*FRENCH-UKRAINIAN JOURNAL OF CHEMISTRY (**2026**, VOLUME **14**, ISSUE **01**)*

Genetic Variability, Trait Associations, and Yield Determinants in Kabuli Chickpea (Cicer arietinum L.) Varieties under Ethiopian Highland Conditions

Haile Tefera

Department of Plant Science, College of Agriculture and Natural Resources, Mekdela Amba University, Gimba, Ethiopia.

teferahaile34@gmail.com

Keywords: *Chickpea, Correlation, Genetic variability, Phenotype*

Improving Kabuli chickpea (*Cicer arietinum* L.) productivity requires the identification of genetically diverse, high-yielding varieties. This study assessed genetic variability, trait associations, and superior varieties for breeding in Ethiopia. Thirteen Kabuli chickpea varieties were evaluated at Wegdi and Legambo districts using a randomized complete block design with three replications. Grain yield and related agronomic traits were analyzed using analysis of variance, genetic parameter estimation, correlation, and path coefficient analyses. Highly significant ($P < 0.01$) differences were observed among varieties for all traits, indicating substantial genetic variability. Broad-sense heritability ranged from 82.21% to 97.47%, suggesting strong genetic control. Grain yield showed positive associations with several yield-related traits. Path analysis identified traits with positive direct effects on yield, highlighting their importance as selection criteria. Qobo (4153 and 3932 kg ha^{-1}), Kasech (3839 and 3767 kg ha^{-1}), Qoqa (3673 and 3543 kg ha^{-1}), and Akuri (3083 and 2883 kg ha^{-1}) consistently produced the highest yields across locations. High genetic variability and heritability indicate strong potential for yield improvement. Qobo, Kasech, Qoqa, and Akuri are promising varieties for cultivation and use in chickpea breeding programs.

Introduction

Chickpea (Cicer arietinum L.; 2n = 2x = 16) is one of the most important grain legumes cultivated worldwide in tropical, subtropical, and temperate regions [10,14]. The crop is valued for its high protein content and plays a significant role in food and nutritional security, income generation, and sustainable agriculture through biological nitrogen fixation, which improves soil fertility and reduces fertilizer requirements. As a member of the Papilionoidea subfamily, chickpea is among the most economically important pulse crops globally [17]. Ethiopia is the largest chickpea producer in Africa, contributing more than 70% of the continent's total production [1]. The crop is an important source of household income and foreign exchange earnings, with substantial domestic consumption and export demand [2]. However, the productivity of Kabuli chickpea remains below its potential due to recurrent drought stress, limited availability of high-yielding and broadly adapted cultivars, and insufficient utilization of genetic diversity in breeding programs. Drought stress adversely affects flowering, pod formation, seed set, and grain filling, resulting in considerable yield losses

through increased flower abortion, pod shedding, and reduced seed size [4,6,13].

The effectiveness of crop improvement programs depends on the availability and exploitation of genetic variability for economically important traits. Estimates of genetic variability, heritability, and genetic advance are essential for identifying superior genotypes and predicting selection response [19]. Similarly, correlation and path coefficient analyses provide insights into the relationships among traits and their direct and indirect effects on grain yield, thereby facilitating the identification of efficient selection criteria for breeding programs [11,12].

Despite the economic importance of Kabuli chickpea in Ethiopia, information on genetic variability, trait associations, and yield determinants of released varieties under the highland agro-ecologies of South Wollo remains limited [3]. Furthermore, the adaptation potential and breeding value of available cultivars have not been adequately characterized under local production conditions. This knowledge gap restricts the identification of superior parental materials and the development of high-yielding, stable, and widely adapted varieties.

Therefore, this study was conducted to evaluate genetic variability, heritability, correlation, and path coefficient relationships among yield and yield-related traits of Kabuli chickpea varieties grown in South Wollo, Ethiopia. This study provides a novel integrated evaluation of genetic parameters and trait associations under highland agro-ecological conditions, generating evidence-based insights to support effective parent selection, varietal recommendation, and the advancement of chickpea breeding programs. Specifically, the study aimed to:

- assess the extent of genetic variability among Kabuli chickpea varieties;
- determine the relationships among grain yield and associated agronomic traits through correlation and path coefficient analyses; and
- identify high-yielding, adaptable, and genetically valuable varieties for cultivar development and genetic improvement programs.

Materials and Methods

Description of the experimental sites

The field experiment was conducted over two growing seasons at two locations in the South Wollo Zone, Amhara Region, Ethiopia, namely Wegdi and Legambo districts. The study sites were selected to represent contrasting agro-ecological conditions suitable for Kabuli chickpea production.

Wegdi district is located in South Wollo Zone between 10°30′-11°30′ N latitude and 38°30′-39°30′ E longitude, at an altitude ranging from 1200 to 1600 meters above sea level. The area is characterized by a semi-arid climate with a mean annual rainfall of 500-800 mm, predominantly occurring from May to September. The average annual temperature ranges from 21°C to 24°C. The dominant soil type of the experimental sites is Vertisol, which is commonly used for pulse crop production in the district.

Legambo district is located in the highland agro-ecological zone of South Wollo at approximately 10°20′ N latitude and 38°20′ E longitude, with an elevation ranging from 2400 to 3100 meters above sea level. The area experiences a cooler climate compared to Wegdi, with mean annual temperatures ranging from 13°C to 17°C. The district also receives seasonal rainfall and is predominantly characterized by Vertisol soils suitable for crop cultivation.

Experimental materials

Thirteen Kabuli chickpea varieties obtained from different national research centers were used for this study. The details of the varieties and their sources are presented in **Table 1**.

Table 1. Kabuli chickpea varieties used in the experiment

Varieties	Maintainer	Varieties	Maintainer	Varieties	Maintainer
Ak. Dubie	SRARC	Habru	DZARC	Qoqa	SRARC
Akuri	SRARC	Hora	DZARC	Shasho	DZARC
Chefe	DZARC	Kasech	SRARC	Teji	DZARC
Dehara	DZARC	Kobo	SRARC		
Enjer	DZARC	Yelbie	SRARC		

Source: SRARC = Sirinka Agricultural Research Center; DZARC = Debre Zeit Agricultural Research Center.

Experimental design

The field experiment was conducted using a randomized complete block design with three replications at each location and season. Kabuli chickpea varieties were randomly assigned within each block to minimize environmental variation effects. Each experimental plot measured 3.0 m × 2.4 m and consisted of eight rows spaced 30 cm apart, with 10 cm intra-row spacing, ensuring an appropriate plant population under rainfed conditions. A spacing of 0.5 m between plots and 1.0 m between blocks was maintained to reduce inter-plot competition and facilitate field management operations.

All agronomic practices, including land preparation, sowing, and field management, were applied uniformly according to local agronomic recommendations for chickpea production. The only factor varying among plots was the Kabuli chickpea variety. To minimize border effects, data were collected from the central rows of each plot, excluding outer rows and border plants. This ensured reliable and representative measurement of yield and yield-related traits.

Data collection

Data were recorded on both plot and plant basis. Plot-level data included days to 50% flowering, days to maturity, aboveground biomass, grain yield, thousand-seed weight, and harvest index. For plant-based measurements, ten randomly selected plants were sampled from the central rows of each plot. These plants were used to record plant height, number of primary and secondary branches per plant, number of pods per plant, seeds per pod, and seeds per plant.

Statistical analysis

All data analyses were performed using R (version 4.4.0, 2024) to ensure the statistical validity and robustness of the results. Analysis of variance (ANOVA) and mean separation were conducted using the *agricolae* package, correlation analysis was performed using the *psych* package. Mean comparisons were carried out using Duncan's Multiple Range Test (DMRT) at $P < 0.05$. Analysis included analysis of variance (ANOVA), estimation of variance components, coefficients of variation,

heritability, genetic advance, correlation, and path coefficient analysis. The statistical model for individual location analysis was:

$$X_{ij} = \mu + G_i + B_j + \varepsilon_{ij}$$

For combined analysis across locations, the model was:

$$Y_{ijk} = \mu + G_i + E_j + (GE)_{ij} + B_k(E_j) + \varepsilon_{ijk}$$

where μ is the overall mean, G is genotype effect, E is environment (location), GE is genotype × environment interaction, B is blocking effect, and ε is the error term.

