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Original Research Article

Character Association and Path Analysis of Garlic (*Allium sativum* L.) for Yield and Its Attributes

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Abstract: This research sought to determine the associations between bulb yield and other traits and to measure their effects of yield attributes on bulb yield of garlic genotypes. The experiment was laid out in randomized complete block design (RCBD) with three replications using twenty garlic genotypes with one standard check variety (HL) at Kulumsa Agricultural Research center, during 2020-2021. Yield and agronomic traits were determined. The data from two years were analyzed separately because the homogeneity of error variances of both seasons were not similar. In both seasons the association analyses indicated that the bulb yield was positively and significantly associated with plant vigor (0.9762), plant height (0.9057), neck thickness (0.5918), leaf width (0.7527), number of clove per bulb (0.766), cloves weight (0.9621), bulb polar diameter (0.9247), pseudo stem length (0.7885), clove height (0.9161), clove diameter (0.6412). Days to maturity and leaf length were negatively correlated with bulb yield at genotypic and phenotypic level. Consequences of path analyses indicated that bulb polar diameter (1.2478), clove height (1.0911), clove weight (0.9621), plant height (0.9057) and plant vigor (0.9762) had the highest positive direct effect on bulb yield at genotype level in first season and number of clove per bulb (0.9971), leaf width (0.9126), neck thickness (0.9912) in the 20221 season. On the other hand, most of the indirect effects of yield components on bulb yield were significant and positive. Because of the significant direct effects and positive correlations of those traits on bulb yield at phenotypic and genotypic levels, may be observed as important traits for garlic genotypes selection programs.

Keywords: Bulb Yield, Direct Effect, Indirect Effect, Path, Season.

INTRODUCTION

Garlic (*Allium sativum L.*) is a bulbous perennial crop cultivated in different temperate and subtropical climates all over the world (Elsharkawy *et al.*, 2021). It belongs to the genus Allium, which includes almost 1008 species distributed in 15 subgenera and more than 70 sections (Friesen *et al.*, 2020, Parreno *et al.*, 2023). After the onion it is the second most widely used cultivated bulb crops in the World (Benke *et al.*, 2021). It is widely grown in Ethiopia's central and highlands, both under irrigation and rain-fed conditions (Martha and Marie, 2019). 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 (Dejen *et al.*, 2021; Tesfaye *et al.*, 2021). 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 (Volk *et al.*, 2004; Tesfaye *et al.*, 2021). Garlic has a high degree of morphological variation due to its vegetative reproduction system (Shemesh and Kamenetsky, 2021). Natural variations in plant parts, have economic significance and suggest the possibility of garlic improvement (Hoogerheide *et al.*, 2017). In addition, a great number of cultivars have resulted through natural and human selection for adaptation in growing areas (Viana *et al.*, 2015). Soma clonal and spontaneous or induced mutations are important breeding methods to create garlic genetic variability (Singh *et al.*, 2021).

Correlated traits are important in studies of plant genetics and breeding because genetic factors, such as pleiotropic activity, developmental interactions of genes, and environmental changes, can create correlations (Horváth *et al.*, 2023). Correlation is a tool that assesses the linear relationship between bulb yield

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and yield components (Melesse and Asfaw, 2024). The degree of correlation is important to select high yielding garlic cultivars (Gehani and Kanbar, 2014). Genotypic and phenotypic correlation coefficients are crucial that indicates the relationship between yield and its component elements (Chotaliya and Kulkarni, 2017). Genotypic selection is more important option to select stable, high-yielding and better-quality of garlic cultivars (Singh *et al*., 2013). Genotypic correlation between more than two characters may be caused by the pleiotropic effects of genes or by the linking of genes controlling the inheritance of more than two characters. While phenotypic correlation is an association between two characters that can be observed and measured, environmental correlation is a two-variable relationship that includes correlation due to environmental traits and non-additive genetic causes (Dabholkar, 1992). Path and correlation coefficients are crucial designed tools used to identify direct or indirect correlations between bulb yield and yield components (Singh e*t al.,* 2018). And furthermore, path coefficient analysis provides a critical evaluation for establishing correlation and evaluating the proportional weight of each trait. Because knowledge regarding association and path coefficient analysis between yield and its components traits are important in determining the component characters that could be used as selection parameters for effective improvement of the crop (singh *et al*., 2011). Therefore, this study was aimed to determine the genotypic and phenotypic associations between various traits and to estimate the contribution of each trait to bulb yield improvement in garlic genotypes.

MATERIALS AND METHODS

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).

