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Trait Correlation and Path Study for Quantitative Traits in Garlic (*Allium sativum* L.) Genotypes

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Abstract: Garlic is a widely cultivated vegetable with both culinary and medicinal uses in Ethiopia. The analyses, focusing on various traits, help in identifying genotypes with high productivity and quality. Garlic reproduces solely vegetatively due to male and female sterility in its gametophytes. Its domestication originated from the wild species Allium longicuspis Regel. The introduction of diverse garlic varieties contributes to enhancing its genetic potential. This study aimed to assess the relationship between different traits and their influence on garlic bulb yield. The experiment conducted during the rainy season of 2020–2021 at the Fogera National Rice Research and Training Center in Ethiopia. The experiment included 49 garlic genotypes arranged in a simple lattice design with two replications. The results revealed significant genotypic correlation coefficients between fresh bulb yield per hectare and bulb weight per plant (r = 0.82***), pseudo-stem height (r = 0.82***), and clove weight (r = 0.81***). Similarly, significant positive phenotypic associations were observed between fresh bulb yield per hectare and clove weight per bulb (r = 0.77***), pseudo-stem height (r = 0.77***), and bulb weight per plant (r = 0.76***). Further analysis indicated that pseudo-stem height (0.42) and clove weight (0.39) exerted the highest phenotypic direct effects on fresh bulb yield per hectare. Therefore, traits such as clove weight, pseudo-stem height, and bulb weight exhibit high genotypic coefficients and significant direct effects on total bulb yield, making them crucial for direct selection to increase bulb yield.

Keywords: Bulb, Clove, Genotypic, Phenotypic, Vegetable.

Research Paper

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1. INTRODUCTION

Allium sativum L., commonly known as garlic, is a member of the Alliaceae family, which encompasses various other known members, including shallots (Allium ascalonicum L.), leeks (Allium ampeloprasum L.), and onions (Allium cepa L.) (Ipek *et al*., 2005). It is classified under a monocotyledon bulb vegetable and with a chromosome number is 2n = 16 (Mahajan *et al.*, 2017). Somaclonal and spontaneous or induced mutations are important breeding methods to create garlic genetic variability (Singh *et al.*, 2021). In conventional breeding new garlic cultivars developed through clonal selection and introductions from different growing environments (Rubatzky and Yamaguchi, 1997). Garlic has a high degree of morphological variation due to its vegetative reproduction system (Shemesh and Kamenetsky, 2021). Garlic's sterility was brought about through evolution and domestication (Etoh, 1985). Garlic produces umbels of flowers but does not produce fertile seeds because of its gametophytes' male and female sterility (Benke *et al.*, 2020b). The origin of garlic is the Tien Shan Mountains in Central Asia (Etoh and Simon, 2002), and it was domesticated from the wild species (Allium longicuspis Regel) (Vavilov, 1951).

Correlation is a tool that assesses the linear relationship between bulb yield and yield components. 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).

Research on garlic breeding in Ethiopia is limited, with bulb yield being a crucial trait that requires immediate direct improvement for productivity (Raja *et al.*, 2017). Path and correlation coefficients are crucial designed tools used to identify direct or indirect correlations between bulb yield and yield components

(Singh *et al*., 2018). And furthermore, path coefficient analysis provides a critical evaluation for establishing correlation and evaluating the proportional weight of each trait. Therefore, the objective of the study was to determine the genotypic and phenotypic associations between various traits and their direct and indirect impacts on garlic bulb yield.

2. MATERIALS AND METHODS

The experiment took place at the Fogera National Rice Research and Training Center within the Horticulture Research Station during the rainy season of 2020–2021. It encompassed 49 garlic genotypes sourced from different regions of Ethiopia. The site, situated at 11° 58′ N latitude and 37° 41′ E longitude. It has an elevation of 1819 meters above sea level and receives an annual rainfall of 1230 mm. The average temperatures range from 12°C to 28°C. The soil is identified as red clay with a pH of 5.48 (Getahun and Getaneh in 2019).