Genetic variance components and coefficients of variation

Genotypic and phenotypic variance components were estimated following standard procedures described by [7].

$$\sigma_g^2 = \frac{MS_g - MS_e}{r}$$
$$\sigma_p^2 = \sigma_g^2 + \sigma_e^2$$

For combined analysis across environments:

$$\sigma_{gl}^2 = \frac{MS_{gl} - MS_e}{r}$$
$$\sigma_g^2 = \frac{MS_g - MS_{gl}}{rl}$$
$$\sigma_p^2 = \sigma_g^2 + \frac{\sigma_{gl}^2}{l} + \frac{\sigma_e^2}{rl}$$

Phenotypic and genotypic coefficients of variation were computed as described by [7]:

$$PCV = \frac{\sqrt{\sigma_p^2}}{\bar{X}} \times 100$$
$$GCV = \frac{\sqrt{\sigma_g^2}}{\bar{X}} \times 100$$

Heritability and genetic advance

Broad-sense heritability was estimated as:

$$H^2 = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

Expected genetic advance (GA) under 5% selection intensity was calculated as following [7]:

$$GA = K \times \sigma_p \times H^2$$

Genetic advance as percent of mean was computed as:

$$GAM = \frac{GA}{\bar{X}} \times 100$$

These parameters indicate the expected response to selection and the efficiency of breeding improvement.

Correlation analysis

Phenotypic and genotypic correlation coefficients among traits were estimated using covariance components as described by [7]:

$$r_p = \frac{Cov_p(xy)}{\sqrt{\sigma_{px}^2 \cdot \sigma_{py}^2}}$$
$$r_g = \frac{Cov_g(xy)}{\sqrt{\sigma_{gx}^2 \cdot \sigma_{gy}^2}}$$

where Cov_p and Cov_g represent phenotypic and genotypic covariances, respectively.

Path coefficient analysis

Path coefficient analysis was performed to partition correlation coefficients into direct and indirect effects of yield-related traits on grain yield, following the method described by [3]. This approach helps to identify the relative importance of individual traits in determining grain yield and supports selection of effective breeding criteria. The relationship between correlation and path coefficients was expressed as:

$$r_{ij} = p_{ij} + \sum(r_{ik} \cdot p_{kj})$$

where $r_{ij}$is the correlation between trait $i$and grain yield j, $p_{ij}$is the direct effect of trait $i$on yield, and $r_{ik} \cdot p_{kj}$ represents the indirect effects through other contributing traits.

The residual effect, which measures the extent to which the included variables explain the variability in grain yield, was described as [3].

$$P_R = \sqrt{1 - \sum(p_{iy} \cdot r_{iy})}$$

Results and Discussions

Analysis of Variance of Studied Traits

The analysis of variance (ANOVA) conducted at individual locations (**Tables 2, 3, 5**, and **6**) and across locations (**Tables 4** and **7**) revealed significant genetic variation among chickpea varieties for the twelve traits evaluated. In the first season, highly significant ($P \leq 0.01$) differences among varieties were observed for all traits, indicating substantial genetic variability and opportunities for selection. This finding agrees with the report of [12], who documented considerable variability for seed yield and related traits in Kabuli chickpea genotypes under Ethiopian conditions.

Across locations, genotype × environment interaction was highly significant for primary and secondary branches per plant, seeds per pod, seeds per plant, thousand-seed weight, biomass yield, and grain yield, suggesting differential varietal responses to environmental conditions. In contrast, days to 50% flowering and days to maturity exhibited only weakly significant interactions, indicating relatively stable expression across test environments (**Table 4**). Similarly, in the second season, ANOVA performed at individual locations and across locations (**Tables 5-7**) showed significant differences among varieties for most of the studied traits, confirming the presence of exploitable genetic variation and the influence of environmental factors on trait expression.

Table 2. Mean squares of traits of Kabuli chickpea varieties at *Wegdi* district in the first season

Traits	Rep.(df=2)	Genotype(df=12)	Error(df=24)	CV
DF	0.64	20.73**	0.47	1.6
PB	0.10	4.05**	0.13	8.4
SB	0.10	12.14**	0.13	6.0
PH	4.41	140.14**	0.49	1.4
PP	2.79	1063.42**	1.24	2.8
SPl	3.77	6860.14**	5.88	3.1
HW	0.54	69.65**	0.18	1.2
BY	16264.00	5983051.00**	72661.00	3.3
GY	40300.00	810659.00**	34694.00	6.1
HI%	8.42	290.33**	15.14	10.1

Note: * in*dicates* significant at 5% and at 1% probability levels, respectively. DF = Days to flowering, PB = Primary branch, SB = Secondary branch, PH = Plant height, PP = Pods per plant, SPl = Seed per plant, HW = Hundred seed weight, BY = Biomass yield, HI = Harvest index, and GY = Grain yield.

Table 3. Mean squares of traits of Kabuli chickpea varieties *Legambo* district in the first season

Traits	Rep.(df=2)	Genotype(df=12)	Error(df=24)	CV
DF	1.64	23.72**	0.78	1.9
PB	0.03	4.80**	0.05	6.3
SB	0.08	17.70**	0.19	7.0
PH	3.41	162.80**	0.55	1.5
PP	0.18	1146.27**	1.10	2.8
SPl	6.26	5637.79**	6.56	3.6
HW	0.33	63.09**	0.11	0.9
BY	13791.00	5969593.00**	78491.00	3.5
GY	59466.00	1006123.00**	29323.00	6.0
HI%	19.75	335.33	19.57	11.9

Table 4. Mean squares of traits of Kabuli chickpea across two locations in the first season

Traits	Rep. (df=2)	Genotype (df=12)	Location (df=1)	Genotype. Location (df=12)	Error (df=50)	CV
DF	2.17	44.14**	472.62**	0.61*	0.31	1.7
PB	0.04	8.34**	8.01**	0.51**	0.09	7.6
SB	0.17	27.57**	0.32ns	2.27**	0.15	6.4
PH	7.78	302.32**	55.85**	0.63ns	0.50	1.4
PP	2.19	2206.24**	113.28	3.45ns	1.15	2.8
SPl	7.17	12210.14**	1280.21**	287.79**	6.09	3.3
HW	0.78	125.99**	10.05**	6.75**	0.14	1.1
BY	29570	11951352**	1005043**	1292**	257.3	3.4
GY	74497	1797009**	779600**	19773**	1739	6
HI%	20.17	620.13**	41.18ns	26.53ns	16.98	10.9

Table 5. Mean squares of traits of Kabuli chickpea at *Wegdi* district in the second season

Traits	Rep.(df=2)	Genotype(df=12)	Error(df=24)	CV
DF	0.53	17.72**	0.37	3.8
PB	0.12	4.12**	0.10	7.4
SB	0.20	13.12**	0.13	7.0
PH	3.01	160.11**	0.42	3.4
PP	2.09	1053.22**	1.14	5.7
SPl	3.62	6760.13**	5.68	6.1
HW	0.43	70.05**	0.15	7.2
BY	14254.10	5873050.00**	71461.00	8.3
GY	30120.00	810450.00**	32493.00	9.8
HI%	6.42	280.30**	14.11	8.3

Table 6. Mean squares of traits of Kabuli chickpea in the *Legambo* area in the second season

Traits	Rep.(df=2)	Genotype(df=12)	Error(df=24)	CV
DF	1.52	21.70**	0.64	3.8
PB	0.02	4.60**	0.03	7.2
SB	0.05	16.80**	0.17	8.6
PH	3.31	152.70**	0.37	4.8
PP	0.16	1126.22**	1.12	6.6
SPl	6.23	5437.76**	6.12	5.7
HW	0.23	61.04**	0.10	6.3
BY	12761.00	5429572.00**	76231.00	7.4
GY	57464.00	1012120.00**	24302.00	8.9
HI%	17.45	321.33	18.46	10.6

Table 7. Nasty squares of traits of Kabuli chickpea varieties across locations in the second season

Traits	Rep. (df=2)	Genotype (df=12)	Location (df=1)	Genotype. Location (df=12)	Error (df=50)	CV
DF	3.11	34.12**	461.32**	0.50*	0.30	6.7
PB	0.10	8.14**	7.21**	0.31**	0.06	8.7
SB	0.14	24.37**	0.21ns	2.12**	0.10	7.3
PH	7.62	231.31**	54.65**	0.43ns	0.43	6.4
PP	2.02	2301.20**	112.20	3.12ns	1.12	7.0
SPl	6.17	11201.12**	1250.20**	231.28**	6.01	7.2
HW	0.67	134.76**	10.01**	6.42**	0.12	5.1
BY	26210	11311342**	1002013**	1252**	252.3	9.4
GY	64457	1784009**	753602**	19570**	1716	10.8
HI%	18.12	520.10**	36.10ns	24.50ns	14.12	11.2

Days to flowering

Significant ($P \leq 0.01$) variation among varieties for days to flowering was observed at Wegdi during both growing seasons, indicating the presence of exploitable genetic variability for earliness. In the first season, the difference between the earliest and latest flowering varieties was 9 days, while an 8-day variation was recorded in the second season. These findings are consistent with previous reports that documented a narrow flowering range (38-47 days) among Kabuli chickpea genotypes [9]. Across seasons and locations, Qobo consistently exhibited early flowering while maintaining favorable yield performance, suggesting its potential use as a parent genotype for developing early-maturing and high-yielding Kabuli chickpea cultivars.

