Interrelationship of Agronomic Traits with Bulb Yield of Garlic (*Allium sativum* L.) Genotypes

Dejen Bekis*, Hussein Mohammed and Dessie Getahun

Fogera National Rice Research and Training Center, 
Hawassa University and Ethiopian Institute of Agricultural Research, Ethiopia

*E-mail address: djbks21@gmail.com

Forty-nine genotypes of garlic (*Allium sativum* L.) were studied to know the association between bulb yield and yield contributing traits using correlation (phenotypic and genotypic) and path coefficient analysis. The experiment was laid out using 7x7 simple lattice design with two replications at Fogera National Rice Research and Training Center (FNRRRC) in 2017/18. Bulb yield per plant showed positive and significant genotypic and phenotypic associations with pseudo stem length, leaf width, bulb diameter and bulb length, indicating that selection based on these traits would help for increasing the yield of garlic. For path coefficient analysis bulb yield was taken as a dependent variable, and rest characters were considered as the independent variables. Pseudo stem length, leaf width, leaf length and bulb length showed high positive direct effects on bulb yield per plant both at genotypic and phenotypic levels. Therefore, these traits should be considered as selection indices to increase the bulb yield of garlic.

Key words: Correlation, Genotypic, Path analysis, Phenotypic

INTRODUCTION

Garlic (*Allium sativum* L.) is an important condiment and is considered as a high value crop in Ethiopia. However, its production and productivity were low (10.47 tonnes/ha) due to genetics and several biotic and abiotic factors affecting its yield and yield related traits (Dejen, 2020; Mohammed *et al*., 2014). The major cause of low production and productivity of garlic in the country includes poor yield potential of varieties (lack of improved varieties) coupled with susceptibility to pests, lack of proper planting materials, inappropriate agronomic practices, unbalanced fertilizer use, and lack of irrigation facilities(Getachew and Asfaw, 2000; Tewodros *et al*., 2014; Mohammed *et al*., 2014; Dejen, 2018).

Among these problems, lack of improved varieties for different agro ecologies of the country is the most serious concern. In many countries, garlic is a long established crop and cultivars have been selected that are well adapted to local conditions and the local market (Rabinowitch and Currah, 2002). However, in Ethiopia only eight varieties are available for the diverse agro-ecologies. Improved varieties and appropriate field management practices are critical for increasing the productivity of garlic in the country. Research on development of varieties has been conducted mainly at Debrezeit Agricultural Research Center (DZARC) by focusing on evaluation of genotypes for dry bulb yield in multi-location variety trials. Five varieties have been released so far from this center (Tseday, Bishetu Netch, Holleta Local, Kurfitu and G104-1). One variety named Chelenko was released from Harmaya University in 2014 (Tewodros *et al*., 2014). Two varieties were also released from Regional Research Centers, one each from Debre-Birhan and Sinana Centers.

However, vegetative growth performance, tolerance to diseases and the yield of the released varieties (Tseday, BishetuNetch, Holleta Local and G104) were lower than the local check during the 2014/2015 rainy season trial surrounding Fogera (Fogera National Rice Research and Training Center (FNRRRC) Horticulture Annual Report, 2016). Various accessions of garlic are under production in different parts of Ethiopia. Garlic is a cash crop in many parts of the country. Increasing its productivity per unit area and its total production will enable farmers get encouraging returns and improve its role in achieving food
self-sufficiency. Genotypes are well adapted to the agro-ecology in which they are produced and are excellent sources of new varieties with higher yield and better quality. Garlic genotypes were collected from different parts of the country by DZARC and FNRRTC. But, full information on the descriptors of these accessions is not available. Limited studies have been made on the variability and association of traits in garlic accessions. In Ethiopia, Kassahun (2006) and Abebech (2013) studied the association of quantitative traits with bulb yield of 25 and 49 garlic accessions, obtained from DZARC, respectively. Chelenko garlic variety was released in 2013 for high altitude garlic growing areas of Eastern and Western Hararghe Zones of Ethiopia (Tewodros et al., 2014). The variety was developed through selection from 252 genotypes collected by DZARC in central Ethiopia and Haramaya district in the Eastern part of the country. This variety was shown to have superior yielding ability and other desirable traits over the standard check 'Tsedey' cultivar (Tewodros et al., 2014). However, in depth study has not been made on the association of traits among garlic accessions collected by FNRRTC from North and South Gonder zone/Makisengit, Libokemikem, Fogera, Farta, Estie; and yet non availability of recommended improved garlic varieties for the farmers of Northern Western, Ethiopia is a major constraint to garlic production.

