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GENETIC VARIABILITY, CORRELATION AND PATH ANALYSIS ON KEY YIELD DETERMINANTS IN CHICKPEA (*CICER ARIETINUM* L.)

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ABSTRACT

Chickpeas are among the most important pulse crops globally, crucial in food security, sustainable agriculture, and human nutrition. Chickpea cultivation was recently migrated from North Sudan to Central Sudan, particularly within the Gezira Scheme, presenting several opportunities for local farmers to enhance their agricultural productivity and income and to diversify their crops during the winter season. This study aimed to investigate the genetic variability, heritability, correlation, and path analysis of 31 chickpeas (Cicer arietinum L.) genotypes, including 21 F1 hybrids and 10 parent lines, under Sudanese conditions. Key yield components such as plant height (cm); days to flowering; days to maturity; number of primary, secondary and tertiary branches; pods per plant; seeds per pod; Hundred seeds weight (g) and seed yield per plant (g) were analyzed. Significant genetic variability was observed for all traits, with high heritability for seed yield per plant (86.3%) and hundred seed weight (88.8%). Correlation analysis revealed a strong positive association at genotypic level between seed yield and secondary branches (0.682), tertiary branches (0.723), and pods per plant (0.714), suggesting that ideal branching pattern and high pod yield are essential for yield improvement. Path coefficient analysis confirmed that the number of pods per plant had the most substantial direct effect on seed yield, while tertiary branches had a negative direct effect but a positive indirect effect through pod production. The findings suggest focusing on traits such as branching patterns, pod production and early maturity to enhance chickpea yield in Sudan.

***Key words*:** Trait association, path coefficient analysis, pod number, grain production, Sudan.

Introduction

Chickpeas, scientifically known as *Cicer arietinum* L., is one of the most significant pulse crops globally, playing a crucial role in food security, sustainable agriculture, and human nutrition. They are the third most important grain legume crop worldwide, with a vast cultivation area spanning over 50 countries across the Mediterranean basin, Central Asia, East Africa, Europe, Australia, and North and South America. According to the FAO's (2023) statistics, global chickpea production reached about 14.6 million tons, with India being the largest producer, accounting for over 70% of the total output. Other key producers include Turkey, Australia, and Pakistan. Chickpea production has experienced steady growth due to increasing global demand for plant-based proteins and the crop's role in sustainable agriculture through nitrogen fixation, reducing the need for synthetic fertilizers, and improving soil structure with their deep and tap roots. These properties make chickpeas an excellent rotation crop, helping to maintain soil health, reduce disease potential, and support biodiversity.

Self-pollination, or autogamy, in chickpeas, leads to the consistent transmission of alleles across generations, resulting in high homozygosity. While this ensures that desirable traits are maintained within a variety, it also reduces the opportunity for new genetic combinations to emerge, which is essential for adapting to changing environmental conditions and disease pressures. Measuring heritability, alongside the phenotypic and genotypic coefficients of variation (PCV and GCV) and genetic advance, offers valuable insights into the observed variation. Estimating how much of the observed variation in traits is due to genetic factors, forecasts the degree of variability in a trait resulting from genetic and environmental factors and predicts the response to selection. These parameters help breeders understand the potential of a breeding program to achieve genetic improvement in future generations and to estimate the response to selection.

Correlation analysis is valuable in chickpea breeding programs because it helps breeders understand the relationships between plant traits and seed yield. This information allows breeders to understand the interrelation between traits at the genotypic and phenotypic levels. However, correlation analysis alone does not reveal the direct and indirect effects of these traits on seed yield. Path coefficient analysis addresses this limitation by partitioning the correlation coefficients into direct and indirect effects. This provides breeders with a clearer understanding of which traits have the most significant impact on seed yield, enabling more efficient selection strategies. The combined use of correlation and path analysis is considered the most effective approach to identifying the key traits that directly influence seed yield and develop high-yielding chickpea varieties. This approach is particularly crucial because chickpea yield is a complex trait influenced by many interconnected factors.

