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Genetic Variability, Genetic Parameters, Growth Characteristics and Yield of Three Garlic (Allium sativum L.) Varieties under Amino Acids and Salicylic Acid Treatments

[1]Abdullah Majid Nayyef Jasim, [2]Shamil Younis Hassan AL-Hamadany, [3]Amer Abdullah Hussein Al-Jubouri

[1,2,3]Hort. & Landscape Design Dept.
College of Agriculture and Forestry, University of Mosul, Iraq.
amer_ah_juboori@uomosul.edu.iq shamil@uomosul.edu.iq mailto:abdullah.24agp84@student.uomosul.edu.iq

ABSTRACT: This study, conducted in Nineveh Governorate, Iraq, investigated the inheritance of certain growth and yield traits. It was carried out during the autumn growing season of 2025-2026 at the Agricultural Research Field, College of Agriculture and Forestry, Mosul. The aim was to estimate the genetic parameters of three garlic cultivars (Iranian, Chinese, and French) under the influence of foliar application of the amino acid casein hydrolysate at three concentrations (0, 1, and 2 g/L) and salicylic acid at two concentrations (0 and 2 g/L). The experiment consisted of eighteen treatments in a completely randomized block design with three replications.The results of the analysis of variance indicate significant differences between the mean squares of the three classes for all the traits under study, except for the traits of total leaf chlorophyll content and the percentage of nitrogen and potassium in the leaves, where the differences did not reach the threshold of significance. The values of genetic variance were significant above zero for all the studied traits except for the traits of total leaf chlorophyll content and the percentage of total soluble solids in the lobes, while the values of environmental variance were significant above zero for all the traits. Heritability in the broad sense was high for the traits of plant height 0.962, number of leaves 0.657, leaf area of the plant 0.905, average bulb weight 0.720, bulb length 0.824, bulb diameter 0.776, average lobe weight 0.651, lobe length 0.863, lobe diameter 0.670, total plant yield (bulbs + leaves) 0.717, total bulb yield 0.720, and marketable bulb yield 0.720. The high heritability is evidence that the appearance of the individual is greatly related to its genetic makeup, and this indicates the possibility of introducing direct improvements to these traits in subsequent seasons. The expected genetic improvement values as a percentage of the average trait were between low for the traits of number of leaves 9.525, total leaf chlorophyll content 3.231, percentage of dry matter in the vegetative body 2.786, number of lobes per bulb 5.188, bulb percentage 6.529, percentage of total soluble solids in the lobes 3.207, percentage of nitrogen in the leaves 1.923, and percentage of potassium in the leaves 3.917. The average for plant height is 22.333, bulb length is 29.206, bulb diameter is 23.732, lobe length is 29.734, lobe diameter is 20.576, and the percentage of phosphorus in the leaves is 10.919. The high for plant leaf area is 43.732, average bulb weight is 51.171, average lobe weight is 42.258, total plant yield (bulbs + leaves) is 34.644, total bulb yield is 51.174, and marketing yield of bulbs is 51.174.