The experiment utilized a simple lattice design with 7x7 layouts replicated twice. Before planting, the experimental area was ploughed and leveled. Double rows were spaced 40 cm apart; with individual rows spaced 20 cm apart and plants positioned 10 cm apart. Cloves were planted with their basal portion at the soil's surface and the tip portion erect. Key parameters such as plant height (cm), leaf count, pseudo stem length (cm), leaf width (mm), leaf length (cm), bulb length (mm), bulb weight (kg), clove count, clove length (mm), clove width (mm), bulb neck diameter (mm), days to maturity, clove weight (kg), total soluble solids (%), bulb diameter (mm), and fresh bulb yield per hectare (t/ha) were meticulously recorded throughout the experiment.

The analysis of correlations and paths for all recorded traits was conducted using SAS 9.4 versions. The SAS PROC candisc function was employed to assess phenotypic and genotypic correlations among yield and yield-related traits. The correlation coefficients were interpreted within the range of -1.0 to +1.0, as outlined by Singh and Singh (2010). Additionally, the SAS Proc IML procedure was utilized to perform path coefficient analysis. Path coefficient scales (>1.0–0.19) were employed to estimate the number of residual values, following the method described by Dewey and Lu in 1959.

3. RESULTS AND DISCUSSION

3.1. Correlations of Traits

The genotypic correlation with total bulb yield per hectare exhibited high significance and a positive correlation with several traits, including bulb weight, pseudo-stem height, clove weight, bulb diameter, bulb length, plant height, leaf length, clove length, leaf width, and clove diameter.

The research identified a strong positive correlation among traits such as clove weight, leaf width, pseudo-stem height, plant height, maturity date, bulb length, bulb diameter, and clove number. Additionally, these traits exhibited a positive relationship with bulb weight, bulb diameter, and pseudo-stem height. Similar findings were reported by Ganie and Jan (2013), Sable (2020), and Yeshiwas *et al*., (2018), who also observed a strong association between plant height, leaf number, bulb weight, clove length, clove number, clove weight, and bulb diameter (Table 1).

The study revealed that both genotypic and environmental factors play a role in influencing phenotypic correlations in plant growth. Leaf number demonstrated a positive correlation with leaf width, length, pseudo-stem height, neck diameter, bulb length, clove diameter, clove number, bulb weight, and total bulb yield. Similarly, plant height exhibited positive correlations with neck diameter, bulb length, clove diameter, bulb weight, and clove weight. These findings align with those of Sharma *et al*., (2016), who reported a positive association between plant height and neck diameter, bulb length, clove diameter, clove number, bulb weight, and total bulb yield (Table 1).

Similar agreements were observed regarding the relationships among bulb diameters, clove length, and clove diameter, total soluble solids, and bulb weight. These agreements included a positive association between clove lengths and clove diameter, bulb weight, clove weight, and total bulb yield, as reported by Benke *et al*., (2020a). Additionally, a positive correlation was found between bulb weight and total bulb yield. Furthermore, bulb weight and clove weight exhibited a positive correlation, consistent with findings reported by Dubey *et al*., (2010) and Tsega *et al*., (2010).

3.2. Path coefficient analysis of garlic quantitative traits

Path coefficient analysis is a valuable tool for dissecting the independent traits that impact bulb yield directly and indirectly. According to the genotypic path coefficient, pseudo stem height, clove weight, and bulb length exhibited highly significant and positive direct effects on total bulb yield. On the other hand, bulb diameter, maturity date, leaf width, clove diameter, and bulb weight revealed insignificantly positive direct effects on total bulb yield. This aligns with previous findings by Ganie and Jan (2013) and Panse (2013), who consistently observed a high direct effect of clove weight and bulb weight on total bulb yield. Moreover, clove length, bulb diameter, leaf length, and bulb weight were found to have a strong indirect effect on bulb yield per hectare. These results highlight the importance of direct selection of traits with high direct effects and significant indirect values, ultimately enhancing total bulb yield per hectare (Table 2).

According to the phenotypic path coefficient analysis, pseudo stem height, clove weight, bulb length, clove number, and plant height displayed a significant and positive direct impact on total bulb yield per hectare. Conversely, leaf number, neck diameter, and clove length had a significant and negative indirect effect. The study also identified residual variations of 0.11 and 0.17 from genotypic and phenotypic path analyses, respectively, which align with previous studies by Bikis *et al*., (2021), Chotaliya, and Kulkarni (2017) (Table 3).

