

# Assessing Genetic Variability and Heritability in Garlic (*Allium sativum* L.) Genotypes for Bulb Yield and Related Traits

## Abstract

One of the fundamental goals of plant breeding is to evaluate genetic diversity in crop species, which aids in the development of breeding approaches. Therefore, this field experiment was conducted to assess mean performance, the genetic variability in garlic genotypes on bulb yield and related traits. The field evaluation of nineteen garlic genotypes and one released variety HL was conducted at Kulumsa Agricultural Research Center using a randomized complete block design with three replications during the main growing season of 2020 and 2021. The analysis of variance indicated there were significant differences among the genotypes for all traits except day of physiological maturity in 2020 season, while only some growth and yield traits are significant in 2021 production season. Some of the genotypes GOG-065/18, GOG-057/18, GOG-047/18, GOG-064/18, GOG-068/18, GOG-045/18, and GOG-018/18 had mean performances higher than the standard check variety HL. The highest significant bulb yield was observed on the genotype G-067/18 ( $9.63 \text{ t ha}^{-1}$ ) and GOG-057/18 ( $9.90 \text{ t ha}^{-1}$ ) in 2020 and 2021 season respectively. Highest phenotypic (PCV) and genotypic (GCV) coefficients of variation recorded for total bulb yield, tons per hectare and number of cloves per bulb, while the day of physiological maturity had the lowest heritability ( $h^2_b$ ) in broad sense and genetic advance as a percent of mean (GAM), 67% and 33.89% (total bulb yield per hectare) and 1.13% to 0.08% (day of physiological maturity) respectively. High phenotypic and genotypic coefficients of variation coupled with high heritability and genetic advance as a percent of mean were observed for total bulb yield, tons per hectare, number of cloves per bulb and clove-cloves per bulb and clove-weight. Therefore, selection for these characters would be effective for selecting genotypes for future garlic breeding programs.

**Keywords:** Bulb yield, Genetic variability, GCV, PCV, Mean performance

## 1. INTRODUCTION

Gar-

lic (*Allium sativum* L.) is a bulbous perennial crop cultivated in different temperate and subtropical climates all over the

world [13]. It belongs to the genus *Allium*, which includes almost 1008 species distributed in 15 subgenera and more

than 70 sections [14,

29]. After the onion it is the second most widely used cultivated bulb crop in the World [7]. It is widely grown in Ethiopia's central and highlands, both under irrigation and rain-fed conditions

[28]. But, the productivity is low primarily due to a lack of suitable plant material, cultivar with low yield potential, and their sensitivity to various environmental stresses [9,

38]. Garlic has a wide range of genetic diversity; depending on soil type, humidity, latitude, altitude, and cultural practices of its cultivation, even a single garlic accession would have a lot of phenotypic variabilities [42,

38]. Natural variations in plant parts, for example, have economic significance and suggest the possibility of garlic improvement [20]. In addition, a great number of cultivars have resulted through natural and human selection for adaptation in

growing areas [41].

The degree of genetic variability in a population [9], which is a universal feature of all species in nature

[20], is a key factor in genetic improvement. When selecting genotypes/accessions for yield and related traits, the variability of the genotypes is the most essential component of breeding [20,

37]. Due to garlic's mode of cultivation, which is usually by clonal propagation, which is an important breeding method and little work has been done on the association between different

traits which are prerequisites for executive selection programme [34]. The basic prerequisite for yield improvement is the presence of genetic variability

in genetic stock and knowledge of inheritance and inter-

relationship of the yield components, along with their relative influence on each other [32]. The degree of variability is a base for a successful breeding

programme. Thus, the information on the native and magnitude of genetic variability present in the genetic stocks, heritability and genetic advance among various traits are of considerable use

in selecting the suitable genotype to include in future breeding programs [24].

Information on the variability and correlation between agronomic characters of different accessions with their yield are important for supporting breeding program of the plant [18]. In addition, knowledge of the nature of association of bulb yield with yield contributing characters is necessary for yield improvement through selection of better varieties [19]. An effective improvement programme in garlic, often based on clonal selection, depends on the availability of sufficient genetic variability in a collection [17, 26].