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INTRODUCTION

Garlic (*Allium sativum* L.) is one of the most important vegetable crops. Garlic, belonging to the Amaryllidaceae family, is a perennial herbaceous plant commonly cultivated as an annual for its bulbs. It is characterized by its shallow root system and vegetative propagation via cloves. Garlic is one of the oldest cultivated plants in the world and ranks second only to bulbs in importance within the Allium genus due to its uses in the food, pharmaceutical, and cosmetic industries. Rich in vitamins and minerals, it is widely used as a food flavoring and as a source of bioactive compounds such as allicin and organosulfur compounds, which possess antioxidant, antibacterial, and antifungal properties. It is also used in traditional medicine to treat various ailments [36].Garlic originated in Central Asia and the eastern Black Sea region and later spread to large parts of the world, particularly temperate and sub-temperate regions of the Northern Hemisphere [26] Garlic is widely cultivated globally, with global production reaching approximately 29.5–29.1 million tons during the years [unclear - possibly "in years unclear"]. The last three, with a cultivated area of 1.7–1.6 million hectares, and in Iraq its production is limited compared to global production, but it represents an important part of local agricultural production, where the cultivated area was estimated at about 7–5 thousand hectares, while total production ranged between 40–60 thousand tons annually [16]. Evaluating garlic cultivars is a crucial step in improving productivity, given the significant differences between cultivars in growth characteristics, yield, and quality. Variety evaluation helps identify the best-adapted cultivars for local environmental conditions. It also assists plant breeders in selecting suitable genetic resources for genetic improvement programs. Studies have shown wide genetic and phenotypic variation among garlic cultivars resulting from environmental adaptation and vegetative propagation [1]. Foliar feeding is also an important method for supplying plants with primary and secondary nutrients, as well as various growth stimulants, which leads to increased vegetative growth, productivity, and improved quality. One type of foliar feeding under study is spraying with amino acids and salicylic acid at different growth stages. These are bioactive compounds that have garnered significant attention in modern agriculture due to their important physiological role in improving plant growth and increasing productivity. Amino acids play a fundamental role in plant life, serving as building blocks for proteins and enzymes. They are also involved in the formation of chlorophyll, plant hormones, and growth-regulating compounds. When sprayed on the entire plant... In vegetative growth, it contributes to activating cell division, increasing leaf area, and improving root formation. It also facilitates the absorption and transport of nutrients within the plant. Furthermore, some amino acids, such as proline, arginine, glycine, and betaine, protect plant cells from osmotic stress by regulating intracellular water balance. Therefore, its use leads to increased vegetative growth, yield, and improved crop quality [20] Salicylic acid, on the other hand, is a natural phenolic compound that acts as a growth regulator and defense signal within the plant. It contributes to regulating many vital processes, such as stomata opening and closing, increasing photosynthetic efficiency, activating antioxidant systems, and stimulating the production of defense compounds. In addition, salicylic acid plays an important role in enhancing plant resistance to biotic and abiotic stresses. It activates the antioxidant system and reduces the accumulation of reactive oxygen species, thus maintaining the integrity of plant membranes and tissues. Therefore, salicylic acid is one of the most widely used compounds in modern foliar spraying programs to improve plant growth and productivity under various environmental conditions. [28].

The traits of any crop are determined by genetic and environmental interactions. Therefore, plant breeders should aim to understand the relationship between plant traits and metabolic processes, as well as phenotypic traits, since these are genetically controlled. This can only be achieved by estimating genetic and phenotypic variations to develop a program for selecting multiple traits simultaneously [2].

Estimating genetic and phenotypic variation is fundamental to quantitative genetic analysis. Variation within and between genetic groups is evaluated to identify areas that can be improved through breeding programs. This estimation provides an understanding of genetic and environmental influences and how traits are transmitted from one generation to the next, which helps in selecting cultivars that are more responsive to improvement [15] Estimating the heritability of quantitative traits is one of the most important indicators that plant breeders have focused on. It has become clear that by estimating heritability in its broadest sense, the contribution of both genetic and environmental influences to the trait's appearance can be determined. Thus, the heritability value can serve as a measure of the relationship between parents and offspring. Heritability is also a crucial genetic parameter that must be known for any quantitative trait, as determining the best breeding method for improving a given trait depends on its estimation. Furthermore, its estimation is important for determining the expected genetic improvement, which represents the most significant application of quantitative heritability theory in plant breeding and improvement programs [5].

Therefore, the current study aims to estimate the heritability ratio, genetic and phenotypic variances and their coefficients, and the expected genetic improvement of yield traits and their components for three different garlic cultivars under study. These cultivars were subjected to foliar spraying with different concentrations of amino acids and salicylic acid at different growth stages under the conditions of Nineveh province. The goal is to select the best traits in subsequent early generations and to more effectively maintain these desirable traits in future breeding programs for this crop.

MATERIALS AND METHODS.

This study was conducted during the autumn growing season of 2025-2026 at the Agricultural Research Field, College of Agriculture and Forestry, Mosul, located at latitude 36.35°N and longitude 43.15°E, at an altitude of 223 meters above sea level [19] The aim was to estimate some genetic parameters of three garlic cultivars (Iranian, Chinese, and French) under the influence of spraying with the amino acid casein hydrolysate at three concentrations (0, 1, and 2 g/L) and salicylic acid at two concentrations (0 and 2 g/L). The plants were sprayed with the three amino acid concentrations and the two salicylic acid concentrations on four separate occasions. The first spraying occurred when the plants reached the second to third true leaf stage, with a 20-day interval between the second, third, and fourth sprayings. The application of the amino acids and salicylic acid was not... Simultaneously, with a one-day interval between each of the four sprays.