Primary branches per plant

The number of primary branches per plant differed significantly ($P \leq 0.01$) among varieties in both seasons at Wegdi, indicating strong genetic control of branching characteristics. In the first season, primary branches ranged from 6.0 to 8.0 per plant, whereas in the second season they ranged from 3.0 to 6.3, with an overall mean of 4.8. Qoqa and Akoso Dubie produced the highest number of primary branches, while Kasech recorded the lowest values. These results are consistent with previous findings that reported primary branch numbers ranging from 3 to 7 among chickpea varieties [16,20]. Increased branching may contribute to enhanced canopy development and yield potential through greater pod-bearing capacity.

Secondary branches per plant

Secondary branches per plant showed highly significant ($P \leq 0.01$) variation among varieties, demonstrating considerable genetic diversity for this trait. During the first season, the number of secondary branches ranged from 2.0 in Akoso Dubie to 10.0 in Qobo, with 60% of the varieties exceeding the grand mean. Similar significant differences were observed in the second season. The observed variation is comparable with previous reports of 3-9 secondary branches per plant among Kabuli chickpea genotypes [7]. Since secondary branches contribute directly to reproductive sites and pod formation, varieties with higher branching capacity may offer advantages for yield improvement.

Plant height

Plant height exhibited highly significant ($P \leq 0.01$) variation among Kabuli chickpea varieties at Wegdi in both seasons, indicating substantial genetic diversity for this trait. In the second season, plant height ranged from 45.7 to 66.3 cm, with a mean of 55.3 cm. Approximately 69% of the varieties recorded plant heights below the mean, while 31% exceeded it. Similar varietal performance was observed at Legambo, suggesting consistent genotype expression across environments. Plant height variation may reflect differences in genetic potential and adaptation to local growing conditions.

Pods per plant

Highly significant ($P \leq 0.01$) differences among varieties were observed for pods per plant at both Wegdi and Legambo during the two growing seasons. The significant variation indicates the presence of exploitable genetic variability for reproductive potential and yield improvement. Since pod number is a major yield component, varieties with higher pod production may contribute to enhanced grain yield. Similar variability for pods per plant among chickpea genotypes has been reported by previous studies [7].

Seeds per plant

Seeds per plant varied significantly ($P \leq 0.01$) among Kabuli chickpea varieties across locations and seasons, demonstrating substantial genetic variation for this important yield component. In the first season, seed number ranged from 12 to 136 seeds plant^{-1}, with Qobo and Qoqa producing the highest values, whereas Akoso Dubie recorded the lowest. In the second season, seed number ranged from 19.3 to 152 seeds plant^{-1}, with an overall mean of 79.7. The observed variation highlights the potential for improving grain yield through selection of genotypes with superior seed-setting ability.

Thousand seed weight

Thousand-seed weight differed significantly ($P \leq 0.01$) among varieties in both seasons, indicating considerable genetic variability for seed size. Genotypes with higher thousand-seed weight generally exhibited desirable market traits and contributed positively to yield performance. The observed variation is consistent with earlier findings, which reported thousand-seed weights ranging from 21 to 50 g among Kabuli chickpea genotypes [21]. The

substantial variation suggests opportunities for simultaneous improvement of seed size and grain yield through selection.

Grain yield

Grain yield exhibited highly significant ($P \leq 0.01$) differences among Kabuli chickpea varieties across locations and seasons, indicating substantial genetic variability for yield performance. The significant varietal differences suggest considerable opportunities for selection and genetic improvement of grain yield under the study environments. At Wegdi, grain yield ranged from 2,353 to 4,153 kg ha^{-1} in the first season and from 2,383 to 4,185 kg ha^{-1} in the second season. Qobo consistently produced the highest grain yield, followed by Kasech and Qoqa, whereas Akoso Dubie recorded the lowest yield in both seasons. In the first season, 31% of the evaluated varieties exceeded the grand mean yield (3,056 kg ha^{-1}), while 69% performed below the mean, reflecting substantial variation in yield potential among genotypes.

Similarly, significant variation in grain yield was observed at Legambo during both seasons. In the first season, grain yield ranged from 1,820 to 3,932 kg ha^{-1}, while in the second season it ranged from 1,920 to 4,032 kg ha^{-1}. Qobo, Kasech, and Qoqa were the highest-yielding varieties, whereas Akoso Dubie consistently produced the lowest yield. The superior and stable performance of Qobo across locations and seasons highlights its wide adaptation and potential for cultivation in the study areas. The observed yield variability is consistent with previous reports that documented grain yield ranges of 2,215–3,955 kg ha^{-1} [15] and 1,789-3,786 kg ha^{-1} [19] among Kabuli chickpea genotypes. The superior performance of Qobo, Kasech, and Qoqa suggests that these varieties possess favorable genetic attributes for grain production and could serve as promising candidates for cultivation and future breeding programs aimed at improving chickpea productivity.

Table 8. Mean performance of Kabuli chickpea varieties at *Wegdi* District in the first season

Geno.	DF	PB	SB	PH	PP	SPI	HW	BY	GY
Ak. D.	44^{e}	2.0^{g}	2.0^{i}	51^{bc}	15^{j}	17.3^{j}	47.7^{a}	6943^{e}	2353^{e}
Akuri	44^{e}	4.7^{cd}	6.0^{d}	45.3^{e}	46^{d}	89.3^{d}	36.3^{d}	9363^{bc}	3083^{c}
Chefe	43^{cd}	4.0^{e}	$5.3d^{g}$	41.7^{f}	25^{i}	28.0^{i}	35.0^{e}	7990^{d}	2813^{cd}
Dehara	46^{f}	4.0^{e}	5.3^{deg}	48.7^{d}	34^{f}	66.0^{f}	36.3^{e}	9178.7^{c}	2913^{c}
Enjer	43^{cd}	4.0^{ce}	6.0^{d}	50.3^{c}	31^{g}	60.7^{g}	30.0^{i}	9769^{ab}	2853^{cd}
Habru	42^{c}	4.0^{cde}	6.0^{de}	51^{bc}	39^{e}	77.3^{e}	38.0^{c}	9216.7^{c}	3040^{c}
Hora	39^{b}	4.7^{c}	5^{defg}	46.0^{e}	27^{h}	46.3^{h}	32.0^{h}	7703.3^{d}	2810^{cd}
Kasech	40^{b}	6.3^{a}	8.7^{b}	62.3^{a}	68^{b}	137^{c}	34^{ef}	9960.7^{a}	3839^{b}
Qobo	37^{a}	5.3^{b}	10.0^{a}	62.3^{a}	67^{b}	134^{c}	33.0^{g}	6382.3^{f}	4155^{a}
Qoqa	46^{f}	6.0^{a}	8.0^{c}	63.3^{a}	70^{a}	143^{b}	39.3^{b}	9053.0^{c}	3673^{b}
Shasho	44^{de}	3.7^{e}	6^{defg}	51^{bc}	51^{c}	150^{a}	28.0^{j}	5506.7^{g}	2803^{cd}
Teji	45^{e}	4.0^{cde}	6.0^{def}	48.0^{d}	24^{i}	26.3^{i}	34^{ef}	8028.7^{g}	2547^{de}
Yelbie	42^{e}	3.0^{f}	4.0^{h}	51.7^{b}	24^{i}	47.0^{h}	34^{f}	6830^{ef}	2850^{cd}
G_{mean}	43	4.3	6.0	51.3	40	78.7	35.2	8148.1	3056
CV	1.6	8.4	6.0	1.4	2.8	3.1	1.2	3.3	6.1
DMRT at 5%	1.3	0.61	0.61	1.18	1.88	4.1	0.71	454.25	313.9

Table 9. Mean performance of Kabuli chickpea varieties at *Legambo* District in the first season

