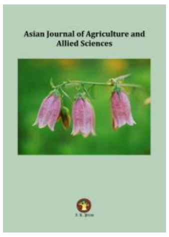

Asian Journal of Agriculture and Allied Sciences

Volume 8, Issue 1, Page 1-13, 2025; Article no.AJAAS.12630

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

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Authors' contributions

This work was carried out in collaboration among all authors. Author NF conceptualized, did data curation, did formal analysis, did the investigation, did the methodology, did the software, did the supervision, did the validation, did the visualization, wrote original draft, wrote, reviewed and edited the manuscript. Author DT did data curation, did formal analysis, did the methodology, did the software, supervised the study, wrote original draft. Author AA did data curation, did the investigation, did the methodology, supervised the study. Authors GW and DF did data curation, did the investigation, did the methodology, supervised the study. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/ajaas/2025/v8i147

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.ikprress.org/review-history/12630

Original Research Article

Received: 25/10/2024
Accepted: 28/12/2024
Published: 08/01/2025

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Cite as: *Fufa, Nimona, Dasta Tsagaye, Awoke Ali, Gizaw Wegayehu, and Demis Fikre. 2025. "Assessing Genetic Variability and Heritability in Genotypes of Garlic (Allium Sativum L.) for Bulb Yield and Related Traits". Asian Journal of Agriculture and Allied Sciences 8 (1):1-13. https://doi.org/10.56557/ajaas/2025/v8i147.*

ABSTRACT

Assessing the genetic diversity of crop species is one of the main objectives of plant breeding since it helps with the creation of breeding strategies. Thus, the purpose of this field experiment was to evaluate the genetic diversity and mean performance of garlic genotypes on bulb yield and associated variables. 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 seasons of 2020 and 2021. The analysis of variance indicated there were significant differences among the genotypes for all traits except days to 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 t ha^{-1}) and GOG-057/18 (9.90 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 days to physiological maturity had the lowest heritability (h^2b) 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 to physiological maturity) respectively. High phenotypic and genotypic coefficients of variation attached with high heritability and genetic advance as percent of mean were observed for total bulb yield tons per hectare number of 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 diversity; GCV; PCV; mean performance.

1. INTRODUCTION

Around the world, garlic (*Allium sativum* L.), a bulbous perennial crop, is grown in a variety of temperate and subtropical regions (Elsharkawy et al., 2021). It is a member of the genus Allium, which has over 70 sections and about 1008 species spread throughout 15 subgenera (Friesen et al., 2020; Parreño et al., 2023). It is the second most commonly grown bulb crop worldwide, below onions (Benke et al., 2021). It is extensively cultivated in the middle and highlands of Ethiopia, both with irrigation and with rainfall (Martha & Marie, 2019). However, the absence of appropriate plant material, cultivars with low yield potential, and their susceptibility to different environmental challenges are the main causes of the low productivity (Dejen et al., 2021; Tesfaye et al., 2021). There is a great deal of genetic diversity in garlic; even a single garlic accession would have several phenotypic variations depending on soil type, humidity, latitude, altitude, and cultural methods of its cultivation (Volk et al., 2004; Tesfaye et al., 2021). For instance, natural changes in plant components have economic value and may lead to improvements in garlic (Hoogerheide et al., 2017). Furthermore, both human and natural selection have produced a large number of cultivars that are adapted to growing environments (Viana et al., 2015).

One of the most important factors in genetic improvement is the level of genetic diversity in a population (Dejen et al., 2021), which is a characteristic shared by all species in nature (Hoogerheide et al., 2017). The most important aspect of breeding is genotype variability when choosing genotypes/accessions for yield and associated variables (Hoogerheide et al., 2017; Tesfaye, 2021). Little research has been done on the relationships between various qualities, which are necessary for carrying out a selection program, because garlic is often cultivated through clonal propagation, an important breeding technique (Singh et al., 2012). The existence of genetic variability in the genetic pool and an understanding of inheritance, the relationships between the yield components, and their relative influences on one another are the fundamental prerequisites for yield enhancement (Sharma & Saini, 2010). The foundation of a good breeding program is the level of variety. In order to choose the best geno-types to incorporate into next breeding operations, it is therefore very helpful to know the heritability, genetic advancement, and native and quantity of genetic variability found in the genetic stocks (Khadi et al., 2022).