Generating information on the association of traits is a prerequisite to devise a variety improvement strategy through selection. Therefore, the objective of the present study is to find out the association between bulb yield and yield contributing traits of Ethiopian garlic through correlation (phenotypic and genotypic correlations) and path coefficient analysis.

MATERIAL AND METHODS

Description of the study area

The experiment was conducted in the North-Western part of Ethiopia at Fogera National Rice Research and Training Center (FNRRTC) during the rainy season of 2017/18. The experimental site is found at Woreta and located 11°58’ N latitude, 37° 41’ E longitude and at an elevation of 1810m above sea level. Based on years’ average meteorological data, the annual rainfall, and mean annual minimum, maximum and average air temperatures are 1300mm, 11.5°C, 27.9°C and 18.3°C, respectively. The soil type is black Vertisol with pH of 5.90 (Dejen, 2020).

Treatments and Design

Forty-nine genotypes consisting of 45 garlic accessions and four released varieties were included in this study. The accessions were obtained at FNRRTC and Debreziet Agricultural Research Center. The experiment was laid out in a 7x7 simple lattice design with two replications. The plot size used was 1.5 m wide, consisting of six rows each of 2 m long. A spacing of 30 x 10cm between rows and plants was used. Healthy and uniform cloves of each accession was selected and planted by hand on ridges of about 20cm height with a planting depth of 4cm. To increase the nutrient content of the soil, Nitrogen and Phosphorus, Nitrogen fertilizer in the form of urea (46% N) and phosphate as DAP/Diammonium Phosphate (18%N and 46% P) at a rate of 100Kg/ha and 200 Kg/ha respectively, were applied (Dejen, 2020). All other agronomic practices were applied uniformly to the entire plot, as recommended by Getachew et al., (2009).

Data collected

All agronomic and yield data were recorded from ten randomly sampled plants in the middle four rows of each experimental plot. However; the phenological parameter was taken on plot basis. The collected quantitative traits were days to maturity (DM), plant height (PH) (cm), pseudo stem length (PSL), number of leaves per plant (LN), leaf width (LW) (cm), Leaf length (LL) (cm), neck diameter (ND) (cm), bulb length (BL) (cm), bulb diameter (BD)(cm) and yield per plant (YP)(gram).

Statistical analysis

The association was estimated using the method suggested by Sharma (1998):

Genotypic $r = \frac{\sigma^2_{g1} \sigma^2_{g2}}{\sqrt{\sigma^2_{g1} \sigma^2_{g2}}}$

Where, $\sigma^2_{g1,2}$ is the genotypic covariance between two traits, $\sigma^2_{g1}$ is the genotypic variance of the first trait, and $\sigma^2_{g2}$ is the genotypic variance of the second trait; and

phenotypic $r = \frac{\sigma_{p12}}{\sqrt{\sigma_{p1} \sigma_{p2}}} = \text{Phenotypic covariance between character 1 and 2}$

$\sigma^2_{p12}$ = Phenotypic variance for character 1 and 2 and

$\sigma^2_{p1} = \text{Phenotypic variance for character 1}$, $\sigma^2_{p2} = \text{phenotypic variance for character 2}$

The phenotypic correlation value was tested for its significance using t-test:

$t_{p} = \frac{r_{p}}{SE(r_{p})}$

Where, $r_{p}$= Phenotypic correlation; $SE (r_{p})$ = Standard error of phenotypic correlation obtained using the following procedure (Sharma, 1998).