Geno.	DF	PB	SB	PH	PP	SPl	HW	BY	GY
Ak. D.	50^{hi}	2^{e}	2^{i}	49^{b}	12^{j}	12^{j}	46^{a}	6689^{e}	1820^{e}
Akuri	49^{dfgh}	4^{c}	6^{de}	43^{d}	46^{d}	92^{d}	36^{ef}	9163^{bc}	2883^{c}
Chefe	47^{cd}	3^{d}	5.7^{de}	40^{e}	22^{hi}	23^{i}	37^{e}	7790^{d}	2613^{cd}
Dehara	51^{i}	3^{d}	4.3^{g}	47^{c}	31^{f}	61^{f}	36^{f}	8945^{c}	2713^{c}
Enjer	47^{cde}	3^{d}	5.3^{ef}	48^{b}	27^{g}	56^{g}	30^{j}	9535^{ab}	2653^{cd}
Habru	47^{cde}	3^{d}	5^{fg}	49^{b}	36^{e}	72^{e}	38^{d}	8917^{c}	2840^{c}
Hora	44^{b}	4^{c}	6.3^{d}	44^{d}	24^{h}	45^{h}	31^{i}	7470^{d}	2610^{cd}
Kasech	46^{c}	6^{a}	9^{bc}	62^{a}	67^{ab}	128^{b}	36^{f}	9767^{a}	3767^{ab}
Qobo	41^{a}	6^{a}	10^{a}	62^{a}	68^{a}	136^{a}	40^{b}	6172^{f}	3932^{a}
Qoqa	51^{i}	5^{a}	8.3^{c}	62^{a}	66^{b}	133^{a}	39^{c}	8820^{c}	3543^{b}
Shasho	48^{defg}	4^{c}	9.3^{ab}	49^{b}	49^{c}	97^{c}	29^{k}	5273^{g}	2763^{c}
Teji	50^{ghi}	3^{d}	5.7^{de}	46^{c}	21^{i}	21^{i}	35^{g}	7795^{d}	2347^{d}
Yelbie	48^{def}	2^{e}	3^{h}	48^{b}	21^{i}	42^{h}	33^{h}	6637^{ef}	2650^{cd}
G_{mean}	48	3.6	6.2	50	38	70.6	35.9	7921.1	2856
CV	1.9	6.3	7.0	1.5	2.8	3.6	0.9	3.5	6.0
DMRT at 5%	1.5	0.4	0.7	1.3	1.8	4.32	0.56	472.12	288.6

Table 10. Mean performance of Kabuli-type chickpea at *Wegdi* District in the second season

Geno.	DF	PB	SB	PH	PP	SPI	HW	BY	GY
Ak. D.	46^{e}	2.0^{g}	2.0^{i}	55^{bc}	18^{j}	19.3^{j}	49.7^{a}	6953^{e}	2383^{e}
Akuri	46^{e}	4.6^{cd}	6.0^{d}	49.3^{e}	49^{d}	91.3^{d}	38.3^{d}	9373^{bc}	3113^{c}
Chefe	45^{cd}	4.0^{e}	5.3^{dg}	45.7^{f}	28^{i}	30.0^{i}	37.0^{e}	7900^{d}	2843^{cd}
Dehara	48^{f}	4.0^{e}	5.3^{deg}	52.7^{d}	37^{f}	68.0^{f}	38.3^{e}	9188.7^{c}	2943^{c}
Enjer	45^{cd}	4.0^{ce}	6.0^{d}	54.3^{c}	34^{g}	62.7^{g}	32.0^{i}	9779^{ab}	2883^{cd}
Habru	45^{c}	4.0^{cde}	6.0^{de}	55^{bc}	42^{e}	79.3^{e}	40.0^{c}	9226.7^{c}	3070^{c}
Hora	41^{b}	4.6^{c}	5^{defg}	50.0^{e}	30^{h}	48.3^{h}	34.0^{h}	7713.3^{d}	2840^{cd}
Kasech	42^{b}	6.3^{a}	8.6^{b}	66.3^{a}	71^{b}	139^{c}	36^{ef}	9970.7^{a}	3869^{b}
Qobo	39^{a}	5.3^{b}	9.0^{a}	66.3^{a}	70^{b}	136^{c}	35.0^{g}	6392.3^{f}	4185^{a}
Qoqa	48^{f}	6.0^{a}	8.0^{c}	67.3^{a}	73^{a}	145^{b}	41.3^{b}	9063.0^{c}	3703^{b}
Shasho	46^{de}	3.7^{e}	6^{defg}	55^{bc}	54^{c}	152^{a}	30.0^{j}	5516.7^{g}	2833^{cd}
Teji	47^{e}	4.0^{cde}	6.0^{def}	52.0^{d}	28^{i}	28.3^{i}	36^{ef}	8038.7^{g}	2577^{de}
Yelbie	44^{e}	3.0^{f}	4.0^{h}	54.7^{b}	28^{i}	49.0^{h}	36^{f}	6840^{ef}	2880^{cd}
G_{mean}	46	4.8	6.0	55.3	45	79.7	37.2	8198.1	3186
CV	3.8	7.4	7.0	3.4	5.7	6.1	7.2	8.3	9.8
DMRT at 5%	1.3	0.61	0.61	1.18	1.88	4.1	0.71	454.25	313.9

Table 11. Mean performance of Kabuli chickpea at *Legambo* District in the second season

Geno.	DF	PB	SB	PH	PP	SPl	HW	BY	GY
Ak. D.	55^{hi}	3^{e}	3^{i}	59^{b}	14^{j}	13^{j}	50^{a}	6789^{e}	1920^{e}
Akuri	54^{dfgh}	5^{c}	7^{de}	53^{d}	48^{d}	10^{d}	40^{ef}	9263^{bc}	2983^{c}
Chefe	52^{cd}	4^{d}	6.7^{de}	50^{e}	24^{hi}	24^{i}	41^{e}	7890^{d}	2713^{cd}
Dehara	56^{i}	4^{d}	5.3^{g}	57^{c}	33^{f}	62^{f}	40^{f}	9045^{c}	2813^{c}
Enjer	52^{cde}	4^{d}	6.3^{ef}	58^{b}	29^{g}	57^{g}	34^{j}	9635^{ab}	2753^{cd}
Habru	52^{cde}	4^{d}	6^{fg}	59^{b}	38^{e}	73^{e}	42^{d}	9017^{c}	2940^{c}
Hora	49^{b}	5^{c}	7.3^{d}	54^{d}	26^{h}	46^{h}	35^{i}	7570^{d}	2710^{cd}
Kasech	51^{c}	7^{a}	10^{bc}	72^{a}	69^{ab}	129^{b}	40^{f}	9867^{a}	3867^{ab}
Qobo	46^{a}	7^{a}	11^{a}	72^{a}	70^{a}	137^{a}	44^{b}	6272^{f}	4032^{a}
Qoqa	56^{i}	6^{a}	9.3^{c}	72^{a}	68^{b}	134^{a}	43^{c}	8920^{c}	3643^{b}
Shasho	53^{defg}	5^{c}	11^{ab}	59^{b}	51^{c}	98^{c}	33^{k}	5373^{g}	2863^{c}
Teji	55^{ghi}	4^{d}	6.7^{de}	56^{c}	23^{i}	23^{i}	39^{g}	7895^{d}	2447^{d}
Yelbie	53^{def}	3^{e}	4^{h}	58^{b}	23^{i}	43^{h}	37^{h}	6737^{ef}	2750^{cd}
G_{mean}	53	6.6	8.2	63	45	72.6	38.9	8221.1	3156
CV	3.8	7.2	8.6	4.8	6.6	5.7	6.3	7.4	8.9
DMRT at 5%	1.5	0.4	0.7	1.3	1.8	4.32	0.56	472.12	288.6

Variance components and coefficients of variation

Substantial phenotypic and genotypic variation was observed among Kabuli chickpea varieties across locations and seasons, indicating the presence of considerable genetic diversity for the studied traits. In both seasons, biomass yield exhibited the highest phenotypic and genotypic variances, whereas the number of seeds per pod showed the lowest variance estimates (**Tables 12** to **17**). Across locations, genotype × environment interaction variance was generally low for most traits, suggesting relatively stable varietal performance across environments.

The phenotypic coefficient of variation (PCV) was consistently higher than the corresponding genotypic coefficient of variation (GCV) for all traits, indicating some environmental influence on trait expression. However, the small differences between PCV and GCV suggest that genetic factors accounted for most of the observed variation. According to [14] and [18], traits with GCV and PCV values exceeding 20% are considered highly variable. In the first season, plant height, thousand-seed weight, biomass yield, and grain yield exhibited moderate to high GCV and PCV values, indicating substantial variability and good prospects for genetic improvement through selection. Similarly, in the second season, high GCV and PCV values were recorded for seeds per plant, pods per plant, biomass yield, and grain yield, demonstrating the availability of exploitable genetic variation for these economically important traits.