In Ethi-

opia, various diversity studies involving germplasm collection, characterization, and evaluation have resulted in the release of different improved varieties [12]. However, the shortage of high yielding and stable varieties remains a major constraint for the low productivity and production of garlic in the country [6]. Production and productivity do not depend only on area and cultural practices but also on the genotypes of the crop and environmental conditions [27]. Garlic yield is the integration of many variables that affect plant growth during the growing period. It is, therefore, necessary to study the genetic variability available in the Ethiopian accessions of garlic that new varieties with higher bulb yield and better bulb quality can be developed through selection from this rich source. Therefore, this study was designed to evaluate the heritability, genetic advance and associations among characters of garlic genotypes and to estimate the contribution of each trait to yield improvement in garlic genotypes.

## **2. MATERIALS AND METHODS**

### **2.1. Description of the Study Area**

The field experiment was conducted at Kulumsa Agricultural Research Center, Southeastern Ethiopia during the rain growing season in 2020 and 2021. KARC is located between latitude and longitude of 8° to 8°2' N and 39°07' to 39°10' E coordinates. The altitude of KARC is 2200 meters above sea level and the annual

al minimum and maximum temperature of 10.5 and 22.8°C respectively with annual rainfall of 832 mm. The rainy season over the sites extends from May through October with soil type classified as clay loam soil with a pH of 6 [1].

## 2.2. Experimental Materials and Design

A total of 20 garlic accessions/genotypes collected from different major garlic producing parts of Ethiopia, and maintained at Debre Zeit Agricultural Research Centre, including one released variety as standard check were used for the experiment (Table 1). The experiment was laid out as a Randomized Complete Block Design (RCBD) where each genotype was replicated three times. Healthy and normal cloves of each accession were selected and planted on prepared plots of 2 m × 2.4 m. Each plot consisted of four rows, with 20 plants per row, and a total of 80 plants per plot with a spacing of 20 cm within a plant and 10 cm between plants. The recommended rate of 242 kg N P<sub>2</sub>O<sub>5</sub> K<sub>2</sub>O ha<sup>-1</sup> was applied at planting as a source of phosphorous and 75 kg N ha<sup>-1</sup> in the form of Urea in two splits, half rate after full emergence and half rate at the initiation of bulb. Field agronomic practices used were as recommended for the garlic crop [15].

Table 1. List of experimental materials included in the study.

Accession code	Accession code	Accession code
GOG-065/18	GOG-075/18	GOG-001/18
GOG-067/18	GOG-018/18	GOG-055/18
GOG-069/18	GOG-068/18	GOG-057/18
GOG-072/18	GOG-059/18	GOG-011/18
GOG-073/18	GOG-061/18	GOG-045/18
GOG-074/18	GOG-047/18	HL*
GOG-058/18	GOG-064/18	

Sources: DzARC-Debre Zeit Agricultural Research Center, \* = released variety

## 2.3. Data Collection

Data collection included determination of days physiological maturity, plant height, leaf length (cm), leaf width (cm), number of clove per bulb, clove weight (g), clove height (cm), bulb polar diameter (cm), bulb equatorial diameter (cm), total bulb yield (tons per hectare). These were recorded from eight randomly sampled plants in the two central rows of each plot [21].

## 2.4. Statistical Analysis

Data collected for quantitative characters were subjected to analysis of variance (ANOVA) using R Statistical software version 4.2.2. [30]. Mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% and 1% level of significance.

### ***Phenotypic and Genotypic Variability***

The variability present in the population was estimated by simple measures- viz., range, mean, standard error, phenotypic and genotypic variances and coefficient of variations. The phenotypic and genotypic variances and coefficient of variations were estimated according to the following methods suggested by Burton and Devane [8].

$$\sigma^2_p = \sigma^2_g + \sigma^2_e \quad \sigma^2_g = \sigma^2_t - \sigma^2_{e/r}$$

Where  $\delta_p^2$  = Phenotypic variance,  $\delta_g^2$  = genotypic variance and  $\delta_e^2$  = environmental variance (error mean square);  $\delta_t^2$  = mean square of treatment and  $r$  = number of replications;

$$\text{Genotypic coefficient of variation (GCV\%)} = \frac{\sqrt{\sigma^2_g}}{\bar{x}} * 100$$

$$\text{Phenotypic coefficient of variation (PCV\%)} = \frac{\sqrt{\sigma^2_p}}{\bar{x}} * 100$$

Where,  $V_g$  = Genotypic variance,  $V_p$  = Phenotypic variance,  $\bar{x}$  = Grand mean of the character. PCV and GCV were categorized as following: 0-10%: low, 10-20%: moderate, 20% and above high [36].