Chickpea (Cicer arietinum) is traditionally cultivated in the Northern region of Sudan along the Nile River, where the winter temperatures can drop significantly, favouring its growth (Jabow *et al*., 2015). Despite the promising growth conditions, chickpea contends with alternative legumes such as faba beans and common beans, which similarly strive for agricultural territory and assets, (Jabow *et al*., 2015; Hamza *et al*., 2023). It is primarily grown under irrigation as well as basin irrigation systems that use residual moisture after the Nile floods recede (Khalifa *et al*., 2016; Mohamed & Ali, 2015). More recently, its cultivation has expanded to central areas like Khartoum, Gezira Scheme and New Halfa (Jabow *et al.*, 2015). The expansion of chickpea cultivation has eastern zones of the Sudan in Hawata, and the Jebel Marra region in the west, with the River Nile and Northern states serving as the primary production zones (Khalifa *et al*., 2016). Chickpea yields in Sudan typically range between 0.83 and 2.8 tons per hectare, with variation depending on weather conditions (Khalifa *et al*., 2016; Hamza *et al*., 2023).

Breeding programs in Sudan have focused on developing cultivars resistant to stresses like Fusarium wilt and drought, along with early-flowering varieties to cope with climate variations (Khalifa *et al*., 2016; Hamza *et al*., 2023). Research has identified certain cultivars like Jebel Marra, which has a low-stress susceptibility index and performs well in low-fertility soils (Mohamed & Ali, 2015), while others such as Matama, Atmoor, and Wad Hamid are high-yielding (Elwadeea *et al*., 2021). Enhancing adaptation by incorporating early maturity traits from desi chickpeas into kabuli types was also pursued to boost yields in Sudan's subtropical regions (Khalifa *et al*., 2016). In the River Nile state, cultivars like Jebel Marra, which exhibit a tall semi-erect growth habit, were found to be well-suited to less fertile high-terrace soils (Mohamed & Ali, 2015). Chickpea breeding in Sudan also targets heat tolerance, given that high temperatures during flowering and pod-filling stages can dramatically reduce yields (Jabow *et al*., 2015; Hamza *et al*., 2023). Disease pressure, particularly from Fusarium wilt caused by Fusarium oxysporum, remains a major constraint on chickpea productivity in Sudan (Khalifa *et al*., 2016; Hamza *et al*., 2023). The breeding objectives for chickpea varieties in Central Sudan should be tailored to address the specific environmental and market conditions of the region. Given the short winter season, the focus should be on developing varieties with stable yield performance, Early maturing, enhanced grain-filling ability, market-preferred seed sizes, and tolerance to short-period drought and high temperature towards the end of the growing season. These traits are crucial for ensuring that the crop can complete its life cycle within the limited growing period while producing high-quality seeds that meet market demands. This study aimed to examine the variability, heritability, and genetic advance of chickpea varieties, as well as to explore the interrelationships between yield and its components. Additionally, the study focused on analyzing the direct and indirect effects of various quantitative traits on seed yield, providing insights into the factors that most significantly influence chickpea productivity.

Materials and Methods

The material is made up of 31 lines comprising twenty-one F1s, seven genetically diverse lines (BG329, BG-384, ICCL-87322, K-850 LM, NDG-8606, PG-92-4, and

Pusa-362) and three well-adapted and released varieties (Avrodhi, KPG-59, and Pant-186).

Experimental Design and Trait Measurement

The experiment was conducted in a randomized complete block design with two replicates, each plot was made of one row 60 cm apart, and 10cm between plants. Data on morphological traits were obtained in two ways, on a plot basis and individual plants. Days to flowering, and days to maturity, were recorded on a plot basis. However, data on plant height, number of pods/plants, number of primary branches, number of secondary branches, number of tertiary branches, Seed per pod and yield per plant, were recorded on five plant bases; selected randomly from each plot. Hundred seed weights were recorded using an electronic balance.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using Statistical Software Package for Agricultural Research Workers (OPSTAT) developed by Sheoran *et al*., (1998). to determine the significance of variation among genotypes for each trait. The means were separated using Duncan's Multiple Range Test (DMRT) at a 5% probability level. The coefficient of variation was calculated as per Genotypic and phenotypic coefficients of variation were estimated according to Burton and Devane (1953). Heritability in a broad sense and genetic advance were calculated as per Johnson *et al*., (1955). Correlation coefficients at phenotypic and genotypic levels were computed as per the methods suggested by Al-Jibouri *et al*., (1958). Path coefficients were estimated according to Dewey and Lu. (1959), where correlation coefficients were partitioned into direct and indirect effects, providing insights into the influence of individual traits on seed yield.