Supporting the plant's breeding program requires knowledge of the diversity and relationship between the agronomic traits of various accessions and their yield (Hakim, 2008). Furthermore, in order to improve yield through the selection of superior cultivars, it is essential to understand the nature of the relationship between bulb yield and yield contributing characteristics (Haydar et al., 2007). Sufficient genetic variety in a collection is necessary for an efficient garlic improvement program, which is frequently based on clonal selection (Gurpree et al., 2013; Kumar et al., 2017). Numerous improved varieties have been released in Ethiopia as a consequence of diversity studies that involved the collection, characterization, and evaluation of germplasm (EAA, 2021). However, one of the main reasons for the low productivity and output of garlic in the nation is still the lack of stable and high-yielding types (Belay et al., 2020). Crop genotypes and environmental factors also affect production and productivity, in addition to geographic location and cultural customs (Lawande et al., 2009). The integration of numerous variables that impact plant growth during the growing season is known as garlic yield.

Therefore, in order to select for new garlic varieties with improved bulb quality and increased bulb production, it is vital to investigate the genetic variability present in Ethiopian accessions. This study was designed, in order to assess the heritability, genetic advancement, and associations among the traits of garlic genotypes, as well as to determine the contribution of each attribute 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 8º' to 8º 2' N and 39º 07' to 39º 10' E coordinates. The altitude of KARC is 2200 meters above sea level and the annual minimum and maximum temperature of 10.5 and 22.8 ^{0}C respectively with annual rain fall 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 (Abayneh et al., 2003).

2.2 Design and Experimental Materials

The experiment included 20 garlic accessions/genotypes, including one released variety as a standard check, that were gathered from the major garlic-producing regions of Ethiopia and kept at the Debre Zeit Agricultural Research Center (Table 1). Each genotype was duplicated three times in the Randomized Complete Block Design (RCBD) experiment. Each accession's healthy, normal cloves were chosen and planted on 2 m × 2.4 m plots that had been prepared. Ten plants were spaced 10 cm apart and 20 cm within each of the four rows that made up each plot, for a total of 80 plants. At planting, the prescribed rate of 242 kilogram NPS ha-1 was applied as a source of phosphorous, and 75 kg N ha-1 in the form of urea was applied in two splits: half at the beginning of the bulb and half after full emergence. The garlic crop was grown using field agronomic techniques as advised (Getachew et al., 2009).

2.3 Data Collection

Plant height, leaf length (cm), leaf width (cm), number of cloves per bulb, clove weight (g), clove height (cm), bulb polar diameter (cm), bulb equatorial diameter (cm), and total bulb yield (tons per hectare) were among the data collected. Eight randomly selected plants from each plot's two central rows provided these (IPGI & Gr, 2001).

Table 1. List of study-related experimental materials

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- DebreZeit Agricultural Research Center, *= a released variety*

2.4 Statistical Analysis

Data collected for quantitative characters were subjected to analysis of variance (ANOVA) using R Statistical software version 4.2.2. (R Core Team, 2021). Duncan's Multiple Range Test (DMRT) was used to perform mean separation at the 5% and 1% levels of significance.

Variability in Phenotype and Genotype: Simple metrics, such as range, mean, standard error, phenotypic and genotypic variances, and coefficient of variations, were used to estimate the population's variability. The following techniques proposed by Burton & De Vane (1953) were used to estimate the phenotypic and genotypic variances as well as the coefficient of variations.

$$\sigma 2_{\mathrm{p}} = \sigma 2_{\mathrm{g}} + \sigma 2_{\mathrm{e}} \qquad \sigma 2_{\mathrm{g}} = \sigma 2_{\mathrm{t}} - \sigma 2_{\mathrm{e/r}}$$

Where δ_p^2 = Phenotypic variance, δ_g^2 = genotypic variance and δ_e^2 = environmental variance (error mean square); δ_t^2 = mean square of treatment and r = number of replications;

Genotypic coefficient of variation (GCV %)

$$= \frac{\sqrt{\sigma 2_{\mathrm{g}}}}{\bar{x}} * 100$$

Phenotypic coefficient of variation (PCV %)

$$= \frac{\sqrt{\sigma 2_{\mathrm{p}}}}{\bar{x}} * 100$$

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 (Shivasubramanian & Menon, 1973).