The cloves of the three cultivars were planted on September 15, 2025, in the designated area for each treatment and duplicate. Suitable cloves for planting were selected and isolated for each variety, excluding very small, diseased cloves unsuitable for planting. Planting was done in rows, represented by the experimental unit, which consisted of two rows, each 2 meters long and 0.60 meters wide, resulting in an area of 2.4 m^2. The spacing between plants was 10 cm, with 20 plants per row, totaling 40 plants per experimental unit (120 plants per treatment). Drip irrigation pipes were then installed at the planting line level for each row.

Agricultural practices were carried out equally for all treatments. NPK compound fertilizer (20:20:20) was added during soil preparation before planting and mixed into the soil at a rate of 200 kg/ha for all experimental treatments [4]. Harvesting was carried out manually using a hoe on the experimental unit plants and the three cultivars on May 23, 2026.

Data were recorded for ten randomly selected plants per experimental unit (30 plants/treatment) after the final application of both amino acid and salicylic acid, and ten days before harvesting. The data were statistically analyzed using SAS software (2007), and Duncan's multiple range test was used to compare mean values at a probability level of 0.05.

After data collection, tabulation, and tabulation for the studied traits were completed, the data were statistically analyzed using a completely randomized block design. The genetic performance of the three cultivars for the studied traits was estimated, along with the estimation of several genetic parameters (phenotypic and genotype variances and their coefficients, broad-sense heritability, expected genetic improvement, and expected genetic improvement as a percentage) for vegetative growth, flowering, yield, and its components, under the influence of the interaction of each of the studied factors. (Cultivars and treatments of spraying with amino acids and salicylic acid) from the ANOVA table for the experimental design used, Table (1) according to [7].

Table (1): ANOVA Table for the Experimental Design

S.O.V	d.f	SS	MS	Cal. F
R	**r – 1 = 2**	**(SSr) = R-CF**	**MSr**	F_r
A	**a – 1= 2**	**(SS_A) =A–CF**	MS_A	F_A
B	**b – 1 = 2**	**($SS_{B)}$ =B–CF**	MS_B	F_B
C	**c – 1 = 1**	**($SS_{c)}$ =C–CF**	MS_C	F_C
AB	**(a-1) (b–1) = 4**	**(SS_{AB}) = AB-A-B+CF**	MS_{AB}	F_{AB}
AC	**(a-1) (c–1) = 2**	**(SS_{AC}) = AC-A-C+CF**	MS_{AC}	F_{AC}
BC	**(b-1) (c–1) = 2**	**(SS_{BC}) = BC-B-C+CF**	MS_{BC}	F_{BC}

ABC	**(a-1) (b–1) (c–1) = 4**	**(SS_{ABC}) = ABC-AB-AC-BC+A+B+C-CF**	**MS_{ABC}**	**F_{ABC}**
Error	**(abc-1) (r-1) =34**	**(SSe) = ABCR-ABC-R+CF**	**MS_e**	
Total	**abcr – 1 = 53**	**SST = ABCR-CF**		

Given that:

R: Number of replicates = 3

A: Cultivars = 3

B: Amino acid spray treatments = 3

C: Salicylic acid spray treatments = 2

Estimation of variance components:

The phenotypic variance components σ2p (genetic σ2g and environmental σ2e) were estimated from the analysis of variance table (Table 1). The significance of the genetic variance σ2g and environmental σ2e was tested against zero using [22] by calculating the variance of each of these variances and extracting their square roots to obtain the standard errors, as follows:

$$\sigma^2_p = \sigma^2_g + \sigma^2_e$$

where:

σ^2_p=Phenotypic variance

σ^2_g = genotypic variance

σ^2_e= environmental variance

$$\sigma^2_g = (MS_g - MS_e) \ / \ R\,B\,C$$

where:

MS_g =Mean square cultivars.
MS_e = Mean squared experimental error.
R = Number of replicates
B = Number of amino acid treatments =3.
C = Number of salicylic acid treatments = 2.

$$\sigma^2_e = MS_e$$

The variance of both the genetic variance (σ^2g) and the environmental variance (σ^2e) was calculated as follows:

The variance of both the genetic variance (σ^2g) and the environmental variance (σ^2e) was calculated as follows:

$$V(g) = \frac{1}{r^2 b^2 c^2} \left\{ \frac{2(Msg)^2}{gen.df.+2} + \frac{2(Mse)^2}{error\ df.+2} \right\}$$

$$V(e) = \frac{2(Mse)^2}{error\ \ df.+2}$$

Estimation of the genotypic and phenotypic coefficients of variation:

These were estimated from the following two equations proposed by [10] to calculate the genotypic coefficient of variation (GCV) and by [13] to calculate the phenotypic coefficient of variation (PCV), using the following equations:

$$GCV\,\% = \left(\sqrt{\sigma^2_g} \ / \ \bar{y} \right) \times 100$$

PCV % = $(\sqrt{\sigma^2_p} / \bar{y}) \times 100$

($\bar{y}$)= the arithmetic mean of the trait.

$\sigma^2 g$ = genotype standard deviation.

$\sigma^2 p$ = phenotype standard deviation.

Estimating Broad Sense Heritability: Broad Sense (H^2b.s.) heritability values were estimated according to the equation provided by [15] which is:

$$H^2_{b.s.} = \frac{\sigma^2_g}{\sigma^2_p}$$

The importance of heritability values in the broad sense was expressed according to the scale presented by [3]:

(Less than 40% is low, 40-60% is medium, and more than 60% is high).

Estimation of Expected Genetic Advance: Expected genetic advance (EGA), which [15] termed the response to selection, was estimated as the difference between the mean of the offspring population resulting from selection and the mean of the original population. It was estimated for each trait using Allard's (1960) equation, as follows:

E.G.A. = $(K\ H^2_{b.s.} \sqrt{\delta^2 P})$

Where:

E.G.A. = Expected genetic improvement.

K = 2.06, representing the selection intensity for 5% of plants.

H2b.s. = Broad-sense heritability.

σ2p = Phenotypic standard deviation.

The expected genetic improvement is estimated as a percentage of the average trait using the method described by [23]

E.G.A. % = $[(K\ H^2_{b.s.} \sqrt{\delta^2 P}) / \bar{y}] \times 100$

Note that ($\bar{y}$) is the arithmetic mean of the trait.

The limits of expected genetic improvement, as reported by [27] were adopted as follows:

(Less than 10% is low, 10-30% is medium, and more than 30% is high.)

RESULTS AND DISCUSSION

The results of the analysis of variance for the studied garlic traits are shown in Table (2). These results indicate that the mean of the three cultivars was significant at a 1% probability level for the traits of plant height, number of leaves, leaf area, percentage of dry matter in the foliage, average weight, length, and diameter of the bulb, number of cloves per bulb, average weight, length, and diameter of the clove, total plant yield (bulbs + leaves), total and marketable bulb yield, and bulb percentage and percentage of phosphorus in the leaves. Significant differences were also observed at a 5% probability level for the percentage of total soluble solids in the cloves, with the exception of the trait of total leaf chlorophyll content and percentage of nitrogen and potassium in the leaves, where the differences did not reach the level of significance.

While the mean squares of the amino acid spray treatments were significant at a 5% probability level for the traits of total leaf chlorophyll content, average bulb weight, total bulb yield, bulb percentage, and percentage of total soluble solids in the cloves, they were significant at a 1% probability level for the traits of plant height, number of leaves, leaf area, percentage of dry matter in the foliage, bulb length and diameter, clove length, and total plant yield (bulbs + leaves), percentage of nitrogen and potassium in the leaves The differences did not reach the level of significance for the remaining traits. The mean squares of the salicylic acid spray treatments were significant at a 1% probability level for plant height, number of leaves, leaf area, total leaf chlorophyll content, percentage of dry matter in the foliage, bulb length, lobe diameter, and total plant yield (bulbs + leaves) and percentage of phosphorus in the leaves. They were significant at a 5% probability level for average bulb weight, bulb diameter, and total bulb yield. Differences for the remaining traits did not reach significance.This is due to the mean squares of the cultivars × amino acid interaction. Differences did not reach significance for any of the studied traits, except for the 5% probability level, which showed significant differences for total leaf chlorophyll content, average bulb weight and length, number of lobes per bulb, total plant yield (bulbs + leaves), and total bulb yield ,marketing of the bulbs was significant, while it was only at a probability level of 1% for the percentage of phosphorus in the leaves..