Results and Discussion

Variability study

The variability in chickpea genotypes was assessed for ten traits, including days to flowering, days to maturity, plant height (cm), number of primary, secondary, and tertiary branches, number of pods per plant, number of seeds per pod, seed yield per plant (g), and hundred seeds weight (g). The findings regarding mean, range, standard deviation (SD), and coefficient of variation (CV, expressed as a percentage) are summarized in Table 1. The data about heritability in the broad sense (expressed as a percentage), phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), environmental coefficient of variation (ECV), genetic advance (GA), and the genetic advance as a percentage of the mean (GAM) are presented in Table 2. The results on variability indicate significant variation among the genotypes for these traits, as evidenced by data on mean, genetic and environmental parameters.

Table 1: Statistical overview of trait variability in chickpeas genotypes.

Trait	Mean	Range		SD	CV (%)
		Min.	Max.		
Days to flowering	55.70	46.30	63.00	4.99	8.96
Days to maturity	108.98	104.00	120.00	3.97	3.64
Plant height (cm)	48.97	31.50	66.20	6.20	12.66
No. of primary branches	7.94	4.00	17.00	2.61	32.91
No. of secondary branches	15.52	3.00	27.00	5.71	36.80
No. of tertiary branches	3.94	0.00	17.40	3.74	94.76
Pods per plant	94.34	31.30	183.00	31.87	33.78
No. Seeds per pod	1.29	1.00	2.00	0.23	17.51
Seeds yield per plant (g)	19.30	6.10	31.80	5.92	30.65
Hundred seeds weight (g)	22.42	11.89	31.60	4.73	21.10

Note: CV = Coefficient of Variation, SD = Standard Deviation.

Days to Flowering and Maturity:

The days to flowering ranged from (46.30) to (63.00) days, with a mean of (55.70) days, a CV of (8.96%) and a heritability estimate of (70.46%). The experiment recorded low GA for days to flowering (7.30) and a moderate GAM (13.10%). Days to flowering recorded a higher genotypic coefficient of variations (GCV) of (7.57) and a lower environmental coefficient of variations (ECV) of (4.91). The days to maturity showed a mean of (108.98) days, with a narrow range (104.00) to (120.00 days) and a CV of (3.64%). Days to maturity recorded moderate heritability of (54.24%), moderate GCV of (2.70) and considerable influence from the environment represented by a moderate ECV of (2.48). The relatively low CV for both traits indicate less variability in these traits within the population under study. Low CV for days to flowering coupled with a higher heritability estimate suggest that the trait is strongly controlled by genetic factors with minimal influence from the environment. This is further supported by the result on the genotypic and environmental coefficient of variations, reinforcing the notion that the observed variation in days to flowering is primarily genetic. The low ECV also implies that the trait is relatively stable across different environments, making it easier to select for this trait in various conditions without significant loss of performance. Similar results were observed by Lamban *et al*., (2023) reporting low environmental influence on these traits. The low CV for Days to maturity, besides indicating low variability, also shows consistent maturity timing across the genotypes studied. Although the GA is low, the moderate and high heritability in both traits suggest that immediate gains from one cycle of selection may be limited in reducing days to

Table 2: Estimates of genetic and environmental variability in chickpeas genotypes.

Trait	Heritability (Percent)	Phenotypic Coefficient of Variations	Genotypic Coefficient of Variations	Environmental Coefficient of Variations	Genetic Advance	Genetic Advance value % means
Days to flowering	70.46	9.02	7.57	4.91	7.30	13.10
Days to maturity	54.24	3.67	2.70	2.48	4.47	4.10
Plant height (cm)	31.52	12.66	7.11	10.48	4.03	8.22
No. of primary branches	79.16	32.88	29.26	15.01	4.26	53.63
No. of secondary branches	90.80	37.07	35.32	11.24	10.76	69.33
No. of tertiary branches	77.75	95.53	84.24	45.06	6.03	153.01
No. of Pods per plant	61.56	34.01	26.68	21.09	40.69	43.13
No. of Seeds per pod	37.09	17.65	10.75	14.00	0.17	13.49
Seeds yield per plant (g)	86.30	30.01	27.88	11.11	10.30	53.34
Hundred seeds weight (g)	88.83	21.26	20.03	7.10	8.72	38.90

flowering or maturity time, Significant improvement can be achieved through careful selection over multiple generations, this could accumulate small gains, eventually leading to significant improvement in the traits. A recurrent selection approach, where multiple cycles of selection are performed, could gradually improve these traits over time. This is conformed with similar suggestions by Nagar & Karnawat (2023) and Hamza, *et al.*, (2023).