Experimental Materials and Design

A total of 20 garlic 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 × 2.4m. Each plot consisted of four rows, with 20 plants per row, and a total of 80 plants per plot with pacing of 20 cm within a plant and 10 cm between plants. The recommended rate of 242 kg NPS ha^{-1} was applied at planting as source of phosphorous and 75 kg N ha^{-1} 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 (Getachew *et al.,* 2009)

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- DebreZeit Agricultural Research Center, *= a released variety

Data Collection

Data collection included determination of days physiological to maturity, plant height, leaf length (cm), leaf width (cm), number of leaf per plant, 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 (IPGRI & Gr, 2001). Genotypic and phenotypic correlations as well as path coefficient analysis were analyzed using R software using vari-ability package (R Core Team 2021). Mean separation was carried out using Duncan's Multiple Range Test (DMRT) at 5% and 1% level of significance. The correlation coefficients were interpreted within the range of -1.0 to +1.0, as outlined by Singh and Singh (2010).

Correlation Analysis

Phenotypic correlation is the relationship between two variables, which includes both genotypic and environmental effects, and genotypic correlation is the inherent association between two variables. These were estimated using the formula suggested by Miller *et al.*, (1958).

$$\mathbf{r}\text{p} = \frac{Pcov\ x.y}{\sqrt{\sigma 2_{\text{g}}\text{X} * \sigma 2_{\text{P}}Y}} \quad \mathbf{r}\text{p} = \frac{Gcov\ x.y}{\sqrt{\sigma 2_{\text{g}}\text{X} * \sigma 2_{\text{P}}Y}}$$

Where, $\mathbf{r}_p$ = phenotypic correlation coefficient, Pcov x.y = phenotypic covariance between character x and y,

$\sigma 2_{g} X$ = phenotypic variance for character x, and $\sigma 2_{P} Y$ = phenotypic variance for character y; $\mathbf{r}_g$ = genotypic correlation coefficient, Gcov x.y = genotypic covariance between characters x and y, $\sigma 2_{g} X$ = genotypic variance for character x, and $\sigma 2_{P} Y$ = genotypic variances for the character y.

Path Coefficient Analysis

In path-coefficient analysis, tuber yield per plant was taken as the resultant (dependent) variable while rest of the characters considered as causal (independent) variables. The direct and indirect effects of the independent characters on bulb yield per plant were estimated by the simultaneous solution of the following general formula suggested by Dewy and Lu (1959):

rij = pij + Σrik pkj where, **rij** = mutual association between the independent character (i) and dependent character (j) as measured by the genotypic correlation coefficients, **pij** = components of direct effects of the independent character (i) on the dependent character (j) as measured by the genotypic path coefficients, and Σ**rikpkj** = summation of components of indirect effects of a given independent character (i) on the given dependent character (j) via all other independent characters (k).

To determine pij values, square matrices of the correlation coefficients between independent characters in all possible pairs inverted and then multiplied by the correlation coefficients between the independent and dependent characters using Agro base statistical package. Residual effects were estimated using the formula: $\sqrt{1-R^2}$ where, $R^2 = \sum P_{ij} r_{ij}$

RESULTS AND DISCUSSION

Phenotypic and Genotypic Correlations

In this study, genotypic correlation (r_g) coefficients were computed in addition to phenotypic correlation (r_p) coefficients to obtain better estimates of the associations between bulb yield and related traits for two seasons (Table 2 & 3). Many of the characters were positively and negatively correlated with each other. Many researcher was reported the existence of association between different traits in garlic genotype (Ranjitha *et al.*, 2018, Esho, 2023). Accordingly the result in 2020 season, total tuber yield per hectare was highly significantly and positively correlated with plant vigor (r_g = 0.9762** and r_p = 0.7764**), plant height (r_g= 0.9057** and r_p = 0.6739**), neck thickness (r_g = 0.5918** and r_p = 0.481**), pseudo stem length (r_g = 0.7885 and r_p = 0.5837), leaf width (r_g = 0.7527** and r_p = 0.5556**), number of clove per bulb (r_g = 0.766** and r_p = 0.6515**), clove weight (r_g = 0.9621** and r_p = 0.5729**), clove height (r_g = 0.9161** and r_p = 0.6613**), clove diameter (r_g = 0.6412** and r_p = 0.3473**), bulb polar diameter (r_g = 0.9247** and r_p = 0.6021**), bulb equatorial diameter (r_g =0.8268** and r_p = 0.683**), both at genotypic and phenotypic level (Table 4). Positive correlations are due to control of the traits which are under control of genes responsible for direct production of ancestors, and they attributes more the bulb yield in garlic and were important for bringing improvement in bulb yield. In line with our results different authors Chataliya and Kulkarni, 2017, Singh *et al.*, (2011), Kumar *et al*., (2017), Melese & Asfaw, 2024, found that total bulb tubers have positive and significant association with total bulb yield. While, physiological maturity (-0.0788^{ns} and 0.0067^{ns}), and leaf length (-0.3279^{ns} and 0.0176^{ns}) was negatively and non-significantly correlated, with total bulb yield per hectare at genotypic and phenotypic level respectively. Negative non-significant genotypic correlation was found between plant vigor and days to maturity, days to maturity and clove diameter, leaf length and plant height, leaf length and number of clove per bulb, weight of clove and leaf length, bulb polar diameter and leaf length. Negative correlations occur due to the restricted supply of ancestor for which traits compete against each other. Bulb equatorial diameter and bulb polar diameter had positive and significant association with each other at both genotypic and phenotypic levels. These were also found to have significant association with bulb weight and clove length which indicated that improvement in one will bring the improvement in the other character, bulb polar diameter also had significant association with bulb yield. Clove weight and clove length were have positive and significant association with each other, also number of clove per bulb had positive and significant association with clove length, clove diameter, hence selection for one character has the opposite effect on the other.