### ***Heritability in the Broad Sense:***

Heritability on plot basis was calculated for each character based on the formula developed by Allard [3] as:  $H =$

$$\frac{\sigma^2_g}{\sigma^2_p} * 100$$

Estimated heritability values were classified according to Singh [35] that heritability values greater than 80% were very high, values from 60–79% were moderately high, values from 40–59% were medium and values less than 40% were low.

### ***Genetic advance:***

The Genetic Advance (broad sense) expected under selection assuming the selection intensity of 5% was calculated by the formulas suggested [22, 3]:

$$G_s = (K)(\delta A)(H)$$

Where,  $G_s$  = expected genetic advance, and  $K$  = the selection differential ( $K=2.06$  at 5% selection intensity),  $\delta A$  = phenotypic standard deviation,  $H$  = heritability.

### **Genetic advance as percent of means (GAM):**

Genetic advance as percent of mean was estimated [21] as follows:

$$GAM = \frac{GA}{\bar{x}} * 100$$

Where,  $GA$  = Genetic advance,  $\bar{x}$  = Grand mean; Genetic advance as percent of mean was categorized as 0-10% = Low, 10-20% = Moderate, >20% = High

## **4. RESULTS AND DISCUSSION**

### **4.1. Analysis of Variance**

A homogeneity test was conducted since the experiment was multi-seasonal that needs to be analyzed with combined ANOVA. Homogeneity of error variances assured that the data of both seasons were not similar so that separated data analysis were preferred rather than combined analysis over years. The combined analysis of variance (ANOVA) showed that there was a highly significant difference in garlic bulb yield in almost all traits. Thus, the mean squares from the analysis of variance for all traits of fourteen garlic accessions are presented in Table 2. There was a highly significant difference ( $P < 0.01$ ) among tested accessions for some traits as: plant vigor, pseudo stem length, leaf width, leaf length, clove diameter, and significant difference ( $P < 0.05$ ) for plant height, number of clove per bulb, clove weight, clove height, bulb equatorial diameter, and total bulb yield, while days to physiological maturity and bulb polar diameter, which had no significant effect in 2020 season. In 2021 season plant vigor, plant height, neck thickness and leaf length highly significant difference ( $P < 0.01$ ) and significant difference ( $P < 0.05$ ) for leaf width and bulb equatorial diameter, other treatments are non-significant. The highly significant differences indicate the existence of large genetic variability for the characters studied, which shows a sample scope for the selection of promising genotypes from the present gene pool for increasing bulb yield. There were less coefficients of variation in most of the characters, indicating good precision in the experiment. These results indicate the presence of variability among the genotypes used for effective selection or vegetable

11] found variability in garlic genotypes for some characters, which supports the present result.

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**Table 2.** Means squares from analysis of variance for agronomic and yield traits of 20 Garlic genotypes tested for two years at Kulumsa.

Source of variation	Year 2020															
	DF	V	MD	PH	Nth	SHL	LW	LL	NCPB	WtC	CH	CD	BPD	BED	Twt	
Replications	2	0.8	25.87	15.16	0.1	16.2	0.001	0.15	2.4	1.94	0.03	0.08	0.06	0.1	7.69	
Genotypes	19	1.37**	35.94 <sup>ns</sup>	23.65*	0.02*	7.77**	0.07**	12.74**	18.66*	0.48*	0.08*	0.03**	0.15	0.19*	6.13*	
Error	38	0.44	23.56	10.84	0.01	2.82	0.02	4.18	8.52	0.23	0.04	0.01	0.1	0.1	0.85	
Mean		4.60	142.72	68.59	0.96	26.01	1.47	44.48	17.75	1.92	2.42	0.97	3.75	4.18	6.61	
CV5%		14.72	3.41	4.85	14.29	7.18	9.84	4.48	16.15	29.40	8.44	12.71	8.48	7.59	16.55	
Year 2021																
Replications	2	0.61	0.42	128.59	0.09	97.25	1.22	120.95	35.83	0.36	0.01	0.01	2.67	5.26	3.5	
Genotypes	19	1.41**	0.82 <sup>ns</sup>	35.46**	0.05**	8.93 <sup>ns</sup>	0.07*	24.25**	123.25 <sup>ns</sup>	0.59 <sup>ns</sup>	0.07 <sup>ns</sup>	0.02 <sup>ns</sup>	0.15	0.19*	7.41*	
Error	38	0.4	0.67	10.8	0.02	6.63	0.03	6.51	106.09	0.39	0.05	0.01	0.1	0.1	6.38	
Mean		2.97	129.12	59.43	0.88	21.15	1.39	40.98	17.18	1.57	2.13	0.94	3.94	4.27	4.68	
CV5%		21.31	0.64	5.53	14.81	12.18	13.20	6.22	5.99	3.97	11.11	12.13	8.16	7.43	5.38	

\*and\*\*, significant at  $p < 0.05$  and  $p < 0.01$ , respectively. <sup>ns</sup>=non-significant difference.