$SE(r_{p}) = \sqrt{\frac{1-r^2_{2p}}{n-2}}$

Where, n is the number of genotypes, $r_{p}$ is phenotypic correlation coefficient.

The coefficient of correlations at genotypic level was tested for their significance using the formula described by Robertson (1959) as indicated below:

$t_{gxy} = \frac{r_{gxy}}{SE_{gxy}}$

The calculated "t" value was compared with the
tabulated “t” value at (n-2) degree of freedom at 5% level of significance. Where, n = number of genotypes

\[ \text{SE}_{r_{xy}} = \frac{1-r_{gxy}}{\sqrt{2H_x H_y}} \]

Where, \( H_x \) = heritability of trait x
\( H_y \) = heritability of trait y

**Path Coefficient Analysis**

The direct and indirect effects of each independent character on the dependent variable was estimated by following the general formula suggested by Dewey and Lu(1959).

The formula: \( r_{ij} = p_{ij} + \sum r_{ik} p_{kj} \)

where, \( r_{ij} \) = Mutual association between the independent character (i) and dependent character (j) as measured by the correlation coefficient, \( p_{ij} \) =components of direct effects of the independent character (i) on the dependent character (j) as measured by the path coefficient and \( \sum r_{ik} p_{kj} = \) summation of components of indirect effect of a given independent character (i) on the given dependent character (j) via all other independent characters (k)

The square matrix of the correlation coefficients between all pairs of the independent and dependent characters was evaluated by using Statistical Package for Agricultural Research (SPAR Microsoft, 1995) software. The formula of residual effect (h):

\[ h = \sqrt{1 - R^2} \text{ where; } R^2 = \Sigma p_{ij} r_{ij} \]

**RESULTS AND DISCUSSION**

**Characters Association**

**Estimation of correlation coefficients at genotypic \( (r_g) \) and phenotypic \( (r_p) \) levels**

Investigating the possibilities of high yield through yield attributes, as primary interest in crop improvement strategies, requires understanding of the amount of the magnitude of correlation among various yield traits. Estimates of phenotypic and genotypic correlation coefficients between each pair of the studied characters are presented in Table 1. In the present study, genotypic correlations values were higher than the corresponding phenotypic ones, which indicated a strong inherent relationship among the characters studied. This finding is in agreement with previous findings of Singh et al. (2013) in garlic and Fasika (2004) in shallot.

Bulb yield, which is the major economic character in garlic, depends on several component traits that are mutually related. The correlation coefficient analysis revealed that bulb yield per plant had positive and significant associations \((p<0.01)\) with pseudo stem length (phenotypic correlation/\( r_{ph} = 0.26^* \) and genotypic correlation/\( r_g = 0.38^{**} \)), leaf width \((r_{ph} = 0.28^{**} \text{ and } r_g = 0.33^*)\), bulb diameter \((r_{ph} = 0.40^{**} \text{ and } r_g = 0.49^{**})\) and bulb length \((r_{ph} = 0.41^{**} \text{ and } r_g = 0.44^{**})\) both at phenotypic and genotypic level. Thus, it indicated that the increase in bulb yield of garlic is mainly attributable to the increase of these traits. Therefore, the indirect selection for higher yield per plant based on these characters would be reliable. This study agrees with the findings of Sandhu et al. (2016) who observed a significant positive association between bulb diameter and yield per plant. Singh et al. (2013) stated positive and significant association of pseudo stem length with bulb yield.

However, yield per plant exhibited non-significant negative correlation with days to maturity, plant height, leaf length and neck diameter at both phenotypic and genotypic levels. This indicated that the increase in these traits might not be associated with economical trait bulb yield. The breeder must be very careful while selecting for these traits which may not have positive influence on bulb yield rather the increase in these traits probably brings about a decline in bulb yield of garlic. These traits had non-significant negative correlation with bulb yield and cannot be used as positive selection traits to increase bulb yield per unit area. These results were consistent with findings of Kuldeep et al. (2017) who found that neck diameter and leaf length had non-significant negative correlation with bulb weight. Among the studied traits, PSL, LW, BD and BL had a positive correlation with bulb yield at genotypic and phenotypic levels, which is considered significant to breeders because component breeding would be very effective under such situation. Selection for these traits may be essential for improvement of bulb yield in garlic. However, it is always important to validate the result by partition the correlation coefficients into direct and indirect effects through component traits; by performing path coefficient analysis.