In second season 2021, total bulb yield was positive and highly significant ($p<0.01$) correlation with clove weight (0.6852**), number of clove per bulb (0.9971**), leaf width (0.9126**), neck thickness (0.9912**), plant height (0.8439**), plant vigor (1.0039**), bulb polar diameter (0.7962**) at genotypic level while, at phenotypic level plant vigor (0.3674**) and neck thickness (0.3444**) shows positive and highly significant (Table 3). Similarly, Melesse *et al*., (2024) reported that total bulb yield showed positive and significant correlation with marketable tuber yield at both phenotypic as well as at genotypic levels. These positive correlations indicating that selection for improving one character will lead to increase the other one which is positively correlated with that character. Total bulb yield was significantly and negatively correlated with days to maturity (-0.9296**), pseudo stem length (-0.9025**), clove diameter (-0.058**) at genotypic level. Negative correlation between two traits implies selection for improving one character will likely cause decrease in the other traits. Bulb equatorial diameter also exhibited positive and highly significant association with bulb polar diameter (r_g =0.7962** and r_p = 0.6524**), at both level. This suggested that the simple selection to improve one trait simultaneously increase the second character. Total bulb yield was positively association with plant height, pseudo stem length and number of clove per bulb at phenotypic level (Table 3).

Table 2: Genotypic and phenotypic correlation coefficients among garlic genotype traits (below genotypic & above phenotypic correlation) in 2020

Trait	V	MD	PH	Nth	Shl	LW	NCB	LL	Wtc	CH	CD	BPD	BED	TWt
V	1**	-0.05^{ns}	0.5803**	0.4628**	0.647**	0.5901**	0.5401**	0.0837^{ns}	0.252^{ns}	0.5406**	0.192^{ns}	0.4832**	0.5484**	0.7764**
Md	-0.2628^{ns}	**1****	0.1452^{ns}	0.1366^{ns}	0.098^{ns}	0.2416^{ns}	0.2675*	0.3097*	-0.1896^{ns}	-0.173^{ns}	-0.2481^{ns}	-0.0199^{ns}	0.0309^{ns}	0.0067^{ns}
Plh	0.0945**	0.0978^{ns}	**1****	0.3769**	0.5694**	0.5952**	0.6742**	0.1185^{ns}	0.4393**	0.4184**	0.2763*	0.5645**	0.5483**	0.6739**
Nth	0.2408^{ns}	0.0356**	0.733**	**1****	0.2914*	0.4458**	0.5251**	0.2871*	0.2993*	0.4163**	0.157^{ns}	0.5129**	0.4179**	0.481**
ShL	0.0816**	-0.158^{ns}	0.0763**	0.0667**	**1****	0.5024**	0.4937**	-0.020^{ns}	0.2224^{ns}	0.4055**	0.2147^{ns}	0.4072**	0.3832**	0.5837**
LW	-0.9502**	0.1639^{ns}	0.0796**	0.0606**	0.0884**	**1****	0.5887**	0.2179^{ns}	0.2149^{ns}	0.4088**	0.1193^{ns}	0.5256**	0.6443**	0.5556**
NCB	0.7409**	0.0806**	0.0786**	0.1015**	0.2625**	0.2641**	**1****	0.2642*	0.346**	0.4118**	0.1539^{ns}	0.5236**	0.5124**	0.6515**
LL	-0.5087*	0.0087**	-0.4374^{ns}	0.0157^{ns}	-0.0425**	0.057^{ns}	-0.4825^{ns}	**1****	-0.2648*	-0.2418^{ns}	-0.4468**	0.0935^{ns}	0.0916^{ns}	0.0176^{ns}
WtC	0.8384**	-0.0611^{ns}	0.1085**	0.4826**	0.0482*	0.0706**	0.5518**	-0.4137^{ns}	**1****	0.5967**	0.6616**	0.4969**	0.5784**	0.5729**
CH	0.0285**	0.0296^{ns}	0.2488**	0.1845^{ns}	0.2145**	0.1649**	0.0535**	0.8379**	0.3249**	**1****	0.4691**	0.6159**	0.7073**	0.6613**
CD	0.5569*	-0.3757^{ns}	0.0175**	-0.4686**	0.0861**	0.1506^{ns}	0.4848*	-0.8706**	0.0835**	0.2361**	**1****	0.3341**	0.4065**	0.3473**
BPD	0.0579**	0.0736**	-0.2536**	0.0746**	0.0704**	0.0387**	0.0929**	-0.0789^{ns}	0.1626**	0.1707**	0.2505**	**1****	0.6524**	0.6021**