CV(%)=coefficient of variation in percent, DF=degree of freedom, V=Vigorosity, MD=Day to maturity, PH=Plant height (cm), Nth=neck thickness, SHL=pseudostem length, LW=leaf width (cm), LL=leaf length (cm), NCPB=Number of cloves per bulb, WtC=clove weight (g), CH=clove height (cm), CD=clove diameter (cm), BPD=bulb polar diameter (cm), BED=bulb diameter (equatorial) (cm), TB Y=total bulb yield (tons per hectare).

#### 4.2. Estimation of Phenotypic and genotypic coefficient of variation

The phenotypic and genotypic variances have been estimated to determine the extent to which genetic and environmental factors influenced the observed variations.

There was a great variation observed for every character that was being studied. Total variability, or phenotypic variability, is observable and is made up of environmental and genotype variation. The results revealed a wider range of variability among twenty garlic genotypes for quantitative traits.

The phenotypic variance ( $\delta^2_p$ ) of all traits was higher than the genotypic variance ( $\delta^2_g$ ). Number of cloves per bulb (111.81) and plant height (8.22) had the highest phenotypic and genotypic coefficients of variation, respectively, whereas the day to clove diameter (0.01) and (0.001) had the lowest phenotypic and genotypic coefficients of variation respectively.

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ly (Table 3). For each trait, the phenotypic coefficient of variation was higher than the genotypic coefficient in both seasons. Thus, the higher genotypic and phenotypic coefficients of variation were found for total bulb yield (20.06% & 24.45%), cloves weight (29.37% for PCV respectively, while the lowest GCV and PCV values observed on day of physiological maturity (1.43% & 3.68%) respectively in 2020 season (Table 3)). Number of cloves per bulb (61.54%) and plant vigor (19.44%) had the highest GCV and PCV respectively in second 2021 season. High GCV and PCV estimates for garlic bulb weight and bulb yield were [23]. The phenotypic coefficient of variation (PCV) was greater than the genotypic coefficient of variation (GCV), which is consistent with findings published [4]. Highest estimates of genotypic and phenotypic coefficients of variation indicate that certain traits are highly likely to improve through selection, whereas other traits are difficult or nearly impossible to improve through selection. Consequently, the larger proportion of phenotypic variance observed on these traits was contributed by the genotypic variance than the environmental variance, indicating that it can be used for breeding programs [43].

#### **4.3. Estimates of heritability and genetic advance**

The proportion of genetic and environmental variation in the population can be determined using broad-sense heritability estimate. The amount of genetic advance that can be expected as a result of phenotypic selection may be precisely estimated using genetic advance and heritability estimate. Among the characters studied, high heritability estimates were found for total bulb yield (67%), while moderate for plant vigor (42% & 45%), leaf length (41% & 47%), pseudostem length (37%), leaf width (41%), and plant height (43%), neck thickness (39%) in 2020 and 2021 seasons respectively. High heritability for the above characters clarified that they were least affected by environmental fluctuations, and selection based on phenotypic performance would be reliable for these traits. This is caused by additive genetic action, thereby, reflecting the efficiency of selection for the improvement of these traits. The results align with the observations of Singh *et al.* [34] and Tsegae *et al.* [40], high heritability was observed for bulb yield of garlic in moderate for some traits. In general, heritability in the broadest sense suggests that, depending on the phenotypic expression, selection might be successful. The genetic advance varied from 1.13 to 33.89% as a percentage of the mean in first season and 0.08 to 26.99% in

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son. The total bulb yield (33.89%) and plant vigor (26.99%) showed the highest genetic advance as a percentage of the mean, while leaf width (10.97%), weight of cloves (16.15%), number of cloves per bulb (11.37%) and neck thickness (15.32%) showed the moderate. In comparison, traits like day of physiological maturity, plant height, pseudostem length, leaf length, weight of clove, clove height, clove diameter, bulb polar diameter, and bulb equatorial diameter showed low genetic advance as percentages of the-

mean. For selecting the best individual, heritability estimates combined with genetic advancement are more helpful than the heritability value a-

lone. For both the total bulb yield per hectare and the number of cloves per bulb, higher heritability and high genetic advance were observed. The results of this study align with different authors, they reported high heritability and high genetic gain for number of leaves per plant, bulb yield per hectare and clove weight per bulb [19, 10, 2, 5].