Heritability in the Broadest Sense: Using Allard's technique, each character's heritability was determined on a plot basis (Allard, 1960).

as: $$H = \frac{\sigma 2_{\mathrm{g}}}{\sigma 2_{\mathrm{p}}} * 100$$

According to Singh et al., (2011) classification of estimated heritability values, values over 80% were considered very high, those between 60 and 79 percent were considered moderately high, those between 40 and 59 percent were considered medium, and those below 40 percent were considered low.

Genetic advance: The Genetic Advance (broad sense) expected under selection assuming the selection intensity of 5% was calculated by the formula suggested (Johanson et al., 1955; Allard, 1960):

Gs= (K) (δA) (H)

Where, Gs = expected genetic advance, and K = the selection differential (K=2.06 at 5% selection intensity), δA= phenotypic standard deviation, H = heritability.

Genetic advance as percent of means (GAM): Genetic advance as percent of mean was estimated (IPGI & Gr, 2001) as follows:

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

Where, GA = Genetic advance, $\bar{x}$ = Genetic advancement as a percentage of mean was classified as follows: 0–10% = Low, 10–20% = Moderate, and >20% = High.

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Since the experiment was multi-seasonal and required combined ANOVA analysis, a homogeneity test was performed. The data from both seasons were certain to be different due to the homogeneity of error variances, which is why independent data analysis was favored over combined analysis spanning years. In practically every feature, the combined analysis of variance (ANOVA) revealed a highly significant difference in garlic bulb production. Therefore, Table 2 displays the mean squares from the analysis of variance for every attribute of the fourteen garlic accessions. For certain traits, such as plant vigor, pseudo stem length, leaf width, leaf length, and clove diameter, there was a highly significant difference (P<0.01) between the tested accessions. Additionally, there was a significant difference (P<0.05) for plant height, number of cloves per bulb, clove weight, clove height, bulb equatorial diameter, and total bulb yield. Days to physiological maturity and bulb polar diameter did not significantly affect the 2020 season.

In the 2021 season, there is a significant difference (P<0.05) for leaf width and bulb equatorial diameter, and a non-significant difference (P<0.01) for plant vigor, plant height, neck thickness, and leaf length. The features under study exhibit a high degree of genetic diversity, as indicated by the highly significant differences. This suggests that there is sufficient room to choose promising genotypes from the current gene pool in order to increase bulb yield. Most of the characteristics had lower coefficients of variation, suggesting that the experiment was rather precise. These findings show that the genotypes utilized for efficient selection or vegetable improvement exhibit heterogeneity. The current result is supported by the findings of other authors (Abebech et al., 2021; Getaneh et al., 2024; Dixit et al., 2021) who discovered diversity in garlic genotypes for certain features.

3.2 Estimation of Phenotypic and Genotypic Coefficient of Variation

To ascertain the degree to which genetic and environmental factors contributed to the observed changes, the phenotypic and genotypic variances have been assessed. Every character under study showed a significant amount of variation. Environmental and genetic variation combine to provide observable total variability, also known as phenotypic variability. The findings showed that there was a great deal of variation in the quantitative features of the twenty garlic genotypes. For every characteristic, the phenotypic variance (ð2p) exceeded the genotypic variance (ð2g).