BED	0.0584^{**}	0.0262^{ns}	0.2544^{**}	0.0742^{**}	0.0609^{*}	0.0068^{**}	0.6572^{**}	0.1974^{ns}	0.3911^{**}	0.509^{**}	0.3908^{*}	0.9247^{**}	**1****	0.683^{**}
Twt	0.9762^{**}	-0.0788^{ns}	0.9057^{**}	0.5918^{**}	0.7885^{**}	0.7527^{**}	0.766^{**}	-0.3279^{ns}	0.9621^{**}	0.9161^{**}	0.6412^{**}	0.9247^{**}	0.8268^{**}	**1****

V= Vigorisity, MD=Days to maturity, PH = Plant height (cm), Nth is neck thickness , SHL is pseudo stem length, LW is leaf width(cm), NCB is Number of clove per bulb, LL is leaf length (cm), 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: Genotypic and phenotypic correlation coefficients among garlic genotype traits (below genotypic & above phenotypic correlation) in 2021

Traits	V	MD	PH	Nth	Shl	LW	NCB	LL	Wtc	CH	CD	BPD	BED	TWt
V	**1****	-0.1008^{ns}	0.5489^{**}	0.4945^{**}	0.3318^{**}	0.413^{**}	0.6349^{**}	0.1331^{ns}	0.1882^{ns}	0.2117^{ns}	-0.0652^{ns}	-0.0707^{ns}	0.0377^{ns}	0.3674^{**}
Md	0.029^{ns}	**1****	0.0445^{ns}	0.0558^{ns}	0.1567^{ns}	0.0982^{ns}	0.0357^{ns}	0.1104^{ns}	-0.2461^{ns}	0.0827^{ns}	0.0044^{ns}	0.0678^{ns}	0.0127^{ns}	-0.1628^{ns}
Plh	0.408^{**}	0.0512^{*}	**1****	0.5474^{**}	0.3536^{**}	0.4523^{**}	0.6859^{**}	0.2455^{ns}	0.1414^{ns}	0.0999^{ns}	-0.1524^{ns}	0.0561^{ns}	0.0224^{ns}	0.3263^{*}
Nth	0.2441^{**}	0.0429^{**}	0.0391^{**}	**1****	0.3123^{*}	0.243^{ns}	0.6007^{**}	-0.0046^{ns}	0.3099^{*}	0.29^{*}	0.0977^{ns}	-0.0845^{ns}	-0.1478^{ns}	0.3444^{**}
ShL	0.0409^{ns}	0.3485^{ns}	0.0254^{**}	0.0614^{**}	**1****	0.2136^{ns}	0.3735^{**}	0.1576^{ns}	0.1956^{ns}	0.3478^{**}	0.2686^{*}	-0.0399^{ns}	0.0027^{ns}	0.328^{*}
LW	0.1262^{**}	-0.2776^{ns}	0.0379^{**}	0.2922^{**}	0.0125^{**}	**1****	0.6147^{**}	0.1158^{ns}	-0.0142^{ns}	-0.1376^{ns}	0.0027^{ns}	-0.0054^{ns}	0.0695^{ns}	0.1087^{ns}
NCB	0.0404^{**}	0.0468^{ns}	0.1799^{**}	0.9186^{**}	0.0211^{**}	0.2302^{**}	**1****	0.1174^{ns}	0.2615^{*}	0.2234^{ns}	-0.0028^{ns}	0.0973^{ns}	0.1008^{ns}	0.2883^{*}
LL	0.2085^{ns}	0.0285^{**}	0.0656^{**}	-0.0789^{ns}	-0.0209^{**}	0.8303^{**}	0.5885^{**}	**1****	-0.1273^{ns}	-0.1618^{ns}	-0.214^{ns}	-0.0604^{ns}	-0.0045^{ns}	0.0035^{ns}
WtC	0.0087^{ns}	0.0676^{ns}	0.04524^{*}	0.6593^{**}	0.2038^{**}	0.358^{ns}	0.6741^{ns}	-0.3699^{ns}	**1****	0.2754^{*}	0.256^{*}	-0.0246^{ns}	0.0641^{ns}	0.1785^{ns}
CH	0.3059^{**}	0.1118^{ns}	0.3643^{ns}	0.5851^{**}	0.0802^{**}	0.2202^{**}	0.5975^{**}	-0.2758^{ns}	0.4027^{**}	**1****	0.2415^{ns}	0.0938^{ns}	0.193^{ns}	0.2273^{ns}