Furthermore, the path analysis indicated that an increase in clove weight and clove number correlates with an increase in total bulb yield per hectare. Conversely, the number of leaves, length of cloves, total soluble solids, and width of leaves exhibited a negative direct effect on total bulb yield, while clove weight and bulb length had a significant positive impact. Similar findings have been reported by Kuma *et al*., (2017), Ghodhani and Singh (2000), Dubey *et al*., (2010), Singh *et al*., (2011), and Panse (2013).

Table 1: Genotypic (below diagonal) and phenotypic (above diagonal) correlation coefficients

	LN	LW	LL	PSH	PH	ND	MD	BL	BD	CL	CD	CN	TSS	BW	CW	BY
LN		0.56***	0.62***	0.31**	0.57***	0.59***	0.19 Ns	0.34**	0.34**	0.39***	0.24*	0.30**	-0.04 ns	0.52***	0.19 ns	0.36**
LW	0.66***		0.70***	0.52***	0.58***	0.47***	-0.05 Ns	0.57***	0.57***	0.53***	0.47***	-0.06 ns	0.07 ns	0.72***	0.48***	0.56***
LL	0.71***	0.80***		0.55***	0.74***	0.59***	0.01 Ns	0.57***	0.65***	0.65***	0.47***	0.07 ns	0.10 ns	0.73***	0.50***	0.66***
PSH	0.27 ns	0.54***	0.59***		0.52***	0.11 ns	-0.48***	0.53***	0.71***	0.60***	0.62***	-0.31**	0.31**	0.74***	0.73***	0.77***
PH	0.64***	0.71***	0.84***	0.61***		0.62***	0.08 Ns	0.47***	0.55***	0.56***	0.42***	0.21*	0.02 ns	0.65***	0.47***	0.66***
ND	0.72***	0.61***	0.72***	0.17 ns	0.71***		0.43***	0.35**	0.35**	0.35**	0.15 ns	0.38***	-0.16 ns	0.47***	0.16 ns	0.40***
MD	0.30*	-0.04 Ns	0.02 Ns	-0.47**	0.01 ns	0.43**		-0.25**	-0.27**	-0.29**	-0.41***	0.55***	-0.21*	-0.15 ns	-0.41***	-0.20*
BL	0.44**	0.66***	0.66***	0.60***	0.60***	0.45**	-0.24 Ns		0.71***	0.61***	0.49***	-0.15 ns	0.07 ns	0.62***	0.59***	0.67***
BD	0.39**	0.64***	0.70***	0.78***	0.63***	0.43**	-0.29*	0.79***		0.65***	0.60***	-0.15 ns	0.25**	0.74***	0.65***	0.75***
CL	0.44**	0.62***	0.75***	0.64***	0.70***	0.46**	-0.28 Ns	0.68***	0.70***		0.61***	-0.15 ns	0.03 ns	0.75***	0.74***	0.65***
CD	0.29*	0.55***	0.61***	0.67***	0.53***	0.22 ns	-0.40**	0.63***	0.69***	0.68***		-0.46***	0.25**	0.58***	0.67***	0.58***
CN	0.35**	-0.02 ns	0.07 Ns	-0.28*	0.25 ns	0.42**	0.61***	-0.13 ns	-0.15 ns	-0.15 ns	-0.44**		-0.28**	0.01 ns	-0.37**	-0.07 ns
TSS	-0.10 ns	0.08 ns	0.07 Ns	0.42**	-0.05 ns	-0.28*	-0.32*	0.10 ns	0.25 ns	0.01 ns	0.27 ns	-0.32 ns		0.16 ns	0.16 ns	0.14 ns
BW	0.55**	0.75***	0.76***	0.76***	0.75***	0.56***	-0.15 Ns	0.71***	0.81***	0.80***	0.66***	0.05 ns	0.14 ns		0.71***	0.76***
CW	0.18 ns	0.52**	0.59***	0.77***	0.54***	0.22 ns	-0.44**	0.65***	0.69***	0.78***	0.70***	-0.35**	0.17 ns	0.74***		0.77***
TBY	0.39**	0.65***	0.72***	0.82***	0.75***	0.43**	-0.23 Ns	0.76***	0.81***	0.70***	0.63***	-0.04 ns	0.14 ns	0.82***	0.81***	