In contrast, the days to clove diameter (0.01) and (0.001) had the lowest phenotypic and genotypic coefficients of variation, respectively, whereas the number of cloves per bulb (111.81) and plant height (8.22) had the largest (Table 3). In both seasons, the phenotypic coefficient of variance for each trait was greater than the genotypic coefficient. Therefore, the 2020 season showed the lowest GCV and PCV values on days to physiological maturity (1.43% & 3.68%), while the highest genotypic and phenotypic coefficients of variation were found for cloves weight (29.37% for PCV) and total bulb yield tons per hectare (20.06% & 24.45%) (Table 3). The second season of 2021 had the highest GCV and PCV, respectively, for the number of cloves per bulb (61.54%) and plant vigor (19.44%). Garlic bulb production and weight were estimated to have high GCV and PCV (Kassahun, 2006). Consistent with prior findings, the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) (Awale et al., 2011). Certain features are very likely to improve through selection, while other traits are difficult or almost impossible to develop through selection, according to high estimates of genotypic and phenotypic coefficients of variation. As a result, the genotypic variance contributed a greater proportion of the phenotypic variance found on these traits than the environmental variance, suggesting that it can be utilized for breeding programs (Yebirzaf & Belete, 2017).

3.3 Estimates of Heritability and Genetic Advance

A broad-sense heritability estimate can be used to calculate the population's fraction of genetic and environmental variation. The anticipated rate of genetic advancement due to phenotypic selection may be precisely estimated using genetic advance and a heritability estimate. Among the characters studied, high heritability estimates was found for total bulb yield (67%), While moderate for plant vigor (42% & 45%), leaf length (41% & 47%), pseudo stem length (37%), leaf width (41%), and plant height (43%), neck thickness (39%) in 2020 and 2021 season respectively. The previously mentioned characters' high heritability made it clear that environmental changes had the least impact on them, therefore selection based on phenotypic performance would be dependable for these qualities. This resulted from additive gene activity, which shows how well selection worked to increase certain qualities. The findings are consistent with those of Singh et al. (2012) and Tsega et al. (2010), who noted that garlic bulb output had a high heritability to moderates for some features. In general, heredity in the widest meaning implies that selection may be effective based on the phenotypic expression.

In the first season, the genetic advance ranged from 1.13 to 33.89% of the mean, whereas in the second season, it ranged from 0.08 to 26.09%. Genetic advance as a percentage of the mean was largest in the total bulb yield (33.89%) and plant vigor (29.99%), while it was moderate in the leaf width (10.97%), clove weight (16.15%), number of cloves per bulb (11.37%), and neck thickness (15.32%). In contrast, low genetic advancement was observed as percentages of the mean for features such as days to physiological maturity, plant height, pseudo stem length, leaf length, weight of the clove, clove height, clove diameter, bulb polar diameter, and bulb equatorial diameter. Heritability estimations and genetic advancement are more useful than the heritability value alone for choosing the finest individual. High heritability and high genetic progress were noted for both the quantity of cloves per bulb and the overall bulb output per hectare. The findings of this study are consistent with those of other authors, who showed strong genetic gain and high heritability for clove weight per bulb, bulb production per hectare, and number of leaves per plant (Haydar et al., 2007; Dhal & Brar, 2013; Abebech et al., 2021; Bayisa, 2021).

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

Source of variation	DF	V	MD	PH	Nth	SHL	LW	LL	NCPB	WtC	CH	CD	BPD	BED	Twt
	Year 2020														
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**	35.94ns	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**	0.82ns	35.46**	0.05**	8.93ns	0.07*	24.25**	123.25ns	0.59ns	0.07ns	0.02ns	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. ns= non-significant difference, CV (%) = coefficient of variation in percent, DF = degree of freedom, V= Vigorisity, MD=Days to maturity, PH = Plant height (cm), Nth is neck thickness , SHL is pseudostem length, LW is leaf width(cm), LL is leaf length (cm), NCPB is Number of clove per bulb, WtC is clove weight (g), CH is clove height (cm), CD clove diameter (cm), BPD is bulb polar diameter (cm), BED is bulb diameter (equatorial) (cm), TBY is total bulb yield (tons per hectare)*