The differences were significant at a 5% probability level for the following traits: The mean squares of the cultivars × salicylic acid interaction were significant at a 1% probability level for bulb length and diameter, and at a 5% probability level for average bulb weight, total plant yield (bulbs + leaves), and total bulb yield, Marketing of bulbs and percentage of phosphorus in leaves,. Differences for the remaining traits were not significant. The mean squares of the amino acid × salicylic acid interaction were significant at a 5% probability level for average bulb weight, total plant yield (bulbs + leaves), and total bulb yield, Marketing of bulbs, and at a probability level of 1% for the percentage of nitrogen, phosphorus and potassium in the leaves. The differences did not reach a significant level for the other qualities. For the three-way interaction, The mean squares were significant at only a 1% probability level for the percentage of phosphorus in the leaves. the mean squares were significant at the 5% probability level for the traits of total leaf chlorophyll content, average bulb weight and diameter, total plant yield (bulbs + leaves), and total bulb yield and marketing for the bulbs. However, the differences for the other traits did not reach significance. This aligns with the findings of [12,19,21,24,25,33], who reported significant differences between genotypes, including cultivars, for growth and yield traits in garlic

Continued from Table (2): Analysis of variance for the studied traits in garlic, representing mean squares values.

Sources of Variation	degrees of freedom	Mean Squares			
		Plant height (cm.plant^{-1})	Number of leaves (leaf.plant^{-1})	Leaf area (cm^2.plant^{-1})	Total leaf chlorophyll content (mg.g^{-1} fresh weight)
replicates	**2**	1.712	0.149	255374.112	58.380
cultivars	**2**	1586.839 **	8.483 **	5590848.399 **	12.750
Amino Acids	**2**	58.439 **	5.291 **	792528.657 **	22.288 *
Salicylic Acid	**1**	86.455 **	5.573 **	685842.998 **	37.821 **
cultivars× Amino Acids	**4**	0.644	0.317	52901.874	17.973 *
cultivars× Salicylic Acid	**2**	3.472	0.274	67245.322	14.314
Amino Acids ×Salicylic Acid	**2**	0.922	0.502	4704.186	8.225
cultivars × Amino Acids ×Salicylic Acid	**4**	5.292	0.101	41155.185	17.873 *
Experimental Error	**34**	3.411	0.239	32209.459	6.075

*** and ** are significant at probability levels of 0.05 and 0.01, respectively.**

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Continued from Table (2): Analysis of variance for the studied traits in garlic, representing mean squares values.

Sources of Variation	degrees of freedom	Mean Squares			
		Percentage of dry matter in the vegetative growth	Average weight bulb (g. bulb-1(	Length bulb (cm. bulb-1(	Diameter bulb (cm. bulb-1)
replicates	2	2.101	558.508	0.068	1.040
cultivars	2	10.567 **	18944.628 **	16.538 **	13.662 **
Amino Acids	2	83.628 **	219.962 *	2.955 **	1.287 **
Salicylic Acid	1	105.040 **	53.600 *	2.140 **	1.227 *
cultivars× Amino Acids	4	1.624	154.134 *	0.568 *	0.245
cultivars× Salicylic Acid	2	2.421	665.947 *	2.079 **	1.614 **
Amino Acids× Salicylic Acid	2	2.140	823.911 *	0.265	0.028
cultivars × Amino Acids ×Salicylic Acid	4	2.784	261.701 *	0.444	0.458 *
Experimental Error	34	2.164	401.036	0.193	0.215

***and ** are significant at the probability levels of 0.05 and 0.01, respectively.**

Continued from Table (2): Analysis of variance for the studied traits in garlic, representing mean squares values.