Heritability estimates

Broad-sense heritability estimates were generally high across locations and seasons, ranging from approximately 83% to 99%, depending on the trait. High heritability (>80%) was recorded for days to flowering, days to maturity, primary and secondary branches per plant, plant height, pods per plant, seeds per pod, seeds per plant, thousand-seed weight, biomass yield, grain yield, and harvest index (**Tables 12-17**). These results indicate that a large proportion of the observed phenotypic variation was genetically controlled and could be effectively transmitted to subsequent generations.

The present findings are consistent with those of [16], who reported high heritability for major yield and yield-related traits in chickpea. According to Pramoda and Gangaprasad (2007), heritability values above 80% are classified as very high, confirming the strong genetic control of the studied traits. Therefore, direct phenotypic selection for these characters is likely to be effective in chickpea improvement programs.

Expected genetic advance

Genetic advance as a percentage of the mean (GAM) varied considerably among traits and environments. In both seasons and across locations, high GAM values (>20%) were observed for primary and secondary branches per plant, plant height, pods per plant, seeds per plant, thousand-seed weight, biomass yield, grain yield, and harvest index (**Tables 12–17**). In the second season, GAM ranged from 10.11% for days to maturity to 124.40% for seeds per plant, indicating substantial opportunities for genetic gain through selection. The combination of high heritability and high genetic advance for yield and yield-related traits suggests the predominance of additive gene action. This implies that selection based on phenotypic performance would be effective for improving grain yield, biomass production, seed size, and related agronomic traits. Consequently, these traits can be considered reliable selection criteria in Kabuli chickpea breeding programs aimed at enhancing productivity and adaptation.

Table 12. Phenomics and genomic variance and constant of deviation, heritability, and genetic advance for traits of Kabuli chickpea varieties at Wegdi District in the first season

Trait	σ_p^2	σ_g^2	σ_e^2	PCV	GCV	H^2	GA	GAM
DF	7.22	6.75	0.47	6.29	6.08	93.49	5.14	12.04
DM	28.57	27.3	1.27	6.17	5.05	95.55	10.44	10.10
PB	1.44	1.3	0.13	27.9	26.52	90.28	2.22	51.63
SB	4.13	4	0.13	33.87	33.33	96.85	4.05	67.44
PH	47.04	46.55	0.49	13.37	13.30	98.90	13.95	27.18
PP	355.3	354.1	1.24	47.01	46.93	99.66	38.62	47.78
SP	0.18	0.15	0.03	22.33	20.38	83.33	0.73	38.24
SPl	2290.6	2284.75	5.88	60.81	60.74	99.74	98.14	124.70
HW	23.34	23.16	0.18	13.72	13.67	99.23	9.86	28.00
BY	2042791	1970130	72661	17.54	17.23	96.44	2833.91	34.78
GY	293349	258655	34694	17.72	16.64	88.17	981.83	32.13

Table 13. Phenotypically and genotypic deviation and constant of deviation, heritability, and genomic advance for traits of Kabuli chickpea varieties in the first season at *Legambo* District

Traits	σ_p^2	σ_g^2	σ_e^2	PCV	GCV	H^2	GA	GAM
DF	8.43	7.65	0.78	6.10	5.60	90.75	5.42	11.36
DM	37.60	30.91	6.69	5.68	5.15	82.21	10.36	9.60
PB	1.63	1.58	0.05	35.46	34.92	96.93	2.54	70.68
SB	6.05	5.84	0.19	39.67	38.98	96.53	4.88	78.74
PH	54.63	54.08	0.55	14.78	14.71	98.99	15.04	30.09
PP	382.82	381.72	1.10	51.90	51.82	99.71	40.11	106.39
SP	0.23	0.2	0.03	26.64	24.85	86.96	85.74	47.64
SPl	1883.62	1877.08	6.56	61.47	6137	99.63	88.90	125.92
HW	21.10	20.99	0.11	12.80	12.76	99.48	9.39	26.17
BY	2042191	1963700	78491	18.04	17.69	96.16	2825.3	35.67
WY	354923	325600	29323	20.86	19.98	91.74	1123.69	39.35
HI%	124.82	105.25	19.57	30.20	27.73	84.32	19.37	52.35

Table 14. Phenotypically and genotypic deviation and constant of deviation, heritability, and genomic advance for traits of Kabuli chickpea in the first season across the two locations

Traits	σ_{gl}^2	σ_p^2	σ_g^2	σ_e^2	PCV	GCV	H^2	GA	GAM
DF	0.1	7.36	7.26	0.31	6.0	5.96	98.6	5.5	12.17
DM	0.65	29.46	28.48	3.9	5.12	5.03	96.7	10.79	10.1
PB	0.14	1.4	1.31	0.09	29.58	28.6	93.6	2.27	56.75
SB	0.71	4.6	4.22	0.15	35.7	34.2	91.7	4.04	67.4
PH	0.04	58.38	50.28	0.5	15.0	13.9	86.1	13.5	26.6
PP	0.77	367.71	367.13	1.15	49.3	49.2	99.8	39.35	101
SP	0.03	0.168	0.15	0.02	22.8	21.5	89.3	0.75	41.8
SPl	93.9	2035.1	1987.1	6.09	60.6	59.8	97.6	90.5	121
HW	2.20	20.89	19.87	0.14	12.9	12.6	95.1	8.94	25.2
BY	344.9	1991891	1991676	257.3	17.6	17.5	99.9	2898.8	36.1
GY	6011	299501	296206	1739	18.5	18.4	98.8	111.7	37.6
HI%	3.18	103.4	98.93	16.98	26.8	26.2	95.7	20	5.0

Table 15. Phenotypically and genotypic deviation and constant of deviation, heritability, and genomic advance for traits of Kabuli chickpea varieties in the first season across the two locations in the second season at Wegdi District

Trait	σ_p^2	σ_g^2	σ_e^2	PCV	GCV	H^2	GA	GAM
DF	9.22	8.75	0.37	6.39	6.18	93.09	5.04	12.14
DM	30.57	29.3	1.17	6.18	5.06	95.56	10.45	10.11
PB	1.74	1.6	0.03	28.0	26.62	90.20	2.21	51.23
SB	4.33	4.3	0.04	33.88	33.34	96.86	4.06	67.45
PH	48.04	47.55	0.46	13.47	13.40	98.98	13.95	27.18
PP	375.3	374.1	1.04	47.21	46.95	99.86	38.82	47.88
SP	0.28	0.25	0.03	22.35	20.40	83.35	0.74	38.23
SPl	2590.6	2584.75	5.08	60.71	60.64	99.64	98.04	124.40
HW	24.34	24.16	0.08	13.73	13.69	99.25	9.87	28.02
BY	2042991	1970330	72641	17.64	17.24	96.54	2833.65	34.88
GY	293359	258665	34690	17.62	16.54	88.08	981.80	32.03

Table 16. Genotypic and phenotypically and deviation and constant of deviation, heritability, and genomic advance for traits of Kabuli chickpea varieties at *Legambo* District in the second season

Traits	σ_p^2	σ_g^2	σ_e^2	PCV	GCV	H^2	GA	GAM
DF	8.63	7.85	0.68	6.10	5.60	90.75	5.42	11.36
DM	38.60	30.81	6.09	5.68	5.15	82.21	10.36	9.60
PB	2.63	2.58	0.15	35.46	34.92	96.93	2.54	70.68
SB	6.05	5.84	0.19	38.67	37.98	96.03	4.08	78.70
PH	55.63	55.08	0.55	14.78	14.71	98.99	15.04	30.09
PP	380.82	380.72	1.00	52.90	52.82	96.71	40.01	104.39
SP	0.43	0.4	0.03	26.60	24.75	86.26	85.71	47.54
SPl	1893.62	1887.08	6.06	60.47	61.35	95.60	87.10	120.92
HW	22.10	21.99	0.11	13.80	12.96	97.48	9.36	26.07
BY	2042291	1963800	78471	18.14	17.89	94.16	2815.3	35.40
WY	354943	325630	29303	20.66	19.78	91.64	1123.61	39.32
HI%	127.82	106.25	19.58	31.20	27.95	86.30	19.07	52.31

Table 17. Genotypic and phenotypically and deviation and constant of deviation, heritability, and genomic advance for traits of Kabuli chickpea across the two locations in the second season

