LR-5391
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RESEARCH ARTICLE

Legume Research- An International Journal

Genetic Variability Studies in Chickpea (*Cicer arietinum* L.) for Yield and Contributing Traits Through Half-diallel Mating Strategy under Late-sown Conditions

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10.18805/LR-5391

ABSTRACT

Background: One of the oldest cultivated legumes, chickpeas (*Cicer arietinum* L.), are essential for world nutrition, especially with climate change. Chickpea output is poor despite rising demand for its nutritional value. Improved genetics can enhance yields to fulfil local and global demands. By selecting better parents and potential hybrids utilising half-diallel mating, breeders can hasten the development of high-yielding, durable cultivars.

Methods: This study examined 55 half-diallel mating genotypes, comprising 10 parental lines and 45 F1 hybrids. At the Acharya Narendra Deva University of Agriculture and Technology Genetics and Plant Breeding Farm in Ayodhya, U.P., these were evaluated using a randomised block design with three replications under late-sown circumstances in 2022-23 *rabi.* Normal agricultural procedures were used. A four-meter row of each genotype was planted with 30 cm between rows and 10 cm between plants. Genetic indices like GCV, PCV, heritability, genetic progress, correlation coefficient and path analysis were evaluated.

Result: ANOVA revealed significant genetic variability across all traits. Biological yield plant^{-1} had the highest PCV and GCV, followed by seed yield plant^{-1}. Heritability and genetic progress were highest for days to 50% flowering and biological yield plant^{-1}, indicating strong genetic control. Days to 50% flowering and maturity inversely linked with most yield-related characteristics. Seed yield was closely associated with primary and secondary branches plant^{-1}, plant height, pods per plant, seeds pod^{-1}, 100-seed weight and biological yield. Path coefficient study showed that all characteristics except days to 50% flowering, days to maturity and plant height influenced grain yield.

Key words: Chickpea, Correlation, GCV, Genetic advance, Heritability, Path-analysis, PCV.

INTRODUCTION

Pulses are vital for enhancing soil quality and fertility due to their ability to fix biological nitrogen, deep root systems and capacity to absorb insoluble soil elements. Diets should include them to lower cancer and cardiovascular disease risk (Carbas *et al.,* 2023). One of the oldest legumes, chickpeas (*Cicer arietinum* L.), provide 18-26% protein, minerals, vitamins, lipids and dietary fibres (Sandhu *et al.*, 2023; Joshi-Saha, 2021). Health benefits from chickpea eating are significant. Indian pulses account for 14% of gross cultivated land, including chickpeas 5% (Annual Report, 2021-22, DPD, Bhopal, India). Despite climate differences, 57 countries grow chickpeas (Merga and Haji, 2019). Turkey, Russia, Myanmar, Pakistan and Ethiopia contributed to India's 80% chickpea production in 2019. Global production was 15.87 million metric tonnes from 15 million hectares in 2021, with India producing 11.91 million from 10.94 million (FAO, 2023). Given rising climate unpredictability, chickpea types must be abiotic stress-resistant. Chickpea resilience and production require genetic enhancement (Piergiovanni *et al.*, 2000). This study examines chickpea production variability and association with its components when sown late.

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How to cite this article: Yadav, A., Nath, S., Bharti, B., Singh, S., Yadav, S., Bhardwaj, R. and Yadav, S.K. (2024). Genetic Variability Studies in Chickpea (*Cicer arietinum* L.) for Yield and Contributing Traits Through Half-diallel Mating Strategy under Late-sown Conditions. Legume Research. 1-7. doi: 10.18805/LR-5391.

Submitted: 24-07-2024 **Accepted:** 25-10-2024 **Online:** 08-11-2024

MATERIALS AND METHODS

A diallel crossing design was used to cross ten genetically different chickpea lines, omitting reciprocals. The formula for crosses was:

$$\frac{p(p-1)}{2}$$

Where
'p' = Number of parents.

At the Genetics and Plant Breeding Farm of Acharya Narendra Deva University of Agriculture and Technology in Ayodhya, Uttar Pradesh, India, 45 F1s and 10 parental lines (BG 256, BG 362, IPC 2004-52, GNG 2207, BG 3043, JAKI 9218, SAKI 9516, RSG 888, GCP 105 and Pant G 186) were grown in late-sown conditions using a randomised block design (RBD For optimal crop growth, prescribed agricultural methods were followed. Each genotype was planted in a four-meter row with 30 cm row spacing and 10 cm plant spacing.