CD	-0.6720**	0.7397**	-0.5185ns	-0.6389*	0.1562**	0.4408**	-0.5198*	-0.6767**	0.0281ns	0.0101**	**1****	-0.1802ns	-0.0553ns	0.1359ns
BPD	-0.1306ns	-0.2953**	0.2638ns	-0.3751**	-0.5837**	-0.8209**	-0.4103ns	0.6255**	0.1563ns	-0.1198ns	-0.0659ns	**1****	0.6524**	0.0664ns
BED	0.1337ns	0.0655**	-0.066ns	-0.4325ns	-0.7717ns	-0.346ns	0.0671ns	0.5884**	0.0981ns	0.0928**	-0.0197ns	0.7962**	**1****	-0.0263ns
Twt	1.0039**	-0.9296**	0.8439**	0.9912**	-0.9025**	0.9126**	0.9971**	-0.1085ns	0.6852**	-0.0169ns	-0.0856**	0.7962**	0.1082*	**1****

Where, V= Vigorisity, MD=Days to maturity, PH = Plant height (cm), Nth is neck thickness , SHL is pseudostem length, LW is leaf width(cm), NCB is Number of clove per bulb, LL is leaf length (cm), 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).

4.2. Path Coefficient Analysis

Path coefficient analysis was performed to divide the correlation coefficients between tuber yield and yield related traits into direct and indirect effects via pathways. In 2020 cropping season clove weight (0.9621, number of clove per bulb (0.766), clove length (1.0911), clove diameter (0.6412), plant vigor (0.9762), plant height (0.9057), neck thickness (0.5918), pseudo stem length (0.7885), leaf width (0.7527), bulb polar diameter (1.2478) and bulb equatorial diameter (0.8268) had highly significant and positive direct effect on total bulb yield at genotypic level (Table 4). This indicates that direct selection for those trait will be effective for improvement of bulb yield of garlic. While at phenotypic level, plan vigor (0.026), plant height (0.6739), pseudo stem length (0.5837), leaf width (0.5556), clove weight (0.5729), clove length (0.6613), clove diameter (0.3473), bulb polar diameter (0.6021), and bulb equatorial diameter (0.0.683) had significant and positive direct effect on total bulb yield. An increase in any of these yield components causes some increase in bulb yield in garlic. On the other hand days to maturity (-0.0788), and leaf length (-0.3279) had negative direct effect on total bulb yield at genotypic level (Table 4). In 2021 cropping season days to maturity (0.3674), plant vigor (1.0039), plant height (0.8439), neck thickness (0.9912), leaf width (0.9126), number of clove per bulb (0.9971), weight of clove (0.6852) and bulb polar diameter (0.7962) had significant and positive direct effect on bulb yield at genotypic level. Plant vigor (0.3674), plant height (0.3263), neck thickness (0.3444), pseudo stem length (0.3280), number of clove per bulb (0.2883) had positive direct effect on bulb yield at phenotypic level (Table 5). These indicate that an increase in any of these yield components causes some increase in bulb yield. Similar research results were reported on different garlic genotypes and determined the direct effects of different yield components on bulb yield (Ranjitha *et al.*, 2018, Kumar *et al.*, 2017, Melesse & Asfaw, 2024, Siddarth *et al.*, 2023). On the other hand pseudo stem length (-0.9025), clove height (-0.016) and leaf length (-0.1085) had negative direct effect on bulb yield at genotypic level, and days to maturity (-0.1628) and bulb equatorial diameter (-0.026) negative and non-significant effect at phenotypic level (Table 5).