Plant Height:

Plant height showed a mean of (48.97) cm with a broader range (31.50) to (66.20) cm and a CV of (12.66%). Plant height exhibited a low heritability estimate (31.52%), coupled with a relatively low genotypic coefficient of variation (GCV) and higher environmental coefficient of variation (ECV), recording (7.11) and (10.48) respectively. Low genetic advance GA and genetic advance value % of means (GAM) were recorded at (4.03) and (8.22%), respectively.

The wider range indicates high diversity in plant height within the material studied. The low heritability estimate (31.52%) combined with relatively higher ECV over GCV indicates that the observed variation in plant height is primarily driven by environmental factors rather than genetic factors. The Low heritability, GA, GAM and higher ECV suggest that despite selection efforts, the expected genetic improvement in plant height would be difficult without considering the environmental dimension. Such traits might require either multi-environment selection trials to control for environmental variability or exploring different populations with more genetic diversity for the trait. Relatively moderate GCV is commonly reported for plant height by several researchers (Thakur, *et al.*, 2018; Kumar, *et al.*, 2021; Ningwal, *et al.*, 2023; Ningwal, *et al.*, 2023; Reddy, *et al.*, 2023; Lamban, *et al.*, 2023; Reddy *et al.*, 2023). Contrasting with reported moderate values, Pravalika, *et al.*, (2024) observe a low GCV for plant height.

Branching Pattern (Primary, Secondary, and Tertiary Branches):

The number of primary, secondary, and tertiary branches exhibited significant variability. The primary branches had a mean of (7.94) with a CV of (32.91%), while secondary branches showed a higher mean of (15.52) with a CV of (36.80%). Tertiary branches displayed the highest CV of (94.76%), with a mean of (3.94), and the range from (0.00) to (17.40). The heritability for the number of primary, secondary, and tertiary branches was high, at (79.16%), (90.80%), and (77.75%), respectively. The corresponding GAMs were (53.63%) for primary branches, (69.33%) for secondary branches, and (153.01%) for tertiary branches. Genotypic Coefficient of Variations are on the higher side, recording (29.26), (35.32) and (84.24) respectively. This is also coupled with relatively higher GCV of (29.26), (35.32) and (84.24), respectively, which is equivalent in magnitude to their corresponding PCV at (32.88), (37.07) and (95.53), respectively. Similar moderate to high heritability and genetic variability were observed in studies by Kumar, et al., (2021); Lamban, *et al.*, (2023) and Pravalika, *et al.*, (2024). These high CV, heritability, GA, GAM, GCV, PCV and lower ECV suggest that these traits show high genetic variability, effective potential for selection, and high responsiveness to genetic improvement. This is due to that this trait is largely controlled by genetic factors with minimal environmental influence. Such traits are ideal targets for breeding programs aimed at achieving significant and reliable improvements. There is not much mention of tertiary branches in the literature. This could be because they are not common in most chickpea genotypes or possibly grouped under the broader category of secondary branches.

Pods per Plant and Seeds per Pod:

The number of pods per plant varied from (31.30) to

Table 3: Genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients of agronomic traits in chickpea.

Trait	DF	DM	PH	NPB	NSB	NTB	NPPP	NSPP	SYPP	HSW
Days to flowering	**1.00**	0.517**	-0.978**	0.166	0.197	0.074	0.447**	-0.298*	-0.093	-0.051
Days to maturity	0.354**	**1.00**	-0.326**	0.125	0.143	0.209	0.199	-0.705**	0.009	-0.024
Plant height (cm)	-0.303*	-0.155	**1.00**	-0.462**	-0.302*	-0.066	-0.377**	0.168	0.266*	0.156
No. of primary branches	0.098	0.030	-0.200	**1.00**	0.455**	0.333**	0.610**	-0.017	0.483**	-0.176
No. of secondary branches	0.122	0.124	-0.081	0.402**	**1.00**	0.616**	0.777**	0.014	0.682**	-0.050
No. of tertiary branches	0.065	0.156	0.123	0.248	0.600**	**1.00**	0.755**	0.035	0.723**	0.292*
No. of Pods per plant	0.195	0.155	-0.001	0.446**	0.724**	0.704**	**1.00**	-0.093	0.714**	-0.017
No. of Seeds per pod	-0.038	-0.222	0.172	0.059	0.002	0.074	-0.032	**1.00**	0.166	-0.266*
Seeds yield per plant (g)	-0.064	0.024	0.147	0.361**	0.626**	0.661**	0.593**	0.153	**1.00**	0.248
Hundred seeds weight (g)	-0.020	-0.007	0.115	-0.166	0.002	0.293*	0.095	-0.123	0.269*	**1.00**