Eleven traits were monitored, including days to 50% flowering, days to maturity, plant height (cm), primary branches plant^{-1}, secondary branches plant^{-1}, pods plant^{-1}, seeds pod^{-1}, 100-seed weight (g), harvest index (%), biological yield plant^{-1} (g) and seed yield plant^{-1} (g). Data were collected from five randomly selected competitive plants per plot. Statistical and biometrical methods, including ANOVA (Panse and Shukhatme, 1985), PCV and GCV (Burton and Devane, 1953), heritability in the broad sense (h^2b) (Allard, 1960), genetic advance as a percentage of the mean (Johnson *et al.*, 1955), correlation coefficient analysis (Searle, 1961) and path coefficient analysis (Dewey and Lu, 1959)., were employed to analyze the traits.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) on the 11 attributes of late-sown (LS) chickpea half-diallel crosses demonstrated significant differences among treatments, parents, hybrids and parent vs. hybrid comparisons for most traits (Table 1). Days to 50% flowering, days to maturity, plant height and pods per plant varied between treatments, demonstrating genetic variation.

The phenotypic variance for the traits was generally higher than the genotypic variance. The PCV was greater than the GCV for all traits, indicating environmental influences on their expression (Table 2). The highest PCV was observed for biological yield plant^{-1} (26.553%), followed by seed yield plant^{-1} (26.511%) and primary branches plant^{-1} (15.876%). Similarly, biological yield plant^{-1} had the greatest GCV value at 26.055%, followed by seed yield plant^{-1} at 25.692% and plant height at 13.843%. The lowest GCV and PCV were recorded for days to maturity (5.807% and 6.051%, respectively). Previous studies by Jeena *et al.* (2005), Jha *et al.* (2015) and Gul *et al.* (2013) have reported significant genetic variability in different yield and yield variables. The significant differences between PCV and GCV suggest environmental sensitivity, whereas minimal differences indicate resilience to environmental changes.

Heritability in the broad sense ranged from 37.6% to 96.3% for all variables that showed significant differences among accessions, indicating moderate to high heredity. Traits such as days to 50% flowering and biological yield plant^{-1} exhibited the highest heritability (96.3%), followed by seed yield plant^{-1} (93.9%), days to maturity (92.1%), 100-seed weight (90%), plant height (83.9%), pods plant^{-1} (82.4%) and harvest index (74.6%). Moderate heritability was observed for secondary branches plant^{-1} (56.2%), primary branches plant^{-1} (48.4%) and seeds pod^{-1} (37.6%). High heritability estimates suggest that these traits are mainly influenced by genetic factors.

The genetic advance (GA) values varied from 0.144% to 22.375%, with the highest GA observed for biological yield plant^{-1} (22.375%), followed by days to 50% flowering (14.282%). Gul *et al.* (2013) also reported significant variability for pods plant^{-1} and seed yield plant^{-1}. High heritability, genetic advance and GCV values for biological yield plant^{-1} and seed yield plant^{-1} suggest substantial improvement potential through selection.

Table 1: ANOVA of half-diallel crosses for 11 characters of chickpea in late sown (LS) condition.

Source of variation	Replicates	Treatment	Parent	Hybrid	Parent vs hybrid	Error
d. f.	2	54	9	44	1	108
Days to 50% flowering	1.43	1.51**	1.07**	1.06**	2.51**	1.89
Days to maturity	1.24*	1.42**	6.71**	8.63**	3.28**	3.96
Primary branches plant^{-1}	9.76	1.64**	8.35	1.28**	2.49**	4.31
Secondary branches plant^{-1}	1.01	1.95**	1.02*	1.57**	2.68**	4.03
Plant height (cm)	4.49	1.53**	1.07**	1.15**	2.23**	9.22
Pods per plant	6.45	5.10**	1.53**	2.71**	1.42**	3.39
Seed pod^{-1}	2.18	6.01**	3.31	5.33**	6.05**	2.14
100 seed weight (g)	1.23	2.06**	1.63**	1.30**	3.92**	7.41
Biological yield plant^{-1} (g)	1.48*	3.72**	6.40**	2.71*	7.58**	4.73
Harvest index (%)	2.37	2.85**	2.13**	3.05**	4.17	2.91
Seed yield plant^{-1} (g)	2.28	5.66**	8.86**	4.01**	1.21**	1.19

'*' Indicates significance at 5% probability level and '**' indicates significance at 1% probability level.