Sources of Variation	degrees of freedom	Mean Squares			
		Number of cloves per bulb(lobule $^{-1}$(	Average weight per cloves (g. lobe $^{-1}$(	Length of cloves (cm. lobe $^{-1}$(	Diameter of cloves (cm. lobe $^{-1}$)
replicates	2	1.994	4.362	0.037	0.094
cultivars	2	10.938 **	90.258 **	4.584 **	1.243 **
Amino Acids	2	0.409	1.377	0.250 **	0.030
Salicylic Acid	1	1.014	1.275	0.082	0.237 **
cultivars× Amino Acids	4	4.738 *	2.838	0.031	0.096
cultivars× Salicylic Acid	2	2.365	3.512	0.052	0.033
Amino Acids× Salicylic Acid	2	2.160	2.609	0.023	0.001
cultivars × Amino Acids ×Salicylic Acid	4	1.005	1.080	0.030	0.008
Experimental Error	34	1.956	2.612	0.040	0.033

- and ** are significant at the probability levels of 0.05 and 0.01, respectively

Continued from Table (2): Analysis of variance for the studied traits in garlic, representing mean squares values.

Sources of Variation	degrees of freedom	Mean Squares			
		Total plant yield (bulbs + leaves) (g. plant^{-1})	Yield Total of bulbs(tons.ha^{-1})	Market yield of bulbs (ton ha^{-1})	Percentage of the bulb
replicates	2	103.177	15.576	15.576	0.093
cultivars	2	14915.670 **	528.346 **	528.346 **	1.464 **
Amino Acids	2	1146.369 **	6.134 *	6.134 *	0.749 *
Salicylic Acid	1	2993.679 **	1.494 *	1.494 *	0.581
cultivars× Amino Acids	4	195.391 *	4.298 *	4.298 *	0.091
cultivars× Salicylic Acid	2	869.237 *	18.572 *	18.572 *	0.006
Amino Acids× Salicylic Acid	2	33.465 *	22.978 *	22.978 *	0.139
cultivars × Amino Acids ×Salicylic Acid	4	59.160 *	7.298 *	7.298 *	0.199
Experimental Error	34	320.132	11.184	11.184	0.244

and ** are significant at the probability levels of 0.05 and 0.01, respectively.

Continued from Table (2): Analysis of variance for the studied traits in garlic, representing mean squares values.

Sources of Variation	degrees of freedom	Mean Squares			
		Percentage total dissolved solids in the lobes (T.S.S.)	Percentage nitrogen in leaves	Percentage phosphorus in leaves	Percentage potassium in leaves
replicates	2	18.796	0.225	0.120	0.112
cultivars	2	46.750 *	0.278	0.021 **	0.029
Amino Acids	2	12.089	0.976 **	0.002	0.050 **
Salicylic Acid	1	9.458	0.033	0.014 **	0.015
cultivars× Amino Acids	4	9.019	0.159	0.016 **	0.013
cultivars× Salicylic Acid	2	8.957	0.279	0.010 *	0.001
Amino Acids× Salicylic Acid	2	12.631	0.665 **	0.012 **	0.047 **
cultivars × Amino	4	8.219	0.094	0.011 **	0.014

Acids ×Salicylic Acid					
Experimental Error	34	14.606	0.115	0.002	0.009

and ** are significant at the probability levels of 0.05 and 0.01, respectively.

Table (3) shows the values of the phenotypic variance components (genetic and environmental) and the genetic parameters (genetic and phenotypic coefficients of variation, broad-sense heritability, expected genetic improvement, and expected genetic improvement as a percentage) for the studied traits in garlic. It is evident that the values of genetic variance were significant above zero for all studied traits except for the total chlorophyll content of the leaves and the percentage of total soluble solids in the cloves. The values of environmental variance were also significant above zero for all traits. These results are consistent with the findings of [14,30,8,12,14,17,21], regarding the significant values of genetic and environmental variance for some garlic traits. **The results** indicate that the values of genetic variance were higher than the values of environmental variance for plant height, number of leaves, average bulb weight, length, and diameter, average lobe weight, length, and diameter, total plant yield (bulbs + leaves), and total bulb yield, and marketing for the bulbs and lower than for all other traits.