Note: Superscript asterisks on the correlation coefficients signify statistical significance: * for $p \leq 0.05$, ** for $p \leq 0.01$.
DF:Days to flowering; DM:Days to maturity; PH:Plant height (cm); NPB:No. of primary branches; NSB:No. of secondary branches; NTB:No. of tertiary branches; NPPP:No. of Pods per plant; NSPP:No. of Seeds per pod; SYPP:Seeds yield per plant (g); HSW:Hundred seeds weight(g)

(183.00), with a mean of (94.34) and a CV of (33.78%). indicating the presence of genotypes with a significantly higher pod production capability in the material studied. This high variability and its direct contribution to yield make it a primary focus for selection in breeding programs. The heritability for pods per plant was (61.56%), with a GA and GAM of (40.69) and (43.13%.) respectively. The moderate to high heritability and GA for pods per plant suggest that this trait can be improved through selection, contributing directly to yield improvement, (Ningwal, *et al*., 2023; Gayathri, *et al*., 2022; Hamza, *et al*., 2023; Nagar & Karnawat 2023; Kandwal, *et al*., 2022). The genotypic and environmental coefficient of variation are approximately equal in effect, recording a value of (26.68) and (21.09), respectively, indicating the importance of environmental effect and the nature of the expression of the trait. The coefficient of variation (CV) for the number of pods per plant is often reported as high, ranging from around 20% to 28%. This suggests a considerable environmental contribution to the variation in this trait (Astereki, *et al*., 2017; Thakur, *et al*., 2018).

The number of seeds per pod was less variable, with a mean of (1.29) and a CV of (17.51%). Number of seeds per pod had a lower heritability (37.09%) and a GAM of (13.49%). The ECV is higher than GCV for the number of seeds per pod, recording (14.00) and (10.75) respectively. The relatively low variability in the number of seeds per pod, combined with the low heritability and a moderate genetic advance as a percentage of the mean suggests that genetic control over this trait is limited. The fact that the environmental coefficient of variation (ECV) is higher than the genotypic coefficient of variation (GCV), indicates that environmental factors have a greater influence on the number of seeds per pod than genetic factors. This suggests that improving this trait through selection may be more challenging, as environmental variability plays a stronger role in its expression, reducing the effectiveness of selection for genetic improvement. The number of seeds per pod is consistently discussed in the literature as a factor in chickpea yield, although they suggest its overall impact is less substantial than the number of pods per plant due to the influence of the environment, (Astereki, *et al*., 2017; Ningwal, *et al*., 2023; Gayathri, *et al*., 2022).

Seed Yield per Plant (g) and Hundred Seeds Weight (g):

Seed yield per plant ranged from (6.10) to (31.80 g), with a mean of (19.30 g) and a CV of (30.65%), indicating substantial variability and potential for yield improvement through selective breeding. Seed yield per plant exhibited high heritability (86.30%) with a GAM of (53.34%). These results indicate that both traits are predominantly controlled by genetic factors, and substantial gains can be expected from selection. The high heritability of seed yield per plant is particularly advantageous for breeding programs focused on enhancing productivity, as it suggests that the observed variation is largely due to genetic differences rather than environmental factors. This argument is further reinforced by higher values for the genotypic coefficient of variation and lower environmental coefficient of variation of (27.88) and (11.11), respectively. Researchers reported significant variation among different chickpea genotypes, (Karthikeyan, *et al*., 2022; Tejasree 2021). A higher genotypic coefficient of variation was reported by Ningwal, *et al*., (2023) and Lamban, *et al*., (2023).

The hundred seeds' weight exhibited a mean of (22.42 g) with a CV of (21.10%), highlighting moderate to higher

Table 4: Genotypic path analysis showing direct (diagonal bold) and indirect (off diagonal) effect on chickpea seed yield.