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**ble 3.** Estimate of variability components for twenty garlic genotypes evaluated at Kulumsa for two seasons 2020 & 2021.

Traits	Year 2020										
	Range		Mean	$\delta_g^2$	$\delta_p^2$	$s_e^2$	PCV	GCV	H <sup>2</sup>	GA	GAM
	Max	Min									
<b>Vigor</b>	6.00	3.00	4.60	0.31	0.75	0.44	18.84	12.11	0.42	0.74	16.05
<b>Daystomaturity</b>	150.0	114	142.72	4.12	27.69	23.57	3.68	1.43	0.15	1.61	1.13
<b>PlantHeight(cm)</b>	76.0	60.8	68.59	4.27	15.12	10.84	5.67	3.01	0.28	2.26	3.29
<b>Neckthickness(cm)</b>	1.38	0.68	0.96	0.002	0.02	0.01	13.43	4.91	0.13	0.04	3.68
<b>Pseudostemlength(cm)</b>	31.00	20.00	26.01	1.65	4.47	2.82	8.13	4.94	0.37	1.62	6.19
<b>Leafwidth(cm)(cm)</b>	1.86	1.08	1.47	0.02	0.04	0.02	13.08	8.35	0.41	0.16	10.97
<b>LeafLength(cm)</b>	50.40	38.20	44.48	2.85	7.04	4.18	5.96	3.79	0.41	2.22	4.98
<b>Numberofclovesperbulb</b>	27.60	9.00	17.75	3.38	11.9	8.52	19.44	10.36	0.28	2.02	11.37
<b>Weightofcloves(g)</b>	4.40	1.00	1.92	0.08	0.32	0.23	29.37	15.17	0.27	0.31	16.15
<b>Cloveheight(cm)</b>	2.9	1.94	2.42	0.02	0.06	0.04	9.89	4.99	0.26	0.13	5.21
<b>Clovesdiameter(cm)</b>	1.34	0.70	0.97	0.01	0.02	0.02	13.59	7.78	0.33	0.09	9.17
<b>BulbPolardiameter(cm)</b>	4.36	3.16	3.75	0.02	0.12	0.11	9.24	3.43	0.14	0.09	2.62
<b>Bulbequatorialdiameter(cm)</b>	5.16	3.50	4.18	0.03	0.13	0.10	8.66	4.17	0.23	0.17	4.15
<b>Totalbulbweight(tha<sup>-1</sup>)</b>	11.37	3.23	6.61	1.76	2.61	0.85	24.45	20.06	0.67	2.24	33.89
	<b>2021</b>										
<b>Vigor</b>	4.00	1.00	2.97	0.33	0.74	0.40	28.85	19.44	0.45	0.80	26.99
<b>Daystomaturity</b>	131.0	127.0	129.12	0.05	0.73	0.68	0.66	0.16	0.06	0.11	0.08
<b>PlantHeight(cm)</b>	68.60	44.8	59.43	8.22	19.03	10.8	7.34	4.83	0.43	3.88	6.53
<b>Neckthickness(cm)</b>	1.30	0.44	0.88	0.01	0.03	0.02	18.96	11.87	0.39	0.14	15.32