Table 2: Mean and range of variability among parents and F1s for 11 characters in half diallel crosses of chickpea in late sown (LS) condition.

Characters	Mean ± SD	Range	Variance		Heritability	Genetic advance	Genetic advance as % of mean	Coefficient of variation	
			Var (g)	Var (p)	Broad sense	5%	5%	GCV	PCV
Days to 50% flowering	53.091±7.11	41.00-70.67	13.304	13.554	96.3	14.282	26.901	13.304	13.554
Days to maturity	116.939±6.89	105.00-133.00	5.807	6.051	92.1	13.423	11.478	5.807	6.051
Primary branches plant^{-1}	1.821±0.23	1.33-2.27	11.043	15.876	48.4	0.288	15.822	11.043	15.876
Secondary branches plant^{-1}	8.823±0.81	7.20-10.73	8.154	10.875	56.2	1.111	12.595	8.154	10.875
Plant height (cm)	50.127±7.24	35.50-63.20	13.843	15.111	83.9	13.096	26.125	13.843	15.111
Pods per plant	42.03±4.13	32.64-50.47	9.482	10.446	82.4	7.453	17.73	9.482	10.446
Seed pod^{-1}	1.902±0.14	1.60-2.33	5.975	9.746	37.6	0.144	7.546	5.975	9.746
100 seed weight (g)	20.588±2.62	13.88-24.80	12.516	13.196	90	5.034	24.453	12.516	13.196
Biological yield plant^{-1} (g)	42.485±11.02	20.13-66.52	26.055	26.553	96.3	22.375	52.665	26.055	26.553
Harvest index (%)	39.558±3.26	33.75-44.56	7.39	8.557	74.6	5.201	13.149	7.39	8.557
Seed yield plant^{-1} (g)	16.741±4.66	8.24-27.41	25.692	26.511	93.9	8.587	51.292	25.692	26.511

Table 3 shows that genotypic and phenotypic correlation coefficients for several traits were similar. This supports Tadesse *et al.* (2016), Jain *et al.* (2023) and Sharma *et al.* (2021). Most genotypic correlation coefficients were slightly higher than phenotypic ones, perhaps due to environmental variables altering trait connections. Nikita and Lal (2022), Jain *et al.* (2023) and Dar *et al.* (2020) studied chickpea.

Seed yield plant^{-1} demonstrated a positive association with all traits, except the time to reach 50% flowering and maturity. Seed yield plant^{-1} showed a notable negative correlation with days to 50% flowering and days to maturity. These findings align with previous studies in chickpea by Jain *et al.* (2020) and Pattanayak *et al.* (2021). Days to 50% flowering exhibited significant negative correlations with primary branches plant^{-1}, secondary branches plant^{-1}, pods plant^{-1}, seeds pod^{-1}, 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}, while it showed a significant positive correlation with days to maturity. Likewise, days to maturity displayed strong negative correlations with primary branches plant^{-1}, secondary branches plant^{-1}, pods plant^{-1}, seeds pod^{-1}, 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}.

Primary branches plant^{-1} were positively correlated with secondary branches plant^{-1}, plant height, pods plant^{-1}, seeds pod^{-1}, 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}, indicating that greater primary branching enhances seed yield components and overall yield. Similarly, secondary branches plant^{-1} showed significant positive correlations with plant height, pods plant^{-1}, seeds pod^{-1}, 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}. Plant height was significantly positively associated with pods plant^{-1}, seeds pod^{-1}, 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}, suggesting that taller plants may contribute to increased seed yield. Pods plant^{-1} showed significant positive correlations with seeds pod^{-1}, 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}, emphasizing the pivotal role of pod number in improving yield. Seeds pod^{-1} were significantly positively correlated with 100-seed weight, biological yield plant^{-1} and seed yield plant^{-1}, emphasizing that higher seed numbers pod^{-1} positively influence overall seed yield. The 100-seed weight was significantly positively correlated with biological yield plant^{-1} and seed yield plant^{-1}, underscoring the importance of seed size in determining yield. Biological yield plant^{-1} had a strong positive correlation with seed yield plant^{-1}, indicating that higher biomass production translates to higher seed yield plant^{-1}. The harvest index exhibited a weak but significant positive correlation with seed yield plant^{-1}, suggesting that a higher harvest index can slightly improve seed yield.