The highest values for the genetic variation coefficient were recorded for plant leaf area (22.322), average bulb weight (29.270), average clove weight (25.421), and total bulb yield (29.271). Conversely, the highest values for the phenotypic variation coefficient were recorded for plant leaf area (23.457), total leaf chlorophyll content (27.529), average bulb weight (34.500), average clove weight (31.511), total plant yield (bulbs + leaves) (23.455), and total bulb yield (34.501) and market yield for the bulbs is 34.501. This aligns with the findings of [11,19,24,25,33] who reported varying values for the genetic and phenotypic variation coefficients of variation in garlic.

It was found that the values of the phenotypic variation coefficient were significantly higher than the values of the genetic variation coefficient for all traits. This indicates the influence of environmental factors, specifically the application of amino acids and salicylic acid sprays, on the studied traits to varying degrees. This is because most of these traits are quantitative, and therefore selection is effective for these traits based on phenotypic characteristics [6].

Broad-sense heritability values ranged from 0.057 for total leaf chlorophyll content to 0.962 for plant height. These values were high for plant height (0.962), number of leaves (0.657), leaf area (0.905), average bulb weight (0.720), bulb length (0.824), bulb diameter (0.776), average clove weight (0.651), clove length (0.863), clove diameter (0.670), total plant yield (bulbs + leaves) (0.717), and total bulb yield (0.720) and marketing yield of the bulbs is 0.720. The values were low for all other traits. Previous studies have yielded varying broad-sense heritability values for some garlic traits, including those of [8,12,14,18,19,21,31] A high heritability of any trait provides breeders with a good opportunity to improve that trait through direct selection [5].

Table (3): Overall mean and components of phenotypic variance (genetic and environmental) and genetic parameters for the studied traits in garlic.

Genetic parameter	studied traits			
	Plant height ($cm.plant^{-1}$)	Number of leaves ($leaf.plant^{-1}$)	Leaf area ($cm^2.plant^{-1}$)	Total leaf chlorophyll content ($mg.g^{-1}$ fresh weight)
Genetic variance	87.968 62.337±	0.458 0.333±	308813.274 219629.700±	0.370 0.507±
Environmental variance	3.411 0.804±	0.239 0.056±	32209.459 7591.842±	6.075 1.431±
Phenotropic variance	91.379	0.697	341022.733	6.445
Coefficient of genetic variation	11.057	5.704	22.322	6.596
Phenotropic coefficient	11.270	7.037	23.457	27.529

Broad-sense heritability	0.962	0.657	0.905	0.057
Expected genetic improvement	18.943	1.130	1088.698	0.298
Expected genetic improvement as a percentage	22.333	9.525	43.732	3.231
Overall average of the trait	84.820	11.863	2489.473	9.222

Genetic parameter	**studied traits**			
	Percentage of dry matter in the vegetative growth	**Average weight of an bulb (g. bulb-1(**	**Length of an bulb (cm. bulb-1**	**Diameter of an bulb (cm. bulb-1)**
Genetic variance	0.466 0.416±	1030.199 744.234±	0.908 0.649±	0.747 0.537±
Environmental variance	2.164 0.510±	401.036 94.525±	0.193 0.045±	0.215 0.051±
Phenotropic variance	2.630	1431.235	1.101	0.962
Coefficient of genetic variation	3.218	29.270	15.626	13.081
Phenotropic coefficient	7.645	34.500	17.207	14.845
Broad-sense heritability	0.177	0.720	0.824	0.776
Expected genetic improvement	0.591	56.112	1.781	1.568
Expected genetic improvement as a percentage	2.786	51.171	29.206	23.732
Overall average of the trait	21.214	109.656	6.098	6.607

Continued from Table (3): The overall average and components of phenotypic variation (genetic and environmental) and genetic parameters of the studied traits in garlic.