Traits	σ_{gl}^2	σ_p^2	σ_g^2	σ_e^2	PCV	GCV	H^2	GA	GAM
DF	0.3	7.46	7.35	0.11	6.0	5.96	98.6	5.5	12.17
DM	0.65	28.36	28.18	3.5	5.12	5.03	96.7	10.70	10.1
PB	0.13	1.4	1.30	0.07	29.58	28.6	91.6	2.27	56.75
SB	0.72	4.8	4.23	0.12	35.7	34.2	90.7	4.04	67.4
PH	0.07	58.39	50.29	0.3	15.0	13.9	86.1	13.5	26.6
PP	0.79	365.71	364.13	1.12	49.3	49.2	93.8	38.35	101
SP	0.03	0.128	0.25	0.02	22.8	21.5	89.3	0.75	41.8
SPl	94.9	2036.1	1988.1	6.03	60.1	59.8	97.6	90.5	121
HW	2.30	20.99	19.97	0.12	12.9	12.6	95.1	8.94	25.2
BY	343.9	1991871	1991656	254.3	17.6	17.5	90.9	2878.8	36.1
GY	6021	299521	296226	1730	18.5	18.4	82.8	111.7	37.6
HI%	3.08	102.4	97.93	16.12	25.8	24.2	89.8	20	5.0

Correlation of yield with yield-related traits

Seed yield is a complex trait and is formed by the effect of numerous multiple traits. Therefore, understanding inheritance and the relation of seed yield and yield-related traits influencing these traits is highly important for formulating selection criteria. At the Phenomics neck and neck, grain yield was muscularly positive and expressively associated with the number of primary and secondary branches per plant, plant height, the number of pods per plant, the number of grains per pod and plant, and the harvest index in the first season (**Tables 18** and **19**). In the second season, at the phenotypic and genotypic level, seed yield was strongly positive and significantly correlated with most traits at the *Wegdi* location (**Table 20**).

Similarly, at Legambo District, at the phenotypic and genotypic level, seed yield was strongly positive and significantly correlated with most traits in the se cond season (**Table 21**).

Table 18. Genotypic (overhead diagonal) and phenotypic (under diagonal) association constants of traits of Kabuli chickpea at *Wegdi* District in the first season

	DF	PB	SB	PH	PP	SPl	HW	BY	GY
DF	1	-0.68*	0.88**	-0.78*	-0.79*	-0.76*	0.88**	0.85**	0.89**
PB	-0.3*	1	0.98**	0.87**	0.91**	0.85**	0.64*	0.46^{ns}	0.96**
SB	0.2*	0.85**	1	0.85**	0.96**	0.89**	0.66*	0.65*	0.93**
PH	-0.24^{ns}	0.56**	0.64**	1	0.87**	0.78**	0.12^{ns}	0.21^{ns}	0.85**
PP	0.24^{ns}	0.81**	0.86**	0.78**	1	0.98**	-0.32^{ns}	0.56^{ns}	0.97**
SPl	0.19^{ns}	0.66**	0.73**	0.72**	0.94**	1	0.64*	0.67*	0.93**
HW	0.33*	-0.30^{ns}	-0.40*	0.09^{ns}	-0.20^{ns}	0.32*	1	0.46^{ns}	0.94**
BY	0.24^{ns}	0.43**	0.22^{ns}	0.03^{ns}	0.15^{ns}	0.01^{ns}	0.11^{ns}	1	0.35^{ns}
GY	0.47**	0.77**	0.87**	0.75**	0.87**	0.74**	-0.16^{ns}	0.15^{ns}	1

Table 19. Genomic (overhead crosswise) and phenotypic (under crosswise) association constants of characters of Kabuli chickpea at *Legambo* District in the first season

	DF	PB	SB	PH	PP	SPl	HW	BY	WY
DF	1	-0.67*	-0.65*	-0.70*	0.86**	-0.74*	0.87**	0.83**	-0.80*
PB	0.50**	1	0.98**	0.87**	0.76*	0.64*	0.85**	0.89**	0.92**
SB	-0.40**	0.89**	1	0.65*	0.97**	0.45^{ns}	-0.78*	-0.80*	0.89**
PH	-0.20^{ns}	0.71**	0.57**	1	0.98**	0.87**	0.43^{ns}	0.82**	0.43^{ns}
PP	-0.30^{ns}	0.93**	0.85**	0.80**	1	0.93**	0.54^{ns}	0.65*	0.82**
SPl	-0.30^{ns}	0.89**	0.80**	0.80**	0.98**	1	-0.60^{ns}	0.43^{ns}	0.97**
HW	0.10^{ns}	0.01^{ns}	-0.30^{ns}	0.30^{ns}	0.03^{ns}	-0.02^{ns}	1	-0.70*	0.87**
BY	0.25^{ns}	0.11^{ns}	-0.10^{ns}	0.10^{ns}	0.14^{ns}	0.14^{ns}	-0.01^{ns}	1	0.76*
GY	-0.50**	0.88**	0.77^{ns}	0.70**	0.90**	0.89**	-0.02^{ns}	0.18^{ns}	1

Table 20. Genomic (overhead crosswise) and phenotypic (under crosswise) association constants of characters of Kabuli chickpea at *Wegdi* District in the second season

	DF	PB	SB	PH	PP	SPl	HW	BY	GY
DF	1	-0.58*	0.98**	-0.58*	-0.89*	-0.79*	0.98**	0.88**	0.79**
PB	-0.30*	1	0.68**	0.86**	0.90**	0.95**	0.65*	0.36^{ns}	0.96**
SB	0.64**	0.85**	1	0.85**	0.96**	0.99**	0.66*	0.75*	0.93**
PH	-0.34^{ns}	0.56**	0.64**	1	0.87**	0.78**	0.12^{ns}	0.21^{ns}	0.85**
PP	0.24^{ns}	0.81**	0.86**	0.78**	1	0.98**	-0.32^{ns}	0.56^{ns}	0.97**
SPl	0.09^{ns}	0.66**	0.73**	0.72**	0.94**	1	0.65*	0.67*	0.94**
HW	0.03*	0.30^{ns}	0.40*	0.09^{ns}	-0.20^{ns}	0.32*	1	0.46^{ns}	0.94**
BY	0.14^{ns}	0.43**	0.22^{ns}	0.03^{ns}	0.15^{ns}	0.01^{ns}	0.11^{ns}	1	0.35^{ns}
GY	0.67**	0.77**	0.87**	0.75**	0.87**	0.64**	0.16^{ns}	0.15^{ns}	1

Table 21. Genomic (overhead crosswise) and phenotypic (under crosswise) association constants of characters of Kabuli chickpea at *Legambo* District in the second season

	DF	PB	SB	PH	PP	SPl	HW	BY	WY
DF	1	-0.59*	-0.75*	-0.6*	0.86**	-0.76*	0.97**	0.86**	-0.8*
PB	-0.5**	1	0.78**	0.87**	0.76*	0.64*	0.85**	0.89**	0.92**
SB	-0.5**	0.79**	1	0.65*	0.87**	0.45^{ns}	-0.68*	-0.80*	0.97**
PH	-0.2^{ns}	0.71**	0.57**	1	0.78**	0.87**	0.23^{ns}	0.82**	0.43^{ns}
PP	-0.3^{ns}	0.93**	0.85**	0.8**	1	0.93**	0.54^{ns}	0.65*	0.82**
SPl	-0.30^{ns}	0.89**	0.80**	0.80**	0.98**	1	-0.60*	0.43^{ns}	0.97**
HW	0.10^{ns}	0.01^{ns}	-0.3^{ns}	0.3^{ns}	0.03^{ns}	-0.02^{ns}	1	-0.7*	0.87**
BY	0.05^{ns}	0.01^{ns}	-0.10^{ns}	0.10^{ns}	0.14^{ns}	0.14^{ns}	-0.01^{ns}	1	0.76*
GY	-0.3^{ns}	0.88**	0.77**	0.76**	0.90**	0.89**	-0.02^{ns}	0.18^{ns}	1

Path coefficient analysis

Genotypic and phenotypic path coefficient analysis was used to decide yield attributes by estimating the direct effects of characters contributing to grain yield. Path coefficient analysis was separating direct effects from the indirect effects through other related characters by separating the correlation coefficient and searching out the relative characters as selection criteria.