Days to maturity showed a positive and significant phenotypic and genotypic correlations with plant height, number of leaves per plant, leaf length, neck diameter and leaf width (Table 1). This suggested that late maturity was a result of the vegetative increment in plant height, number of leaves per plant, leaf length, neck diameter and leaf width, which led to relatively giant plant morphology. Plant height showed a positive and significant correlation with leaf number, leaf length, neck diameter, pseudo stem length and leaf width. In harmony with this study, Kuldeep et al. (2017) reported that plant height was positively and significantly correlated with leaf number, leaf length and leaf width. Plant height also showed a positive and significant genotypic relationship with the number of leaves per plant and it was positively and significantly correlated with leaf length that obviously led to increment in a photosynthetic area that might have partly contributed to increment in yield of bulb per plant.

Number of leaves per plant indicated positive and significant phenotypic and genotypic correlation with all
studied traits except bulb length. The number of leaves per plant showed a positive contribution to bulb yield per plant via exhibited positive correlation with all traits except bulb length. Leaf length was positively and significantly correlated with neck diameter and leaf width at both levels. At both levels, neck diameter had a significant positive correlation with leaf width. This agreed with the work of Ahmed (2018) who has reported positive correlation between bulb diameter and bulb length but noted a non-significant correlation between leaf width and bulb diameter of garlic.

Generally, a negative correlation between two traits implies selection for improving one trait will likely cause a decrease in the other trait, whereas for positive correlation, simultaneous improvements of both traits is achieved. Many of the characters correlated positively among themselves, which ranged from low to high levels of correlation. Those characters with positive and significant correlation with each other and with bulb yield per plant indicated that such characters were probably equally important in determining bulb yield per plant. In agreement with Kalloo (1988) reported that if any component of yield had positive correlation with yield, then there may be the possibility to increase total yield by selecting a particular component. Characters that showed a non-significant correlation with each other indicated the independent nature of character about the other.

Table 1: Genotypic and phenotypic correlation top (diagonal) and bottom (off diagonal) values respectively for 10 traits of 49 garlic genotypes