Pseudostemlength(cm)	28.2	14.2	21.15	0.77	7.39	6.63	12.86	4.14	0.10	0.58	2.75
Leafwidth(cm)(cm)	1.92	0.56	1.39	0.01	0.05	0.03	15.27	7.68	0.25	0.11	7.97
LeafLength(cm)	50.0	30.0	40.98	5.91	12.42	6.51	8.59	5.93	0.47	3.45	8.43
Numberofclovesperbulb	93.2	6.6	17.18	5.72	111.81	106.09	61.54	13.92	0.05	1.11	6.48
Weightofcloves(g)	5.88	0.77	1.57	0.06	0.46	0.39	42.96	16.42	0.15	0.20	12.93
Cloveheight(cm)	2.78	1.68	2.13	0.01	0.06	0.05	11.79	3.95	0.11	0.06	2.72
Clovesdiameter(cm)	1.24	0.68	0.94	0.001	0.01	0.01	12.83	3.35	0.07	0.02	2.00
BulbPolardiameter(cm)	4.79	2.88	3.94	0.02	0.12	0.10	8.78	3.26	0.14	0.09	2.48
Bulbequatorialdiameter(cm)	5.46	3.04	4.27	0.03	0.13	0.10	8.48	4.09	0.23	0.17	4.07
Totalbulbweight( $\text{tha}^{-1}$ )	21.86	0.78	4.68	0.34	6.72	6.38	55.31	12.51	0.05	0.27	5.83

Where:  $\delta^2_p$ =Phenotypicvariance,  $\delta^2_g$ =Genotypicvariance, PCV=phenotypiccoefficientofvariance, GCV=Genotypiccoefficientofvariance,  $H^2$ =Heritabilityinbroadssense, GA(5%)=geneticadvanceat5%selectionintensity, GAM(%)=geneticadvanceaspercentmean.

#### 4.4. Mean Performance of Genotypes

The mean performance values for all traits showed a wider range of variation among the twenty garlic genotypes. The study of variance revealed that there was a highly and significant variation among the genotypes in most of the traits such as plant vigor, plant height, pseudostem length, leaf width, leaf length, bulb equatorial diameter, clove diameter, clove weight, clove height and total bulb yield (Table 4). The genotype GOG-047/18 and GOG-067/18 were had the highest vegetative performance in plant height, leaf length and leaf width among all the others which was non-significant with standard check HL, despite the fact that the minimum mean performance of plant height was recorded in GOG-070/18. Due to the different genetic components of each genotype, there was variation in the vegetative performance, this could be the result of physiological processes that have been triggered by stimulants that have an effect on the plant's growth and metabolism. The outcomes agree with the research conducted by Sandhu *et al.* [31], Khare *et al.* [25], and Singh *et al.* [33], which revealed there is significant variation in the mean performance of genotypes varied significantly in terms of leaf width and length in garlic. Also, there was a significant variation in clove weight and height among genotypes GOG-067/18, had a significant and maximum clove weight, clove height and clove diameter which results a genotype stop performed better in bulb yield. Highest significant difference in number of clove per bulb was given by genotype GOG-075/18 (24.53), while genotype GOG-

069/18 had the lowest mean (14.6) (Table 3). These findings are closely in line with findings of different authors, who reported that a significant difference was observed between the genotypes on clove length, average weight of clove, number of clove per bulb and clove diameter [33, 5, 26].

The bulb equatorial diameters showed significant differences between the genotypes. Out of all the genotypes, genotype GOG-047/18 had the highest mean bulb equatorial diameter (43.72 cm), while genotype G-009/19 had the lowest mean (3.73 cm). There was a highly significant difference in bulb yield per hectare between the genotypes; G-067/18 had the highest bulb yield (9.63 t ha<sup>-1</sup>) and GOG-061/18 the lowest mean bulb yield (3.91 t ha<sup>-1</sup>) in 2020 season, while GOG-057/18 had the highest (9.90 t ha<sup>-1</sup>) with a list mean bulb yield of 1.26 t ha<sup>-1</sup> was recorded from genotype GOG-064/18 in 2021 season. These results are consistent with the reported significant variation among the genotypes for their charactering garlic with another authors [39, 25, 5] are closely aligned with the results obtained.

**Ta-ble 4.** Mean performances of twenty genotypes for bulb yield and other traits evaluated at Kulumsa for two seasons 2020 & 2021.