Genetic parameter	**studied traits**			
	Number of cloves per bulb(cloves - 1(	**Average weight cloves (g. cloves - 1(**	**Length of cloves (cm. cloves - 1(**	**Diameter of cloves (cm. cloves - 1)**
Genetic variance	0.499 0.430±	4.869 3.546±	0.252 0.180±	0.067 0.049±
Environmental variance	1.956 0.461±	2.612 0.616±	0.040 0.009±	0.033 0.008±
Phenotropic variance	2.455	7.481	0.292	0.100
Coefficient of genetic variation	5.595	25.421	15.532	12.215
Phenotropic coefficient	12.410	31.511	16.719	14.923
Broad-sense heritability	0.203	0.651	0.863	0.670

Expected genetic improvement	0.655	3.668	0.961	0.436
Expected genetic improvement as a percentage	5.188	42.258	29.734	20.576
Overall average of the trait	12.626	8.680	3.232	2.119

Genetic markers	**studied characteristics**			
	Total plant yield (bulbs + leaves) (g. plant-1)	**Total yield of bulbs (tons.ha-1)**	**Market yield of bulbs (ton ha⁻¹)**	**Percentage of the bulb**
Genetic variance	810.863 585.958±	28.731 20.756±	28.731 20.756±	0.067 0.058±
Environmental variance	320.132 75.456±	11.184 2.636±	11.184 2.636±	0.244 0.058±
Phenotropic variance	1130.995	39.915	39.915	0.311
Coefficient of genetic variation	19.860	29.271	29.271	6.842
Phenotropic coefficient	23.455	34.501	34.501	14.742
Broad-sense heritability	0.717	0.720	0.720	0.215
Expected genetic improvement	49.673	9.371	9.371	0.247
Expected genetic improvement as a percentage	34.644	51.174	51.174	6.529
Overall average of the trait	143.382	18.312	18.312	3.783

Continued from Table (3): The overall average and components of phenotypic variation (genetic and environmental) and genetic parameters of the studied traits in garlic.

Genetic markers	**studied characteristics**			
	Percentage of total dissolved solids in the lobes (TSS)	**Percentage of nitrogen in leaves**	**Percentage of phosphorus in leaves**	**Percentage of potassium in leaves**
Genetic variance	1.785 1.846±	0.009 0.011±	0.001 0.0004±	0.001 0.001±

Environmental variance	14.606 3.443±	0.115 0.027±	0.002 0.001±	0.009 0.002±
Phenotropic variance	16.391	0.124	0.003	0.010
Coefficient of genetic variation	4.755	3.379	9.087	5.899
Phenotropic coefficient	14.410	12.540	15.739	18.656
Broad-sense heritability	0.108	0.074	0.333	0.100
Expected genetic improvement	0.901	0.054	0.038	0.021
Expected genetic improvement as a percentage	3.207	1.923	10.919	3.917
Overall average of the trait	28.096	2.808	0.348	0.536

Table (3) also indicates that the expected genetic improvement values, as a percentage of the average trait, ranged from low for the traits of number of leaves (9.525), total leaf chlorophyll content (3.231), percentage of dry matter in the vegetative body (2.786), number of lobes per bulb (5.188), bulb percentage (6.529), and percentage of total soluble solids in the lobes (3.207); The percentage of nitrogen in the leaves is 1.923 and the percentage of potassium in the leaves is 3.917. to medium for the traits of plant height (22.333), bulb length (29.206), bulb diameter (23.732), lobe length (29.734), and lobe diameter (20.576);The percentage of phosphorus in the leaves is 10.919 and high for the traits of plant leaf area (43.732), average bulb weight (51.171), average lobe weight (42.258), total plant yield (bulbs + leaves) (34.644), and total bulb yield (51.174) and marketing yield for the bulbs is 51.174. [8,9,12,19,21,24,25,33] However, the values of genetic improvement varied for the traits studied in the garlic plant..

The relationship between the genetic parameters (genetic and phenotypic coefficients of variation, heritability, and expected genetic improvement as a percentage) suggests that their values were consistent, either increasing or decreasing for most of the studied traits. This indicates a strong relationship between them. Therefore, based on this strong relationship, the expected genetic improvement in future selection cycles can be predicted using the values of the phenotypic coefficient of variation. In such cases, mass selection can achieve the desired crop improvement aims [34]

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