Table 22. Appraisal of indirect effects (off-diagonal) and direct effect (boldface) at the phenotypic level in Kabuli chickpea varieties at *Wegdi* District in the first season

	DF	PB	SB	PH	PP	SPI	HW	BY	GY
DF	**0.07**	0.02	0.01	-0.04	0.03	0.03	0.04	0.02	**0.71****
PB	0.03	**0.52**	0.07	0.01	0.02	0.04	0.06	0.05	**0.85****
SB	0.08	0.07	**0.75**	0.02	-0.07	-0.06	0.03	0.08	**0.86****
HP	0.06	0.03	0.04	**0.04**	0.02	0.06	-0.04	0.03	**-0.45***
PP	0.04	-0.05	-0.03	0.04	**-0.08**	0.02	0.03	0.06	**0.34***
SPl	0.06	0.03	0.04	0.06	0.03	**0.08**	0.04	0.07	**0.76****
HW	0.07	0.05	0.04	0.03	0.07	0.06	**0.05**	0.04	**0.25***
BY	0.05	-0.06	0.02	0.04	0.05	0.03	-0.06	**0.04**	**0.67****

Residual value =0.12

Table 23. Appraisal of subsidiary effects (off-crosswise) and directs effects (boldface) at the phenotypic level in Kabuli chickpea varieties at *Wegdi* District in the second

	DF	PB	SB	PH	PP	SPI	HW	BY	GY
DF	**0.09**	0.02	0.01	-0.04	0.02	0.03	0.05	0.03	**0.81****
PB	0.04	**0.53**	0.07	0.01	0.02	0.04	0.06	0.05	**0.87****
SB	0.06	0.07	**0.76**	0.02	-0.07	-0.06	0.03	0.08	**0.96****
HP	0.06	0.03	0.04	**0.05**	0.02	0.06	-0.04	0.03	**-0.48***
PP	0.04	-0.05	-0.03	0.04	**-0.07**	0.02	0.03	0.06	**0.54***
SPl	0.07	0.04	0.04	0.05	0.03	**0.09**	0.04	0.07	**0.78****
HW	0.08	0.05	0.04	0.03	0.07	0.06	**0.06**	0.04	**0.35***
BY	0.05	-0.06	0.02	0.04	0.05	0.03	-0.06	**0.03**	**0.87****

Residual value =0.13

Phenotypic straight and indirect effects of appeals on kernels yield

In the first and second seasons, at the study area, all traits had a great phenotypic direct effect on the grain yield of Kabuli chickpea that directed the association between these characters as good contributors to grain yield, respectively, at *Wegdi* District (**Tables 22** and **23**).

Table 24. Appraisal of indirect effects (off-crosswise) and directs effect (boldface) at the genotypic level in Kabuli chickpea varieties tested at the *Wegdi* location in the first season

	DF	PB	SB	PH	PP	SPl	HW	BY	GY
DF	**-0.02**	0.75	-0.09	0.08	0.68	0.08	0.76	0.08	**0.39***
PB	0.07	**0.69**	-0.07	0.07	0.07	-0.08	0.05	0.07	**0.93****
SB	0.14	0.06	**0.08**	0.76	0.08	0.09	0.65	0.09	**0.65****
PH	0.07	0.03	0.06	**0.06**	0.08	0.77	0.08	0.04	**0.47***
PP	0.06	0.09	0.08	0.09	**0.07**	0.67	0.08	0.44	**0.58****
SPl	0.07	0.09	0.13	0.09	0.04	**0.64**	0.74	0.74	**0.87****
HW	0.08	0.25	0.05	0.07	0.08	0.04	**0.09**	0.32	**0.52****
BY	0.05	0.08	0.03	0.07	0.04	0.64	0.04	**0.74**	**0.87****

Residual value = 0.03

Table 25. Genotypic Path Analysis of Direct (boldface) and Indirect Trait Effects in Kabuli Chickpea Varieties at Wegdi, Second Season

	DF	PB	SB	PH	PP	SPl	HW	BY	GY
DF	**-0.04**	0.75	-0.09	0.08	0.68	0.08	0.76	0.08	**0.48***
PB	0.07	**0.70**	-0.07	0.07	0.07	-0.08	0.05	0.07	**0.96****
SB	0.14	0.06	**0.07**	0.76	0.08	0.09	0.65	0.09	**0.76****
PH	0.07	0.03	0.06	**0.08**	0.08	0.77	0.08	0.04	**0.57***
PP	0.06	0.09	0.08	0.09	**0.09**	0.67	0.08	0.44	**0.68****
SPl	0.07	0.09	0.13	0.09	0.04	**0.84**	0.74	0.74	**0.88****
HW	0.08	0.25	0.05	0.07	0.08	0.04	**0.08**	0.32	**0.62****
BY	0.05	0.08	0.03	0.07	0.04	0.64	0.04	**0.75**	**0.89****

Residual value = 0.04

Genotypic straight and indirect effects of behaviors on kernels yield

In the first and the second season, at the study area, the genotypic direct and indirect effects of traits on grain yield were presented in **Table 24** and **25**. Biomass yield (0.74), followed by primary branch (0.69), seed per plant (0.64), days to maturity (0.59), secondary branch (0.08), plant height (0.06), pods per plant (0.07), hundred seed weight (0.09), and harvest index (0.04), exerted a positive direct effect on grain yield. In agreement with the present study, (15) reported for hundred seed weight, days to maturity, primary branch, and harvest index. However, days to flowering (-0.02) had a negative direct effect on grain yield. Hundred seed weight showed highly significant positive genotypic correlations and considerable positive direct effect on grain yield. In the first and the second season, at the study area, the genotypic indirect and direct effects of traits on grain yield were indicated (**Tables 26** and **27**).

Table 26. Phenotypic Path Coefficients Showing Direct (boldface) and Indirect Trait Effects in Kabuli Chickpea at Legambo District (First Season)

	DF	PB	SB	PH	PP	SPI	HW	BY	GY
DF	**0.06**	0.02	0.04	-0.03	0.02	0.03	0.05	0.03	**0.61****
PB	0.04	**0.66**	0.06	0.04	0.03	0.04	0.05	0.04	**0.75****
SB	0.07	0.06	**0.85**	0.03	-0.06	-0.07	0.03	0.07	**0.76****
HP	0.05	0.03	0.04	**0.64**	0.05	0.05	-0.04	0.05	**-0.46***
PP	0.04	-0.05	-0.04	0.04	**-0.09**	0.05	0.03	0.05	**0.44***
SPl	0.05	0.02	0.05	0.06	0.03	**0.07**	0.04	0.06	**0.86****
HW	0.07	0.06	0.04	0.03	0.07	0.06	**0.05**	0.04	**0.35***
BY	0.04	-0.06	0.03	0.04	0.05	0.03	-0.07	**0.04**	**0.77****

Residual value = 0.05

Table 27. Phenotypic Path Coefficients Showing Direct (boldface) and Indirect Trait Effects in Kabuli Chickpea at Legambo District During the Second Season

	DF	PB	SB	PH	PP	SPI	HW	BY	GY
DF	**0.07**	0.02	0.04	-0.04	0.02	0.03	0.05	0.03	**0.66****
PB	0.05	**0.75**	0.06	0.04	0.03	0.04	0.05	0.04	**0.95****
SB	0.07	0.06	**0.92**	0.03	-0.06	-0.07	0.03	0.07	**0.78****
HP	0.05	0.03	0.04	**0.74**	0.05	0.05	-0.04	0.05	**-0.56***
PP	0.05	-0.05	-0.04	0.04	**-0.09**	0.05	0.03	0.05	**0.64***
SPl	0.07	0.02	0.05	0.06	0.03	**0.08**	0.04	0.06	**0.86****
HW	0.07	0.06	0.04	0.03	0.07	0.06	**0.06**	0.04	**0.65***
BY	0.05	-0.06	0.03	0.04	0.05	0.03	-0.07	**0.05**	**0.87****

Residual value = 0.07

Phenotypic straight and indirect effects of behaviors on kernels yield

At the study area, secondary branch per plant (0.85) and primary branch per plant (0.66) had a great phenotypic direct effect on the grain yield of Kabuli chickpea that directed the association between these characters as good contributors to grain yield at the Legambo location (**Table 26**).