*Note: *, **/*** significance at 0.05 and 0.01 probability levels, respectively; LN = leaf number; LW = leaf width; LL = leaf length; PSH = pseudo stem height; PH = plant height; ND = neck diameter; MD = maturity date; BL = bulb length; BD = bulb diameter; CL= clove length; CD = clove diameter; CN = clove number; TSS = total soluble solid; BW = bulb weight; CW = clove weight; BY = bulb yield.*

Table 2: Genotypic path coefficient analysis direct (diagonal and bold) and indirect effects of traits on bulb yield of garlic

	LN	LW	LL	PSH	PH	ND	MD	BL	BD	CL	CD	CN	TSS	BW	CW	Rg
LN	**-0.12**	0.03	0.09	0.11	0.07	-0.02	0.02	0.11	0.03	-0.08	0.00	0.06	0.01	0.01	0.07	0.39**
LW	-0.08	**0.04**	0.10	0.22	0.08	-0.02	0.00	0.16	0.04	-0.11	0.01	0.00	-0.01	0.01	0.20	0.65***
LL	-0.08	0.04	**0.12**	0.24	0.09	-0.02	0.00	0.17	0.05	-0.14	0.01	0.01	-0.01	0.01	0.23	0.72***
PSH	-0.03	0.02	0.07	**0.41**	0.07	0.00	-0.03	0.15	0.05	-0.12	0.01	-0.05	-0.04	0.01	0.30	0.82***
PH	-0.07	0.03	0.10	0.25	**0.11**	-0.02	0.00	0.15	0.04	-0.13	0.01	0.05	0.00	0.01	0.21	0.75***
ND	-0.08	0.03	0.09	0.07	0.08	**-0.03**	0.03	0.11	0.03	-0.08	0.00	0.08	0.02	0.01	0.08	0.43**
MD	-0.03	0.00	0.00	-0.19	0.00	-0.01	**0.07**	-0.06	-0.02	0.05	-0.01	0.11	0.03	0.00	-0.17	-0.23ns
BL	-0.05	0.03	0.08	0.24	0.07	-0.01	-0.02	**0.25**	0.05	-0.12	0.01	-0.02	-0.01	0.01	0.25	0.76***
BD	-0.05	0.03	0.08	0.32	0.07	-0.01	-0.02	0.20	**0.07**	-0.13	0.01	-0.03	-0.02	0.01	0.27	0.81***
CL	-0.05	0.03	0.09	0.26	0.08	-0.01	-0.02	0.17	0.05	**-0.18**	0.01	-0.03	0.00	0.01	0.31	0.70***
CD	-0.03	0.02	0.07	0.27	0.06	-0.01	-0.03	0.16	0.05	-0.12	**0.02**	-0.08	-0.02	0.01	0.27	0.63***
CN	-0.04	0.00	0.01	-0.11	0.03	-0.01	0.04	-0.03	-0.01	0.03	-0.01	**0.18**	0.03	0.00	-0.14	-0.04ns

	LN	LW	LL	PSH	PH	ND	MD	BL	BD	CL	CD	CN	TSS	BW	CW	Rg
TSS	0.01	0.00	0.01	0.17	-0.01	0.01	-0.02	0.02	0.02	0.00	0.00	-0.06	**-0.08**	0.00	0.06	0.14ns
BW	-0.06	0.03	0.09	0.31	0.08	-0.01	-0.01	0.18	0.05	-0.15	0.01	0.01	-0.01	**0.01**	0.29	0.82***
CW	-0.02	0.02	0.07	0.31	0.06	-0.01	-0.03	0.16	0.05	-0.14	0.01	-0.07	-0.01	0.01	**0.39**	0.81***

Note: residual = 0.11; rg = genotypic correlation; LN = leaf number; LW = leaf width; LL = leaf length; PSH = pseudo stem height; PH = plant height; ND = neck diameter; MD = maturity date; BL = bulb length; BD = bulb diameter; CL= clove length; CD = clove diameter; CN = clove number; TSS = total soluble solid; BW = bulb weight; CW = clove weight; BY = bulb yield.