Table 4: Genotypic and phenotypic path coefficient analysis (Diagonal (bold) value indicates direct effect; above and below the diagonal value indicates indirect effect) among eight yield and yield component traits in garlic genotypes during 2020 season

Traits		V	MD	PH	Nth	Shl	LW	NCB	LL	WtC	CH	CD	BPD	BED	rg/ rp
V	G	**-0.4960**	0.0794	0.6721	0.2134	-0.2856	0.8875	-0.0093	0.4450	-0.5723	-0.1415	0.2341	-0.5397	0.4891	0.9762**
	P	**0.4927**	-0.0024	0.0494	-0.0087	0.0246	-0.0350	0.0838	-0.0007	0.0761	0.0497	-0.0132	0.0072	0.0523	0.7764**

LL		NCB		LW		Shl		Nth		PH		MD
G	P	G	P	G	P	G	P	G	P	G	P	G
0.7834	0.2660	-0.1083	0.2892	-0.4217	0.3186	-0.2439	0.2302	-0.6591	0.2859	-0.5087	-0.0246	0.3931
-0.3177	0.0126	-0.3342	0.0114	-0.0495	0.0046	0.0465	0.0065	-0.3135	0.0068	-0.0900	**0.0470**	**-0.3021**
-0.2915	0.0574	0.7256	0.0507	0.5863	0.0485	0.5587	0.0321	0.4886	**0.0852**	**0.6665**	0.0124	0.1985
0.1965	-0.0098	0.4368	-0.0083	0.4430	-0.0054	0.2745	**-0.0181**	**0.4844**	-0.0070	0.3552	-0.0026	0.5026
0.2550	0.0188	-0.3182	0.0192	-0.2090	**0.0381**	**-0.3435**	0.0111	-0.1946	0.0217	-0.2879	0.0037	0.0529
0.1132	-0.0351	0.7245	**-0.0594**	**0.9874**	-0.0300	0.2083	-0.0265	0.8162	-0.0355	0.7473	-0.0144	0.3254
0.0014	**0.1553**	**-0.0126**	0.0915	-0.0109	0.0767	-0.0117	0.0816	-0.0114	0.1047	-0.0137	0.0415	-0.0139
-0.8497	-0.0023	0.0956	-0.0019	-0.0484	0.0002	0.6309	-0.0025	-0.3446	-0.0010	0.3717	-0.0027	-0.8936
0.2141	0.1047	-0.5473	0.0641	-0.4575	0.0672	-0.3366	0.0918	-0.8074	0.1329	-0.6047	-0.0574	-0.1093
0.1152	0.0378	-0.1175	0.0379	-0.1163	0.0373	-0.1023	0.0389	-0.0391	0.0383	-0.1416	-0.0159	-0.0179
-0.4461	-0.0106	0.2479	-0.0081	0.0781	-0.0148	0.2988	-0.0122	0.2888	-0.0189	0.3163	0.0170	-0.1203
0.0292	0.0078	-0.4776	0.0078	-0.5322	0.0060	-0.4087	0.0077	0.5090	0.0084	-0.3531	-0.0003	-0.2197
-0.1308	0.0489	0.4512	0.0615	0.5035	0.0366	0.2172	0.0410	0.3745	0.0524	0.4484	0.0030	0.1255
-0.3279^{ns}	0.6515^{**}	0.766^{**}	0.5556^{**}	0.7527^{**}	0.5837^{**}	0.7885^{**}	0.481^{**}	0.5918^{**}	0.6739^{**}	0.9057^{**}	0.0067^{ns}	-0.0788^{ns}