The correlations between seed yield plant^{-1} and other quantitative features found in this study have been previously reported in chickpea by Meena and Kumar (2012), Jha *et al.* (2012) and Gul *et al.* (2013).

The correlation analysis shows that agronomic variables affect chickpea output under varied sowing conditions

Table 3: Estimates of genotypic and phenotypic correlation coefficients between eleven characters of half-diallel crosses of chickpea in latesown (LS) condition.

Characters	Correlation coefficient	Days to maturity	Primary branches plant^{-1}	Secondary branches plant^{-1}	Plant height	Pods plant^{-1}	Seeds pod^{-1}	100 seed weight	Biological yield	Harvest index	Seed yield
Days to 50% flowering	r_g	0.729**	-0.495**	-0.615**	-0.447**	-0.631**	-0.712**	-0.392**	-0.559**	-0.053	-0.582**
	r_p	0.695**	-0.316**	-0.455**	-0.413**	-0.566**	-0.418**	-0.363**	-0.533**	-0.052	-0.551**
Days to maturity	r_g		-0.802**	-0.898**	-0.412**	-0.849**	-0.815**	-0.737**	-0.806**	-0.075	-0.843**
	r_p		-0.504**	-0.654**	-0.352**	-0.762**	-0.445**	-0.659**	-0.757**	-0.039	-0.775**
Primary branches plant^{-1}	r_g			0.868**	0.596**	0.935**	0.633**	0.831**	0.851**	0.065	0.883**
	r_p			0.427**	0.394**	0.533**	0.299**	0.548**	0.557**	0.091	0.588**
Secondary branches plant^{-1}	r_g				0.570**	0.904**	0.911**	0.789**	0.855**	0.144	0.920**
	r_p				0.412**	0.649**	0.387**	0.590**	0.631**	0.133	0.689**
Plant height	r_g					0.674**	0.541**	0.690**	0.656**	0.074	0.688**
	r_p					0.566**	0.231**	0.612**	0.581**	0.024	0.593**
Pods plant^{-1}	r_g						0.879**	0.853**	0.918**	0.116	0.966**
	r_p						0.356**	0.747**	0.833**	0.119	0.871**
Seeds pod^{-1}	r_g							0.643**	0.848**	0.053	0.885**
	r_p							0.273**	0.587**	0.155*	0.649**
100 seed weight	r_g								0.879**	0.100	0.919**
	r_p								0.823**	0.122	0.861**
Biological yield	r_g									-0.196*	0.951**
	r_p									-0.173*	0.938**
Harvest index	r_g										0.109
	r_p										0.169*

'*' Indicates significance at 5% probability level and '**' indicates significance at 1% probability level.

Table 4: Direct and indirect effects of ten characters on seed yield per plant of half-diallel crosses of chickpea in late sown (LS) condition.