Genotypes	Year 2020													
	DM	V	PH	Nth	ShL	LW	LL	NCPB	WtC	CH	CD	BPD	BED	Twt
GOG-065/18	139.33	4.67	70.87	0.97	27.47	1.39	44.60	16.13	2.20	2.39	1.08	3.73	4.01	7.31
GOG-067/18	142.33	5.33	73.47	1.06	26.6	1.46	47.13	16.27	3.07	2.75	1.14	3.93	4.57	9.63
GOG-069/18	143.33	4.00	66.33	0.98	27.07	1.32	44.27	14.60	2.13	2.43	1.09	3.72	3.99	6.25
GOG-072/18	144.33	4.17	67.03	1.01	25.27	1.56	45.40	19.47	2.20	2.42	0.98	4.01	4.38	6.15
GOG-073/18	145.00	4.00	66.33	1.00	26.13	1.41	43.27	16.80	1.60	2.35	0.95	3.57	3.90	5.22
GOG-074/18	142.67	4.67	71.13	1.03	24.53	1.63	45.47	18.00	2.47	2.55	1.08	3.96	4.49	6.61
GOG-058/18	139.67	4.17	64.06	0.83	24.00	1.25	40.33	14.93	1.67	2.38	1.01	3.51	4.04	5.16
GOG-075/18	147.67	4.33	66.93	1.11	23.93	1.55	44.47	24.53	1.87	2.36	0.88	3.85	4.34	6.81
GOG-018/18	144.67	4.33	69.40	0.95	26.47	1.43	46.00	16.27	1.80	2.37	1.06	3.73	4.24	5.99
GOG-001/18	139.00	4.33	66.93	0.83	25.73	1.29	42.87	17.80	1.47	2.36	0.97	3.68	3.98	6.27
GOG-055/18	144.67	3.67	68.40	0.84	24.73	1.46	43.53	20.27	1.53	2.14	0.86	3.48	3.94	5.21
GOG-057/18	132.33	5.33	66.93	0.98	26.80	1.57	42.00	16.73	2.07	2.44	0.96	3.90	4.24	7.42
GOG-011/18	146.00	4.17	68.73	0.91	25.53	1.35	44.33	20.33	1.67	2.25	0.79	3.55	3.97	5.52
GOG-045/18	143.67	4.33	65.53	0.88	24.73	1.35	43.17	20.47	1.53	2.21	0.87	3.50	4.06	6.23
GOG-059/18	140.00	4.33	67.80	0.87	24.80	1.43	42.40	14.67	1.93	2.41	1.04	3.60	4.09	5.84
GOG-061/18	142.00	4.00	65.73	0.93	23.60	1.31	42.33	18.53	1.27	2.16	0.78	3.38	3.73	3.91
GOG-047/18	142.00	6.00	73.53	0.95	28.20	1.79	46.47	15.47	2.07	2.74	0.98	3.95	4.72	8.96
GOG-064/18	145.67	5.5	69.93	0.95	27.2	1.60	47.07	16.80	2.13	2.65	0.95	4.05	4.35	8.73

GOG-068/18	143.33	4.67	73.87	0.95	27.53	1.56	46.00	16.93	1.87	2.57	0.91	3.66	4.31	8.17
HL(St.Check)	146.67	6.00	68.93	1.11	29.80	1.75	48.67	20.00	1.87	2.43	1.00	4.23	4.34	6.86
LSD(5%)	Ns	1.12	5.48	0.23	3.08	0.24	3.29	4.73	0.93	0.34	0.20	ns	0.52	1.81
CV(5%)	3.41	14.72	4.85	14.29	7.18	9.84	4.48	16.15	29.40	8.44	12.71	8.48	7.59	16.55