	BED		BPD		CD		CH		WtC	
p	G	P	G	P	G	p	G	P	G	P
0.2697	-0.5523	0.2378	-0.1811	0.0948	-0.6837	0.2665	-0.5387	0.1240	-0.2542	0.0412
0.0015	-0.0804	-0.0009	-0.1793	-0.0116	0.0710	-0.0081	-0.0392	-0.0089	-0.0484	0.0146
0.0467	0.6341	0.0481	0.6356	0.0234	0.4116	0.0356	0.6857	0.0374	0.5905	0.0101
-0.0080	0.3849	-0.0097	0.6661	-0.0033	0.2731	-0.0079	0.1377	-0.0057	0.5730	-0.0054
0.0146	-0.1583	0.0155	-0.3792	0.0082	-0.2003	0.0155	-0.2552	0.0085	-0.1693	-0.0008
-0.0384	0.9213	-0.0312	0.8551	-0.0070	0.3026	-0.0246	0.6779	-0.0126	0.3312	-0.0130
0.0796	-0.0121	0.0814	-0.0163	0.0240	-0.0061	0.0640	-0.0108	0.0538	-0.0101	0.0410
-0.0008	0.2357	-0.0008	0.0670	0.0039	0.7400	0.0021	0.7112	0.0023	0.2666	**-0.0087**
0.1745	-0.6765	0.1501	-0.7180	0.1992	-0.5897	0.1818	-0.7678	**0.3024**	**-0.6826**	-0.0801
0.0646	-0.1504	0.0565	-0.1198	0.0437	-0.1168	**0.0916**	**-0.1376**	0.0552	-0.1548	-0.0222
-0.0273	0.2533	-0.0225	0.4227	**-0.0710**	**0.5123**	-0.0327	0.4350	-0.0452	0.4426	0.0306
0.0097	-0.4439	**0.0148**	**-0.3702**	0.0049	-0.3055	0.0091	-0.3222	0.0074	-0.3894	0.0014
0.0958	**0.4714**	0.0623	0.5652	0.0379	0.2331	0.0672	0.5151	0.0551	0.4672	0.0088
0.683^{**}	0.8268^{**}	0.6021^{**}	1.2478^{**}	0.3473^{**}	0.6412^{**}	0.6613^{**}	1.0911^{**}	0.5729^{**}	0.9621^{**}	0.0176^{ns}

Where, G=phenotypic path coefficient analysis; P=phenotypic path coefficient analysis; ns, *, ** = non-significant, Significant at 5% and 1%, respectively; rg-Genotypic correlation with total bulb yield (t ha^{-1}); rg-Phenotypic correlation with total bulb yield (t ha^{-1}); Genotypic Residual effect = 0.9792 & Phenotypic Residual effect 0.1947;

V= Vigorisity, MD=Days to maturity, PH = Plant height (cm), Nth is neck thickness, SHL is pseudo stem length, LW is leaf width (cm), NCPB is Number of clove per bulb, LL is leaf length (cm), 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)

Table 5: Genotypic and phenotypic path coefficient analysis (Diagonal (bold) value indicates direct effect; above and below the diagonal value indicates indirect effect) among eight yield and yield component traits in garlic genotypes during 2021 season

Traits		V	MD	PH	Nth	Shl	LW	NCB	LL	WtC	CH	CD	BPD	BED	rg/rp
V	G	-0.5835	-0.3016	0.4027	0.1389	0.5046	-0.6264	0.0329	-0.0296	-0.0572	0.2379	0.4554	0.3246	0.5052	1.0039**
	P	0.2288	0.0208	0.0936	0.0678	0.0595	-0.0032	-0.083	-0.0005	-0.0048	0.0196	-0.0077	-0.017	-0.0065	0.3674**
MD	G	-0.2786	-0.3174	0.8779	-0.2541	0.4002	0.3288	0.6054	0.6204	-0.4427	0.0594	-0.2993	0.2186	-0.589	0.9296**
	P	-0.0231	-0.2056	0.0076	0.0077	0.0281	-0.0008	-0.0047	-0.0004	0.0062	0.0077	0.0000	0.0164	-0.0022	-0.1628^{ns}
PH	G	-0.0698	0.6866	-0.4676	0.3766	0.7379	-0.9852	0.2141	-0.1400	-0.6131	0.1704	0.6645	0.6576	-0.3881	0.8439**
	P	0.1255	-0.0092	0.1705	0.0750	0.0635	-0.0035	-0.0896	-0.0009	-0.0036	0.0091	-0.0202	0.0136	-0.0038	0.3263*
Nth	G	-0.7185	0.0786	-0.7691	0.4254	0.7336	-0.3540	0.7449	0.0431	-0.3111	0.2740	0.9450	0.6772	-0.7779	0.9912**
	P	0.1135	-0.0116	0.0936	0.1377	0.0562	-0.0018	-0.0787	0.0000	-0.0079	0.0264	0.0132	-0.0209	0.0249	0.3444**
Shl	G	-0.3502	-0.4589	-0.2951	0.3593	0.1662	-0.7462	0.9412	0.0089	-0.5636	0.8329	-0.7427	0.5558	-0.6101	-0.9025**
	P	0.0758	-0.0322	0.0603	0.0428	0.1794	-0.0017	-0.0488	-0.0006	-0.005	0.0320	0.0357	-0.0095	-0.0005	0.3280*
LW	G	-0.6128	0.3657	-0.4114	0.6765	0.1754	-0.3895	0.9906	-0.4745	-0.3414	0.5714	0.2528	0.1463	-0.0365	0.9126**
	P	0.0938	-0.0204	0.0773	0.0308	0.0384	-0.0079	-0.0804	-0.0004	0.0004	-0.012	0.0000	0.0000	-0.0108	0.1087ns