Table 28: Appraisal of indirect effects (off-crosswise) and straight effect (boldface) at the genotypic level in Kabuli chickpea at the *Legambo* location in the first season

	DF	PB	SB	PH	PP	SPl	HW	BY	GY
DF	**-0.03**	0.07	-0.08	0.06	0.08	0.06	0.07	0.08	**0.49***
PB	0.08	**0.69**	-0.07	0.06	0.05	-0.08	0.05	0.09	**0.83****
SB	0.04	0.06	**0.08**	0.07	0.09	0.08	0.65	0.09	**0.75****
PH	0.05	0.04	0.07	**0.09**	0.08	0.07	0.08	0.04	**0.57***
PP	0.05	0.08	0.06	0.07	**0.06**	0.06	0.05	0.04	**0.68****
SPl	0.06	0.09	0.03	0.08	0.06	**0.65**	0.76	0.04	**0.85****
HW	0.04	0.05	0.06	0.07	0.08	0.04	**0.09**	0.02	**0.58****
BY	0.06	0.07	0.04	0.08	0.04	0.04	0.05	**0.74**	**0.77****

Residual value = 0.06

Table 29. Appraisals of indirect effects (off-crosswise) and straight effects (boldface) at the genotypic level in Kabuli chickpea at the *Legambo* location in the second season

	DF	PB	SB	PH	PP	SPl	HW	BY	GY
DF	**-0.05**	0.08	-0.09	0.06	0.08	0.08	0.07	0.09	**0.58***
PB	0.07	**0.68**	-0.07	0.06	0.05	-0.08	0.05	0.09	**0.84****
SB	0.04	0.06	**0.09**	0.07	0.09	0.08	0.65	0.09	**0.78****
PH	0.06	0.04	0.07	**0.09**	0.08	0.07	0.08	0.04	**0.67***
PP	0.07	0.08	0.06	0.07	**0.07**	0.06	0.05	0.04	**0.67****
SPl	0.06	0.09	0.03	0.08	0.06	**0.75**	0.76	0.04	**0.87****
HW	0.04	0.05	0.06	0.08	0.07	0.04	**0.09**	0.02	**0.68****
BY	0.06	0.07	0.04	0.08	0.04	0.04	0.05	**0.76**	**0.87****

Residual value = 0.05

Genotypic straight and indirect effects of behaviors on kernels yield

In the first and the second season, at the study area, the genotypic direct and indirect effects of traits on grain yield were presented (Table 28 and 29). Days to maturity (0.79), followed by biomass (0.74), primary branch (0.69), and seed per plant (0.65), exerted a positive direct effect on grain yield.

Conclusion

The present study revealed substantial genetic variability among Kabuli chickpea varieties for grain yield and yield-related traits across Wegdi and Legambo districts during the two cropping seasons. Significant differences among genotypes, coupled with high heritability and genetic advance estimates for several agronomic traits, indicated considerable potential for genetic improvement through selection. The relatively high genotypic and phenotypic coefficients of variation observed for grain yield, biomass yield, seed number per plant, and pod number per plant further confirmed the existence of exploitable genetic variation.

Among the evaluated genotypes, Qobo consistently produced the highest grain yield across locations and seasons, followed by Kasech, Qoqa, and Akuri. These varieties demonstrated superior yield performance, adaptability, and desirable agronomic characteristics under the study environments. Therefore, Qobo, Kasech, Qoqa, and Akuri are recommended for cultivation, seed multiplication, and dissemination in the study areas and similar agro-ecological zones. Furthermore, these varieties can serve as valuable parental materials in future Kabuli chickpea breeding programs aimed at improving grain yield and related agronomic traits.

References

[1] Athwal DS and Brar HS. Genetics of some mutants in Cicer arietinum L. Journal of Research Punjab Agricultural University. 1964;1:129-134.

[2] Basha S, Jayalakshmi V, Ahammed S, Kamakshi N. Studies on growth and yield characters of chickpea (Cicer arietinum L.) varieties suitable for mechanical harvesting. Tropical Plant Research 2020;7(3):634-637.

[3] Chala B, Abera T, Nandeshwar B. Influence of Inter and Intra Row Spacing on Yield and Yield Components of Chickpea (Cicer arietinum L.) in Jimma Horro District, Western Ethiopia. International Journal of Plant & Soil Science 2020;16(5):32-42.

[4] Cobos M, Izquierdo I, Sanz M, Tomás A, Gil J, Flores F, Rubio J. Genotype and environment effects on sensory, nutritional, and physical traits in chickpea (Cicer arietinum L.). Spanish Journal of Agricultural Research 2016;14(4):e0709.

[5] Wolday K, Teklu A. Response of Chickpea (Cicier Arietinium L.) to Rhizobium Inoculation and Blended fertilizer Rates in Laelay Maichew, Central Zone of Tigray, Northern Ethiopia. Agricultural Science 2020;2(2):122-128.

[6] Joshi M, Aggarwal D, Sanyal A. Cultivar identification and diversity analysis based on morphological descriptors and image analysis in chickpea (Cicer arietinum L.). Legume Research 2017;41(5):647–655.

[7] Kumar P, Prajapat O, and Parihar R. Effect of different levels of phosphorus, sulfur, and cultivars on growth and economics of chickpea (Cicer arietinum L.). Int. J.Farm Sci. 2017;7:57–59.

[8] Kumawat S, Babbar A, Solanki R, Biswal M, Banjarey P. Morphological Characterization of Elite Kabuli Chickpea Lines. International Journal of Current Microbiology and Applied Sciences 2020;9(9):1241-1250.

[9] Madhuri R, Jayalakshmi V. Identification of high yielding mechanical harvestable chickpea (Cicer arietinum L.) genotypes under rainfed and irrigated conditions. International Journal of Chemical Studies 2020;8(1):368-375.

[10] Maheri-sis N, Chamani M, Sadeghi A, Aghazadeh AM. Nutritional evaluation of kabuli and desi type chickpeas (cicer arietinum L .) for ruminants using in vitro gas production technique. African Journal of Biotechnology 2008;7(16):2946–2951.

[11] Mannur D, Babbar A, Thudi M, Sabbavarapu M, Roorkiwal M, Yeri S, Bansal V, Jayalakshmi S, Singh Yadav S, Rathore A, Chamarthi S, Mallikarjuna B, Gaur P, Varshney R. Super Annigeri 1 and improved JG 74: two Fusarium wilt-resistant introgression lines developed using marker-assisted backcrossing approach in chickpea (Cicer arietinum L.). Molecular Breeding 2018;39(1).

[12] Maqbool MA, Aslam M, Ali H, Shah TM. Evaluation of advanced chickpea (Cicer Arietinum L.) accessions based on drought tolerance indices and SSR markers against different water treatments. Pakistan Journal of Botany 2016;48(4):1421–1429.

[13] Mekuanint T, Tsehaye Y, Egziabher Y. Response of Two Chickpea (Cicer arietinum L.) Varieties to Rates of Blended Fertilizer and Row Spacing at Tselemti District, Northern Ethiopia. Advances in Agriculture 2018;2018:1-8.

[14] Ruth Muruiki, Paul Kimurto, Vincent Vandez, Rao Gangarao, Said Silim, Moses Siambi. Effect of Drought Stress on Yield Performance of Parental Chickpea Genotypes in Semi-arid Tropics. Journal of Life Sciences 2018;12(3):159-168.

[15] Michaelson L, Napier J, Molino D, Faure J. Plant sphingolipids: Their importance in cellular organization and adaption. Biochimica et Biophysica Acta (BBA) - Molecular and Cell Biology of Lipids 2016;1861(9):1329-1335.

[16] Panda D, Bhakta R, Chauhan D. Association analysis in Kabuli chickpea (Cicer arietinum L.). Journal of Applied and Natural Science 2022;14(SI):36-40.

[17] Purushothaman R, Upadhyaya H, Gaur P, Gowda C, Krishnamurthy L. Kabuli and desi chickpeas differ in their requirement for reproductive duration. Field Crops Research 2014;163:24-31.

[18] Rashid K, Akhtar M, Cheema KL, Rasool I, Zahid A, Hussain A, Aqeel M, Anwar SA, Amin M, Qadeer Z, Khalid MJ. Development of selection criteria for assessment of chickpea (Cicer arientum L.) on physio-morphic attributes under drought stress at seedling stage and maturity. Plant Cell Biotechnology and Molecular Biology 2021;22(3–4):98–109.

[19] Johnson N, Johnson C, Thavarajah P, Kumar S, Thavarajah D. The roles and potential of lentil prebiotic carbohydrates in human and plant health. Plants People Planet 2020;2(4):310-319.

[20] Sarwar N, Akhtar KP, Shah TM, Atta BM. Evaluation of chickpea advance genotypes against blight and wilt diseases under field conditions. International Journal of Agriculture and Biology 2012;14(6):993–996.

[21] Pal V, Singh G, Dhaliwal S. Agronomic biofortification of chickpea with zinc and iron through application of zinc and urea. Communications in Soil Science and Plant Analysis 2019;50(15):1864-1877.