Trait	DF	DM	PH	NPB	NSB	NTB	NPPP	NSPP	HSW	CSYPP
Days to flowering	**-0.32**	0.526	-0.608	0.031	0.033	-0.075	0.682	-0.321	-0.042	-0.093
Days to maturity	-0.166	**1.019**	-0.202	0.024	0.024	-0.212	0.304	-0.761	-0.02	0.009
Plant height (cm)	0.313	-0.331	**0.622**	-0.087	-0.051	0.067	-0.575	0.181	0.126	0.266*
No. of primary branches	-0.053	0.127	-0.287	**0.189**	0.077	-0.338	0.93	-0.018	-0.143	0.483**
No. of secondary branches	-0.063	0.146	-0.188	0.086	**0.168**	-0.627	1.185	0.015	-0.041	0.682**
No. of tertiary branches	-0.024	0.212	-0.041	0.063	0.104	**-1.017**	1.152	0.037	0.237	0.723**
No. of Pods per plant	-0.143	0.203	-0.234	0.115	0.131	-0.768	**1.525**	-0.101	-0.014	0.714**
No. of Seeds per pod	0.095	-0.718	0.104	-0.003	0.002	-0.035	-0.142	**1.079**	-0.216	0.166
Hundred seeds weight (g)	0.016	-0.025	0.097	-0.033	-0.009	-0.297	-0.026	-0.288	**0.811**	0.269*

Note: Genotypic Residual Value = -0.14462

DF:Days to flowering; DM:Days to maturity; PH:Plant height (cm); NPB:No. of primary branches; NSB:No. of secondary branches; NTB:No. of tertiary branches; NPPP:No. of Pods per plant; NSPP:No. of Seeds per pod; HSW:Hundred seeds weight(g); CSYPP:Correlation with Seeds yield per plant (g);

genetic diversity in seed size, which is an important trait for market preference and yield determination. Hundred seed weights showed even higher heritability (88.83%) with a GAM of (38.90%). it suggests that the observed variation is largely due to genetic differences rather than environmental factors. The result on hundred seed weight conforms to the work by Tsehaye *et al.*, (2020), Karthikeyan, *et al.*, (2022) and Lamban, *et al.*, (2023).

Association Study:

The associations between yield and its contributing traits were analyzed and partitioned into genotypic and phenotypic correlation coefficients as per Table 3. The Genotypic correlation coefficients (rg) were presented above the diagonal and the phenotypic correlation coefficients (rp) are below the diagonal. The correlation analysis demonstrated significant positive strong relationships at the genotypic level between seed yield per plant and several traits, including the number of secondary branches (rg = 0.68), tertiary branches (rg = 0.72), and pods per plant (rg = 0.71). Seed yields also recorded a significant moderate positive relation with primary branches of (rg = 0.48). These correlation values suggest that increasing these traits can directly enhance seed yield making them the most important trait that contributes to seed yield. It also highlights the contribution of branching patterns on seed yield. This conforms with the work of Karthikeyan, *et al.*, (2022) and Tsehaye *et al.*, (2020) for secondary branches; Karthikeyan, *et al.*, (2022), Tsehaye *et al.*, (2020), Ningwal, *et al.*, (2023); Jan, *et al.*, (2021) and Singh, *et al.*, (2021) for pods per plant. Similar results were observed at the genotypic level in the association between pods per plant with primary, secondary and tertiary branches, recording (rg = 0.61), (rg = 0.78) and (rg = 0.76), respectively. The above results highlight the importance of the branching pattern on pod yield and ultimately on seed yield. Several sources recorded a strong positive relationship between the number of pods a chickpea plant produces and its branching pattern, particularly the number of secondary branches, (Tsehaye, *et al.*, 2020; Shaikh, *et al.*, 2020; Yadav, *et al.*, 2020; Singh, *et al.*, 2021; Guptha, *et al.*, 2021; Pravalika, *et al.*, 2024).

A strong negative association was observed at the genotypic level between days to flowering and plant height, recording a highly significant negative correlation coefficient (r‰ = -0.98). This indicates that early-flowering genotypes generally exhibit taller plant height and conform with results obtained by Tsehaye *et al.*, (2020) and Hamza, *et al.*, (2023). Tsehaye *et al.*, (2020) on Desi-type chickpea reported that early flowering genotypes had taller plant heights, as they could allocate more time and resources to vegetative growth before the onset of flowering. Similarly, Anil Kumar *et al.*, (2021) found that early-maturing chickpea lines were positively correlated with plant height and grain yield, reinforcing the role of early flowering in determining favourable plant architecture. In another study by Jan *et al.*, (2021), late flowering genotypes were noted to be shorter and more compact, as their extended time to reproductive maturity reduced their vegetative development, a pattern observed in both irrigated and rainfed conditions. Furthermore, Karthikeyan *et al*. (2022) confirmed the same in chickpeas, noting that the trade-off between vegetative growth and early flowering was a key factor in determining plant height, with early flowering genotypes generally achieving greater height.