BED		BPD		CD		CH		WtC		LL		NCB
G	P	G	P	G	p	G	P	G	P	G	P	G
-0.8022	-0.0161	0.7293	-0.0133	0.5795	0.0487	-0.2271	0.0429	-0.0489	0.0304	-0.1109	0.1451	-0.6923
0.2512	-0.0139	0.8139	0.0000	-0.2871	-0.0173	-0.1475	0.0503	-0.0891	-0.0227	-0.0864	-0.0073	-0.0616
0.7564	0.0096	0.0251	-0.026	0.5010	0.0169	-0.1976	0.0241	-0.3348	0.0419	-0.078	0.1170	-0.5301
-0.7570	-0.0118	-0.8521	0.0136	-0.6491	0.0391	0.0531	0.0425	0.7737	-0.0006	-0.1656	0.0824	0.2592
-0.4139	-0.0071	-0.2967	0.0482	0.0255	0.0624	0.3991	0.0351	0.186	0.0283	-0.0402	0.0670	0.5854
0.5194	0.0000	0.6031	0.0000	-0.0809	0.0010	-0.3618	0.0001	-0.5713	-0.0009	-0.3469	-0.0048	-0.0827
0.8654	-0.0127	-0.0008	0.0003	-0.6908	-0.0292	0.2615	-0.0342	0.2104	-0.0153	0.3249	-0.1307	0.8949
-0.3351	0.0002	-0.4046	0.0008	0.6377	0.0006	0.0063	0.0005	0.5478	-0.0036	-0.4889	-0.0004	-0.7695
-0.6062	0.0007	-0.9912	-0.0066	-0.1237	-0.0070	-0.1536	-0.0254	-0.5416	0.0032	0.4062	-0.0067	-0.6284
0.3737	0.0085	-0.1778	0.0213	0.3792	0.0917	0.2678	0.0254	0.6552	-0.0149	-0.1276	0.0206	0.2707
0.3626	-0.0223	0.2007	0.1283	-0.0517	0.0307	-0.476	0.0343	-0.0569	-0.0284	0.4061	-0.0003	0.5833
-0.9892	0.241	-0.4928	-0.0405	0.1639	0.0221	0.1475	-0.0062	-0.3895	-0.0145	-0.028	0.0235	0.7734
0.8831	-0.1092	0.6545	0.0115	-0.4891	-0.033	0.4123	-0.0109	0.3442	0.0007	0.2268	-0.0169	0.3948
0.1082ns	0.0664ns	0.7962**	0.1359ns	-0.0856*	0.2273ns	-0.016ns	0.1785ns	0.6852**	0.0035ns	-0.1085ns	0.2883*	0.9971**

	P	0.0088	-0.0027	0.0039	-0.0204	0.0005	-0.0005	-0.0132	0.0000	-0.0017	0.0182	-0.0091	0.1574	-0.1679	-0.0263ns

where, G=phenotypic path coefficient analysis; P=phenotypic path coefficient analysis; ns, *, ** = non-significant, Significant at 5% and 1%, respectively; rG-Genotypic correlation with total tuber yield (t ha^{-1}); rP-Phenotypic correlation with total tuber yield (t ha^{-1}); Genotypic Residual effect = 0.7042 & Phenotypic Residual effect 0.7991; V= Vigorisity, MD=Days to maturity, PH = Plant height (cm), Nth is neck thickness , SHL is pseudo stem length, LW is leaf width(cm), NCPB is Number of clove per bulb, LL is leaf length (cm), 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).

CONCLUSION

Correlation and path analyses of the result indicated that Plant height, number of clove per bulb, clove weight, clove height, clove diameter, bulb polar diameter, and bulb equatorial diameter were the main components to bulb yield. For this reason, these traits could be used more significantly for garlic improvement. As a result, bulb yield was significantly and positively correlated with number of clove per bulb, clove weight, clove height, clove diameter, bulb polar diameter, bulb equatorial diameter, plant vigor, plant height, neck thickness, pseudo stem length, and leaf width. While bulb yield was significant and negatively correlated with days to maturity, pseudo stem length, clove diameter at genotypic level. Negative correlation between two traits implies selection for improving one character will likely cause decrease in the other traits. The result of path analysis indicated that clove weight, number of clove per bulb, length, clove diameter, plant vigor, plant height, neck thickness, pseudo stem length, leaf width, bulb polar diameter and bulb equatorial diameter had highly significant and positive direct effect on total bulb yield at both genotypic and phenotypic level. The traits that are directly and significantly associated with bulb yield should be considered in selection at garlic improvement programs that aim to increasing bulb yield.

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