#### Year2021

GOG-065/18	129.30	3.33	61.87	0.94	21.60	1.50	41.87	15.20	1.77	2.15	0.95	3.92	4.10	5.44
GOG-067/18	129.30	2.67	55.93	0.79	17.33	1.11	37.33	14.93	1.54	2.11	0.91	4.13	4.66	3.73
GOG-069/18	129.00	2.33	57.87	0.93	19.40	1.10	40.07	15.20	1.44	2.12	0.86	3.91	4.08	3.87
GOG-072/18	128.67	3.67	62.33	0.95	20.93	1.33	41.40	15.73	1.62	2.29	0.94	4.20	4.47	4.56
GOG-073/18	130.00	2.50	59.60	0.82	20.60	1.48	41.73	14.67	1.44	1.96	1.05	3.77	3.98	3.56
GOG-074/18	129.67	2.67	62.00	0.77	20.33	1.45	42.80	42.60	1.42	2.01	0.87	4.15	4.58	4.10
GOG-058/18	129.33	3.00	60.60	0.76	21.93	1.30	41.20	13.67	1.35	2.04	0.86	3.71	4.13	4.40
GOG-075/18	128.67	3.33	57.87	0.85	19.00	1.58	41.67	20.27	1.17	2.08	0.79	4.05	4.43	4.90
GOG-018/18	128.33	3.33	65.80	1.15	22.87	1.53	45.47	15.80	3.16	2.23	0.93	3.93	4.33	5.95
GOG-001/18	128.67	3.00	60.27	0.85	22.33	1.52	41.20	15.27	1.52	2.22	0.99	3.87	4.01	4.48
GOG-055/18	128.67	2.67	57.53	0.83	19.00	1.40	37.80	18.67	1.09	1.89	0.91	3.68	4.03	4.39
GOG-057/18	128.00	2.67	58.07	0.91	20.13	1.37	39.80	13.67	1.65	2.06	0.95	4.09	4.33	9.90
GOG-011/18	129.67	3.00	58.67	1.04	21.40	1.46	41.20	17.13	1.31	1.99	0.91	3.74	4.06	4.26
GOG-045/18	129.33	4.00	60.67	0.92	21.87	1.51	41.73	16.87	1.49	2.19	1.03	3.69	4.15	5.24
GOG-059/18	129.33	2.33	60.20	0.90	23.60	1.51	42.00	14.93	1.37	2.19	1.06	3.79	4.18	3.85
GOG-061/18	129.67	3.00	57.73	0.91	22.20	1.32	39.67	15.73	1.54	2.18	0.90	3.57	3.81	4.87
GOG-047/18	129.33	3.33	59.93	0.95	24.53	1.53	43.93	15.60	1.64	2.47	1.01	4.14	4.81	4.97
GOG-064/18	129.00	1.00	48.60	0.49	20.13	1.07	32.13	9.80	1.77	2.06	1.03	4.25	4.44	5.26
GOG-068/18	129.67	4.00	59.67	0.94	22.67	1.45	42.80	18.47	2.09	2.50	0.96	3.85	4.40	5.68
HL(St.Check)	128.67	3.67	63.33	0.87	21.07	1.40	43.93	19.47	1.08	1.92	0.85	4.42	4.43	4.37
LSD(5%)	1.36	ns	5.43	0.22	ns	0.30	4.22	ns	ns	ns	ns	ns	0.53	3.17
CV(5%)	0.64	21.31	5.53	14.81	12.18	13.20	6.22	5.99	3.97	11.11	12.13	8.16	7.43	5.38

**Note:** ns=non-significant difference, CV(%)=coefficient of variation in percent, V=Vigorosity, MD=Daystomaturity, PH=Plantheight(cm), Nthisneckthickness, SHLispseudostemlength, LWisleafwidth(cm), LLisleaflength(cm), NCPBisNumberofcloveperbulb, WtCisclove weight(g), CHis clove height(cm), CD clove diameter(cm), BPD isbulbpolar diameter(cm), BED isbulbdiameter(equatorial)(cm), Twisttotalbulbyield(tonsperectare).

## 5. CONCLUSION

The analysis of variance in the current experimental study showed that there were highly significant differences in each character's genotype. Total bulb yield showed highly significant variability among the genotypes, ranging from 4.78 to 12.72  $\text{tha}^{-1}$ , with a mean of 7.97  $\text{tha}^{-1}$ . In terms of total bulb yield, the genotypes GOG-065/18, GOG-057/18, GOG-

047/18, GOG-064/18, GOG-068/18, GOG-045/18, and GOG-018/18 had mean performances higher than the mean of the standard check variety (HL), whereas the genotype GOG-073/18 produced lower yields. For every character under study, phenotypic coefficients of variation were generally greater than genotypic coefficients of variation, suggesting that environmental factors in addition to genetic factors influence how characters are expressed. The highest phenotypic coefficient of variation was found for cloves per bulb, clove weight, and bulb yield per hectare. Leaf weight was found to have a moderate PCV; on the other hand, day to maturity, plant height, number of leaves, leaf length, clove height, bulb polarity, and equatorial diameter were found to have low PCV. Both the total bulb yield per hectare and the number of cloves per bulb showed high GCV as a percentage of the mean, along with high heritability and high genetic advance. This study suggests that selection would be beneficial in bringing out the greatest attributes in garlic due to its high PCV, GCV, heritability, and genetic gain. Since these traits additionally showed sufficient genetic variability, emphasis should be given to them when choosing genotypes during the yield improvement program as good selection criteria to improve bulb yield in garlic through breeding or selection.

#### **Disclaimer (Artificial intelligence)**

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

#### **Conflict of Interests**

Authors have declared that no conflict of interests exist

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