<table>
<thead>
<tr>
<th>Traits</th>
<th>DM</th>
<th>PH</th>
<th>LN</th>
<th>LL</th>
<th>ND</th>
<th>PSL</th>
<th>LW</th>
<th>BD</th>
<th>BL</th>
<th>YP</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>1.00</td>
<td>0.77**</td>
<td>0.58**</td>
<td>0.92**</td>
<td>0.79**</td>
<td>-0.12NS</td>
<td>0.52**</td>
<td>-0.18NS</td>
<td>-0.19NS</td>
<td>-0.17NS</td>
</tr>
<tr>
<td>PH</td>
<td>0.72**</td>
<td>1.00</td>
<td>0.84**</td>
<td>0.81**</td>
<td>0.85**</td>
<td>0.37**</td>
<td>0.75**</td>
<td>0.09NS</td>
<td>-0.11NS</td>
<td>-0.04NS</td>
</tr>
<tr>
<td>LN</td>
<td>0.54**</td>
<td>0.71**</td>
<td>1.00</td>
<td>0.63**</td>
<td>0.76**</td>
<td>0.47**</td>
<td>0.81**</td>
<td>0.30*</td>
<td>0.04NS</td>
<td>0.19NS</td>
</tr>
<tr>
<td>LL</td>
<td>0.85**</td>
<td>0.75**</td>
<td>0.61**</td>
<td>1.00</td>
<td>0.84**</td>
<td>-0.15NS</td>
<td>0.55**</td>
<td>-0.21NS</td>
<td>-0.21NS</td>
<td>-0.17NS</td>
</tr>
<tr>
<td>ND</td>
<td>0.72**</td>
<td>0.76**</td>
<td>0.66**</td>
<td>0.74**</td>
<td>1.00</td>
<td>0.11NS</td>
<td>0.70**</td>
<td>0.04NS</td>
<td>-0.13NS</td>
<td>-0.05NS</td>
</tr>
<tr>
<td>PSL</td>
<td>-0.04NS</td>
<td>0.39**</td>
<td>0.45**</td>
<td>-0.07NS</td>
<td>0.12NS</td>
<td>1.00</td>
<td>0.49**</td>
<td>0.55**</td>
<td>0.16NS</td>
<td>0.38**</td>
</tr>
<tr>
<td>LW</td>
<td>0.44**</td>
<td>0.64**</td>
<td>0.62**</td>
<td>0.45**</td>
<td>0.62**</td>
<td>0.43**</td>
<td>1.00</td>
<td>0.44**</td>
<td>0.17NS</td>
<td>0.33**</td>
</tr>
<tr>
<td>BD</td>
<td>-0.12NS</td>
<td>0.09NS</td>
<td>0.28**</td>
<td>-0.15NS</td>
<td>0.07NS</td>
<td>0.48**</td>
<td>0.37209**</td>
<td>1.00</td>
<td>0.60**</td>
<td>0.49**</td>
</tr>
<tr>
<td>BL</td>
<td>-0.14NS</td>
<td>-0.09NS</td>
<td>-0.09NS</td>
<td>-0.19NS</td>
<td>-0.09NS</td>
<td>0.06NS</td>
<td>0.12NS</td>
<td>0.56**</td>
<td>1.00</td>
<td>0.44**</td>
</tr>
<tr>
<td>YP</td>
<td>-0.11NS</td>
<td>-0.03NS</td>
<td>0.01NS</td>
<td>-0.11NS</td>
<td>-0.003NS</td>
<td>0.26*</td>
<td>0.28**</td>
<td>0.40**</td>
<td>0.41**</td>
<td>1.00</td>
</tr>
</tbody>
</table>

*DM = number of days from emergence to physiological maturity, PH = Plant Height, LN = Leaf Number, LL = Leaf length, ND = Neck Diameter, PSL = Pseudo stem Length, LW = Leaf Width, BD = Bulb Diameter, BL = Bulb Length, YP = Yield per plant in gram

Path Coefficient Analysis

Path coefficient analysis was carried out by taking bulb yield per plant as a dependent variable and the other nine yield contributing characters as independent variables.

Genotypic path coefficient

In the current investigation, the result of genotypic path coefficient analysis showed that pseudo stem length (0.46) had the highest positive direct effect on bulb yield per plant followed by leaf width (0.44), leaf length (0.43), bulb length (0.25) and leaf number (0.16), whereas, a negative direct effect was observed for plant height (-0.95), neck diameter (-0.03) and days to maturity (-0.02), while bulb diameter (0.02) had a very little positive direct effect on bulb yield per plant. However, it exhibited significant and positive association with bulb yield per plant (Table 2). This indicating the true relationship between these characters as an excellent contributor to bulb yield per plant in garlic. Thus, pseudo stem length, leaf width, leaf length and bulb length could be the most important yield component characters which might be selected for yield improvement. Similar results for leaf width, bulb length and plant height had been reported by Ahmed (2018). Similarly, Kuldeep et al. (2017) reported that direct influence of leaf length on bulb yield per plant was very high and positive and its indirect influence through leaf width was also positive. However, leaf length was showed a negative indirect effect on the length of bulb in garlic.
Phenotypic path coefficient

A similar trend as in path coefficient analysis of the genotypic correlations was observed in path coefficient analysis at the phenotypic level, except for neck diameter which was slightly positive in phenotypic but negative in genotypic path coefficient analysis (Table 2). The highest positive direct effect which contributed towards bulb yield per plant at phenotypic level was bulb length (0.34), followed by leaf width (0.30), pseudo stem length (0.25), leaf length (0.15), leaf number (0.06), bulb and neck diameter (0.02). Kuldeep et al. (2017) reported a significant and positive phenotypic association of leaf length ($r=0.28^*$) with bulb yield in garlic. In contrast, Sandhu et al. (2017) reported a non-significant association between leaf width and bulb weight at both phenotypic and genotypic levels.