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

Traits	Range		Mean	δ_g^2	δ_p^2	s_e^2	PCV	GCV	H^2	GA	GAM
	Max	Min									
Year 2020											
Vigor	6.00	3.00	4.60	0.31	0.75	0.44	18.84	12.11	0.42	0.74	16.05
Days to maturity	150.0	114	142.72	4.12	27.69	23.57	3.68	1.43	0.15	1.61	1.13
Plant Height (cm)	76.0	60.8	68.59	4.27	15.12	10.84	5.67	3.01	0.28	2.26	3.29
Neck thickness (cm)	1.38	0.68	0.96	0.002	0.02	0.01	13.43	4.91	0.13	0.04	3.68
Pseudostem length(cm)	31.00	20.00	26.01	1.65	4.47	2.82	8.13	4.94	0.37	1.62	6.19
Leaf width(cm) (cm)	1.86	1.08	1.47	0.02	0.04	0.02	13.08	8.35	0.41	0.16	10.97
Leaf Length(cm)	50.40	38.20	44.48	2.85	7.04	4.18	5.96	3.79	0.41	2.22	4.98
Number of cloves per bulb	27.60	9.00	17.75	3.38	11.9	8.52	19.44	10.36	0.28	2.02	11.37
Weight of cloves (g)	4.40	1.00	1.92	0.08	0.32	0.23	29.37	15.17	0.27	0.31	16.15
Clove height (cm)	2.9	1.94	2.42	0.02	0.06	0.04	9.89	4.99	0.26	0.13	5.21
Cloves diameter(cm)	1.34	0.70	0.97	0.01	0.02	0.02	13.59	7.78	0.33	0.09	9.17
Bulb Polar diameter (cm)	4.36	3.16	3.75	0.02	0.12	0.11	9.24	3.43	0.14	0.09	2.62
Bulb equatorial diameter(cm)	5.16	3.50	4.18	0.03	0.13	0.10	8.66	4.17	0.23	0.17	4.15
Total bulb weight (t ha^{-1})	11.37	3.23	6.61	1.76	2.61	0.85	24.45	20.06	0.67	2.24	33.89
2021											
Vigor	4.00	1.00	2.97	0.33	0.74	0.40	28.85	19.44	0.45	0.80	26.99
Days to maturity	131.0	127.0	129.12	0.05	0.73	0.68	0.66	0.16	0.06	0.11	0.08
Plant Height (cm)	68.60	44.8	59.43	8.22	19.03	10.8	7.34	4.83	0.43	3.88	6.53
Neck thickness (cm)	1.30	0.44	0.88	0.01	0.03	0.02	18.96	11.87	0.39	0.14	15.32
Pseudostem length(cm)	28.2	14.2	21.15	0.77	7.39	6.63	12.86	4.14	0.10	0.58	2.75
Leaf width(cm) (cm)	1.92	0.56	1.39	0.01	0.05	0.03	15.27	7.68	0.25	0.11	7.97
Leaf Length(cm)	50.0	30.0	40.98	5.91	12.42	6.51	8.59	5.93	0.47	3.45	8.43
Number of cloves per bulb	93.2	6.6	17.18	5.72	111.81	106.09	61.54	13.92	0.05	1.11	6.48
Weight of cloves (g)	5.88	0.77	1.57	0.06	0.46	0.39	42.96	16.42	0.15	0.20	12.93
Clove height (cm)	2.78	1.68	2.13	0.01	0.06	0.05	11.79	3.95	0.11	0.06	2.72
Cloves diameter(cm)	1.24	0.68	0.94	0.001	0.01	0.01	12.83	3.35	0.07	0.02	2.00
Bulb Polar diameter (cm)	4.79	2.88	3.94	0.02	0.12	0.10	8.78	3.26	0.14	0.09	2.48
Bulb equatorial diameter(cm)	5.46	3.04	4.27	0.03	0.13	0.10	8.48	4.09	0.23	0.17	4.07
Total bulb weight (t ha^{-1})	21.86	0.78	4.68	0.34	6.72	6.38	55.31	12.51	0.05	0.27	5.83

Where: δ^2p =Phenotypic variance, δ^2g =Genotypic variance, PCV = phenotypic coefficient of variance, GCV = Genotypic coefficient of variation, H^2= Heritability in broad sense, GA (5%) = genetic advance at 5% selection intensity, GAM (%) = genetic advance as percent mean

Table 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
Year 2021														
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