This finding is particularly important when considering the development of early-maturing varieties that can benefit from a longer grain-filling period and better escape drought conditions at the end of the growing season (Kumar *et al.*, 2021). Plant height is a complex trait in chickpeas that plays a significant role in determining yield. While generally, taller plants are associated with higher yields, the relationship is not always straightforward due to the influence of other traits and environmental factors. It is worth noting that chickpea genotypes that flower early are often less sensitive to photoperiod changes and focus on rapid vegetative growth in a given light environment. In contrast, late flowering genotypes may experience more photoperiod-controlled delays due to the linear relation between flowering time and photoperiod length, allowing less time for vegetative growth as they respond to seasonal changes, (Roberts, *et al.*, 1985 and Daba, *et al.*, 2016).

The Path Coefficient Analysis:

Both correlation and path analysis provide a comprehensive approach to examining the relation between traits. Correlation analysis serves as an initial step in identifying the strength and direction of the relationships between traits, while path analysis extends this foundational work by breaking down these associations into direct and indirect effects, offering a more nuanced understanding of how traits influence key yield traits. The results of the path analysis are presented in Table 4. The relation between seed yield was portioned into direct effect (diagonal) and indirect effect (off the diagonal). The genotypic path analysis of chickpea seed yield reveals critical insights into how various traits influence yield. The number of pods per plant emerges as the most influential trait, with a strong positive direct effect on yield. This trait consistently shows a strong, positive direct effect on seed yield in several reports making it a key target for selection in breeding programs (Astereki, *et al*., 2017; Tejasree, *et al*., 2021; Paul, *et al*., 2022; Reddy, *et al*., 2023; Ningwal, *et al*., 2023).

The Number of seeds per pod and days to maturity recorded strong positive direct effect on seeds yield of (1.079) and (1.019) respectively. Both traits contribute positively to yield, indicating that the high frequency of double seeds per pod and longer maturity periods are beneficial for higher yields. This is consistent with reports by Banik, *et al*., (2017); Tsehaye, *et al*., (2020); Yadav, *et al*., (2020); Ningwal *et al*., (2023) for days to maturity and (Shaikh, *et al*., 2020; Ram, *et al*., 2023; Jain, *et al*., 2022) for seeds per pod.

Traits such as plant height and hundred seed weight have positive but moderate direct effects on yield, playing supportive roles in the overall breeding objectives, (Astereki, *et al.*, 2017; Banik, *et al.*, 2017; Pattanayak, *et al.*, 2021; Jain, *et al.*, 2022). On the other hand, the number of tertiary branches has strong negative direct relations with seed yield, in spite it recorded a moderately strong relation at genotypic level with seed yield in the association study. This revealed that this trait is influencing yield indirectly. Tertiary branches and secondary branches, exhibited a significant indirect effect on seed yield, primarily through the number of pods per plant. These results suggest that traits related to pod production, such as the number of secondary and tertiary branches, are critical contributors to seed yield, underscoring their importance in breeding for high-yield varieties, (Singh, *et al*., 2021; Ningwal, *et al*., 2023). The estimate of the genotypic residual effect being of very low magnitude (-0.14462) and the variables included in the study explain most of the variability for the seed yield Trait in chickpeas.

Conclusion

The variability observed in these traits underscores the potential for genetic improvement in chickpeas through breeding programs. The high variability in traits like plant height, branching patterns, pods per plant, and seed yield per plant provides opportunities for selecting superior genotypes that combine early maturity with high yield potential. The high heritability estimates for key yield-related traits such as seed yield per plant, hundred seed weight, and branching traits suggest that significant genetic gains can be achieved through selection. In contrast, traits like plant height and seeds per pod, with lower heritability, may require alternative breeding strategies, such as the incorporation of MAS or genomic selection, to effectively enhance these characteristics. The association and path study suggests the selection should be based on traits like the number of pods per plant, seeds per pod, and primary and secondary branching while carefully managing traits like tertiary branches to enhance overall seed yield potential.

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