significant. Genotypes Karad Local (43.80 cm), C-2272 (44.82 cm), PG-1628-15-13 (41.47 cm), PG 1616-5-6 (45.27 cm) and PG-1623-3-4 (42.62 cm) exhibited a mean greater than mean of population, with non-significant regression coefficients (bi = 0.86, 1.24, 0.71, 0.92, and 0.91 respectively) close to unity and non significant S^2di, indicating average stability and suitability across all three environments.

The results obtained are similar to Dhopre et al (2022) and Tiwari et al (2022).

Seed yield per plant: The genotypes PG-1609-4-19 (14.23 g), PG-1628-15-13 (13.52 g), PG-1517-1-8 (13.69 g), Phule Vikram (15.49 g) and Digvijay (13.66 g) exhibited high mean values and non-significant regression coefficients (bi = 1.06, 1.32, 1.14, 0.97 and 1.09 respectively) close to unity, with non-significant deviation from regression, indicating average stability across all three environments. Genotypes: Narayangaon Local, Jaki-Mahabeej, ICCX-171060, C-2272, PG-1616-5-6, PG-211110, PG-1623-3-4 and ICCX-171028 exhibited significant deviation from regression (6.46, 1.23, 2.66, 1.49, 1.06, 1.16, 1.35 and 4.17 respectively) indicating their unpredictable nature over all environments. The pooled analysis of variance showed a significant genotype and environment effects on seed yield per plant, indicating that differences among the genotypes and environments significantly impacted yield. When compared to pooled error, the linear as well as non-linear components of the G × E interaction were significant. The equivalent results were observed by Singh et al (2021), Dhopre et al (2022), Tiwari et al (2022), Chetariya et al (2023) and Jayalakshmi et al (2024).

CONCLUSION

This study successfully tackled the core challenge faced by chickpea farmers: finding varieties that can produce a reliable harvest despite unpredictable environmental conditions. The experiment clearly demonstrated that the performance of chickpea genotypes is not just about their genetics, it's also about how they interact with their environment.

The most practical takeaway for farmers is that sowing date matters immensely. The research proved that the earliest sowing date (October 20) provided the most favourable conditions for all traits, leading to the best possible growth and yield. But the real success of this study lied in identifying several champion genotypes. The analysis pinpointed genotypes like Phule Vikram, PG-1609-4-19 and PG-1628-15-13 as ideal, stable performers. These were the all-rounders that could be trusted to deliver a high yield across different environments.

The study also found a specialized genotype (PG-211110) that was particularly resilient and well-suited for less favourable conditions, which is a huge advantage for farmers facing challenging growing seasons. Ultimately, this research gives breeders and farmers a clear, data-backed list of chickpea genotypes they can rely on. By selecting these stable, high-performing genotypes, we can make chickpea production more predictable and help ensure a more bountiful harvest for years to come.

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