Characters	Days to 50% flowering	Days to maturity	Primary branches plant^{-1}	Secondary branches plant^{-1}	Plant height (cm)	Pods per plant^{-1}	Seeds pod^{-1}	100-seed weight (g)	Biological yield plant^{-1} (g)	Harvest index (%)	Correlation coefficients with seed yield plant^{-1}
Days to 50% flowering	**0.0082**	-0.0074	-0.0008	-0.0104	-0.0040	-0.0523	-0.0466	-0.0424	-0.3823	-0.0129	-0.551**
Days to maturity	0.0057	**-0.0106**	-0.0012	-0.0150	-0.0034	-0.0704	-0.0496	-0.0771	-0.5433	-0.0097	-0.775**
Primary branches plant^{-1}	-0.0026	0.0054	**0.0025**	0.0098	0.0038	0.0492	0.0334	0.0641	0.3998	0.0225	0.588**
Secondary branches plant^{-1}	-0.0037	0.0070	0.0010	**0.0229**	0.0040	0.0600	0.0432	0.0690	0.4528	0.0328	0.689**
Plant height(cm)	-0.0034	0.0037	0.0010	0.0094	**0.0096**	0.0523	0.0258	0.0715	0.4172	0.0059	0.593**
Pods per plant	-0.0047	0.0081	0.0013	0.0148	0.0055	**0.0924**	0.0398	0.0874	0.5975	0.0294	0.871**
Seed pod^{-1}	-0.0034	0.0047	0.0007	0.0089	0.0022	0.0329	**0.1116**	0.0319	0.4210	0.0384	0.649**
100 seed weight (g)	-0.0030	0.0070	0.0013	0.0135	0.0059	0.0690	0.0305	**0.1169**	0.5901	0.0301	0.861**
Biological yield plant^{-1} (g)	-0.0044	0.0081	0.0014	0.0144	0.0056	0.0770	0.0655	0.0962	**0.7175**	-0.0429	0.938**
Harvest index (%)	-0.0004	0.0004	0.0002	0.0030	0.0002	0.0110	0.0173	0.0142	-0.1244	**0.2476**	0.169*

R square= 0.9975, Residual effect= 0.0502, Direct effects on main diagonal (bold figures).

(Kumar and Abbo, 2001). These associated yield qualities can improve grain yield, according to Johanson *et al.* (1955).

Breeders can improve chickpea output and global food security by focussing on features like biological yield plant^{-1}, pods plant^{-1} and seeds pod^{-1}, especially under changing climates. Paul (2022), Meena (2021), Irshad (2022), Kumawat (2021) and Maphosa (2020) had similar results.

Correlation coefficients show trait associations without causal. Thus, path coefficient analysis at the phenotypic level divides correlation coefficients into direct and indirect effects (Table 4), with seed yield per plant as the dependent variable.

Path coefficient analysis (Table 4) revealed that biological yield plant^{-1} (0.7175) exhibited the highest positive direct effect on seed yield plant^{-1}, followed by harvest index (0.2476), 100-seed weight (0.1169), seeds pod^{-1} (0.1116), pods plant^{-1} (0.0924), secondary branches plant^{-1} (0.0229), plant height (0.0096) and primary branches plant^{-1} (0.0025). Previous studies by Mallu *et al.* (2015), Güler *et al.* (2001) and Fiaz and Aslam (2015) also observed similar positive direct effects of these traits on seed yield. The negative and substantial direct effects on seed yield per plant were exerted by days to maturity (-0.0106). Very low contribution of direct effect of characters to be considered for some consequences. The high indirect effects of pods per plant (0.5975), 100 seed weight (0.5901), secondary branches per plant (0.4528), seeds per pod (0.4210), plant height (0.4172) and primary branches per plant (0.3998) via biological yield per plant and rest of the characters indirect contribution showed very low and negative effects on seed yield. The path coefficient analysis reveals that biological yield per plant is the most critical trait directly influencing seed yield in both timely and late-sown conditions. This aligns with the findings of Neha *et al.* (2022) and Solanki and Singh (2020), who reported that increased biomass is strongly correlated with higher seed yield in chickpea and various crops.

CONCLUSION

The analysis of variance (ANOVA) on late-sown chickpea half-diallel crosses showed significant genetic variety for days to 50% flowering, days to maturity, plant height and number of pods plant^{-1}. The study found more phenotypic variance than genotypic variation, suggesting environmental effect on trait expression. High PCV and GCV values were found for biological yield plant^{-1} and seed yield plant^{-1}, with most characteristics having high broad sense heritability. This suggests that genetics strongly influence these features and that selection can improve them.

In chickpea breeding projects to increase yield, correlation analysis showed the importance of variables like biological yield plant^{-1}, pods plant^{-1} and 100-seed weight. Path coefficient research showed that factors like biological yield plant^{-1}, harvest index and 100-seed weight directly improve seed yield plant^{-1}, indicating their value.

The findings imply that selecting essential agronomic features can boost chickpea yield, improving global food security in shifting climates.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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