Genotypes	Year 2020													
	DM	**V**	**PH**	**Nth**	**ShL**	**LW**	**LL**	**NCPB**	**WtC**	**CH**	**CD**	**BPD**	**BED**	**Twt**
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= Vigorisity, MD=Days to maturity, PH = Plant height (cm), Nth is neck thickness, SHL is pseudostem length, LW is leaf width(cm), LL is leaf length (cm), NCPB is Number of clove per bulb, WtC is clove weight (g), CH is clove height (cm), CD clove diameter (cm), BPD is bulb polar diameter (cm), BED is bulb diameter (equatorial) (cm), Twt is total bulb yield (tons per hectare)

3.4 Genotype Mean Performance

The twenty garlic genotypes varied greatly in their mean performance levels for all traits. Plant vigor, plant height, pseudo-stem length, leaf width, leaf length, bulb equatorial diameter, clove diameter, clove weight, clove height, and total bulb output were among the variables in which the study of variance showed a highly and significant difference across the genotypes (Table 4). Despite the fact that GOG-070/18 had the lowest mean performance of plant height, the genotypes GOG-047/18 and GOG-067/18 had the highest vegetative performance in terms of plant height, leaf length, and leaf breadth among all the others, which was non-significant with standard check HL. Variability in vegetative performance was caused by the distinct genetic components of each genotype; this could be the consequence of physiological processes induced by stimulants that impact the development and metabolism of the plant. The results are consistent with studies by Sandhu et al. (2015), Khar et al. (2015), and Singh et al. (2015), which found that genotypes differed significantly in their mean performance of garlic leaf width and length. Additionally, there was a notable difference in the weight and height of the cloves between genotypes GOG-067/18. These genotypes had a substantial and maximum clove weight, clove height, and clove diameter, which led to a higher bulb yield.

In terms of the number of cloves per bulb, genotype GOG-075/18 had the highest significant difference (24.53), whereas genotype GOG-069/18 had the lowest mean (14.6) (Table 3). These results closely match those of other authors who found that there were notable genotype-based changes in clove length, average weight, number of cloves per bulb, and clove diameter (Singh et al., 2015; Bayisa, 2021; Kumar et al., 2017). The genotypes differed significantly in the bulb equatorial diameter. The mean bulb equatorial diameter of genotype GOG-047/18 was the biggest of all the genotypes (43.72 cm), while the mean of genotype G-009/19 was the lowest (3.73 cm). The genotypes showed a highly significant difference in bulb yield per hectare; in the 2020 season, G-067/18 had the highest bulb yield (9.63 t ha-1), while GOG-061/18 had the lowest mean bulb yield (3.91 t ha-1). In the 2021 season, genotype GOG-064/18 had the highest bulb yield (9.90 t ha-1). The results obtained closely match the considerable variance among genotypes for this trait in garlic that has been reported by previous investigators (Tsega et al., 2011; Khar et al., 2015; Bayisa, 2021).

4. CONCLUSION

The current experimental study's analysis of variance revealed that the genotypes of each character varied in highly significant ways. With a mean of 7.97 t ha-1 and a range of 4.78 to 12.72 t ha-1, the genotypes' differences in total bulb yield were extremely significant. The genotypes GOG-065/18, GOG-057/18, GOG-047/18, GOG-064/18, GOG-068/18, GOG-045/18, and GOG-018/18 all outperformed the standard check variety (HL) in terms of total bulb yield, but the genotype GOG-073/18 yielded lower yields. Phenotypic coefficients of variation were typically higher than genotypic coefficients of variation for all the characters studied, indicating that environmental influences, in addition to genetic ones, affect the expression of characters. Bulb yield per hectare, clove weight, and cloves per bulb had the highest phenotypic coefficient of variation. Days to maturity, plant height, number of leaves, leaf length, clove height, bulb polarity, and equatorial diameter were shown to have low PCV, but leaf weight had a moderate PCV. In addition to high heritability and high genetic advancement, both the number of cloves per bulb and the total bulb output per hectare displayed significant GCV as a proportion of the mean. Given garlic's high PCV, GCV, heritability, and genetic gain, this study indicates that selection would be helpful in highlighting its best qualities. 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.

ACKNOWLEDGEMENTS

This study was supported by the Ethiopian Institute of Agricultural Research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://prh.ikprress.org/review-history/12630