Table 3: Phenotypic path coefficient analysis of direct (diagonal and bold) and indirect effects of traits on bulb yield of garlic

	LN	LW	LL	PSH	PH	ND	MD	BL	BD	CL	CD	CN	TSS	BW	CW	rp
LN	**-0.11**	-0.01	0.05	0.13	0.06	0.05	0.02	0.06	0.04	-0.03	0.01	0.05	0.00	-0.04	0.07	0.36**
LW	-0.06	**-0.03**	0.06	0.22	0.06	0.04	-0.01	0.10	0.06	-0.04	0.02	-0.01	0.00	-0.05	0.19	0.56***
LL	-0.07	-0.02	**0.08**	0.23	0.08	0.05	0.00	0.10	0.07	-0.05	0.02	0.01	0.00	-0.05	0.20	0.66***
PSH	-0.03	-0.01	0.05	**0.42**	0.05	0.01	-0.05	0.10	0.08	-0.05	0.03	-0.05	-0.01	-0.05	0.29	0.77***
PH	-0.06	-0.01	0.06	0.22	**0.10**	0.05	0.01	0.08	0.06	-0.04	0.02	0.04	0.00	-0.05	0.18	0.66***
ND	-0.07	-0.01	0.05	0.05	0.06	**0.09**	0.05	0.06	0.04	-0.03	0.01	0.07	0.00	-0.03	0.06	0.40***
MD	-0.02	0.00	0.00	-0.20	0.01	0.04	**0.10**	-0.04	-0.03	0.02	-0.02	0.09	0.00	0.01	-0.16	-0.20*
BL	-0.04	-0.01	0.05	0.23	0.05	0.03	-0.03	**0.18**	0.08	-0.05	0.02	-0.02	0.00	-0.04	0.23	0.67***
BD	-0.04	-0.01	0.06	0.30	0.06	0.03	-0.03	0.13	**0.11**	-0.05	0.03	-0.03	-0.01	-0.05	0.25	0.75***
CL	-0.04	-0.01	0.05	0.25	0.06	0.03	-0.03	0.11	0.07	**-0.08**	0.03	-0.02	0.00	-0.05	0.29	0.65***
CD	-0.03	-0.01	0.04	0.26	0.04	0.01	-0.04	0.09	0.07	-0.05	**0.05**	-0.08	-0.01	-0.04	0.26	0.58***
CN	-0.03	0.00	0.01	-0.13	0.02	0.03	0.06	-0.03	-0.02	0.01	-0.02	**0.17**	0.01	0.00	-0.14	-0.07ns
TSS	0.00	0.00	0.01	0.13	0.00	-0.01	-0.02	0.01	0.03	0.00	0.01	-0.05	**-0.02**	-0.01	0.06	0.14ns
BW	-0.06	-0.02	0.06	0.31	0.07	0.04	-0.02	0.11	0.08	-0.06	0.03	0.00	0.00	**-0.07**	0.28	0.76***
CW	-0.02	-0.01	0.04	0.31	0.05	0.01	-0.04	0.11	0.07	-0.06	0.03	-0.06	0.00	-0.05	**0.39**	0.77***

Note: residual = 0.17; rp = phenotypic correlation; LN = leaf number; LW = leaf width; LL = leaf length; PSH = pseudo stem height; PH = plant height; ND = neck diameter; MD = maturity date; BL = bulb length; BD = bulb diameter; CL= clove length; CD = clove diameter; CN = clove number; TSS = total soluble solid; BW = bulb weight; CW = clove weight; BY = bulb yield

4. CONCLUSIONS

The study uncovered a robust positive correlation between genotypic and phenotypic factors, where traits such as bulb weight, pseudo stem length, clove weight, bulb diameter, plant height, leaf length, clove length, leaf width, and clove diameter significantly influenced total bulb yield per hectare. This suggests that selecting traits with high direct effects and high indirect values can effectively enhance garlic bulb yield per hectare.

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