Bulb length had positive indirect effect on bulb yield per plant via bulb diameter followed by leaf width and pseudo stem length. In contrast, the negative indirect effect on bulb yield per plant was exhibited by days to maturity, leaf length, plant height, leaf number and neck diameter. Leaf width had positive indirect effect on bulb yield per plant via all studied traits. Similarly, leaf width had positive indirect effect on bulb yield per plant via all studied traits at genotypic level (Table 2). Pseudo stem length had positive indirect effect on bulb yield per plant via bulb diameter, leaf width, leaf number, plant height, neck diameter and bulb length, whereas, the negative indirect effect on bulb yield per plant was exhibited by days to maturity and leaf length. The positive non-significant correlation and a positive high direct effect of bulb length and leaf width on bulb yield per plant was also reported by Ahmed (2018). However, number of leaves per plant and leaf length had negative direct effect.

Based on the genotypic and phenotypic path analysis, agronomic characters that showed positive direct effects on bulb yield per plant were: pseudo stem length, leaf width, leaf length, bulb length, leaf number and bulb diameter. This result agrees with that of Kuldeep et al. (2017) for number of leaves per plant and leaf length; Ahmed (2018) for leaf width, bulb length and bulb diameter. In contrast, Singh et al. (2013) stated that pseudo stem length showed a negative direct effect on yield of garlic. Therefore, the present study indicated that pseudo stem length, leaf width, leaf length, bulb length, leaf number and bulb diameter had a significant positive influence on bulb yield of garlic.

Table 2: Estimates of direct (bold and diagonal) and indirect effect (off diagonal) of nine traits on bulb yield of 49 garlic genotypes at genotypic level at Fogera in 2017/2018

<table>
<thead>
<tr>
<th>Traits</th>
<th>DM</th>
<th>PH</th>
<th>LN</th>
<th>LL</th>
<th>ND</th>
<th>PSL</th>
<th>LW</th>
<th>BD</th>
<th>BL</th>
<th>(r_{ph})</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>-0.02</td>
<td>-0.73</td>
<td>0.09</td>
<td>0.40</td>
<td>-0.03</td>
<td>-0.06</td>
<td>0.23</td>
<td>0.00</td>
<td>-0.05</td>
<td>-0.17</td>
</tr>
<tr>
<td>PH</td>
<td>-0.02</td>
<td>-0.95</td>
<td>0.14</td>
<td>0.35</td>
<td>-0.03</td>
<td>0.17</td>
<td>0.33</td>
<td>0.00</td>
<td>-0.03</td>
<td>-0.04</td>
</tr>
<tr>
<td>LN</td>
<td>-0.01</td>
<td>-0.79</td>
<td>0.16</td>
<td>0.27</td>
<td>-0.03</td>
<td>0.22</td>
<td>0.35</td>
<td>0.01</td>
<td>0.01</td>
<td>0.19</td>
</tr>
<tr>
<td>LL</td>
<td>-0.02</td>
<td>-0.77</td>
<td>0.10</td>
<td>0.43</td>
<td>-0.03</td>
<td>-0.07</td>
<td>0.24</td>
<td>0.00</td>
<td>-0.05</td>
<td>-0.17</td>
</tr>
<tr>
<td>ND</td>
<td>-0.02</td>
<td>-0.81</td>
<td>0.12</td>
<td>0.36</td>
<td>-0.03</td>
<td>0.05</td>
<td>0.30</td>
<td>0.00</td>
<td>-0.03</td>
<td>-0.05</td>
</tr>
<tr>
<td>PSL</td>
<td>0.00</td>
<td>-0.36</td>
<td>0.08</td>
<td>-0.06</td>
<td>0.00</td>
<td>0.46</td>
<td>0.21</td>
<td>0.01</td>
<td>0.04</td>
<td>0.38**</td>
</tr>
<tr>
<td>LW</td>
<td>-0.01</td>
<td>-0.72</td>
<td>0.13</td>
<td>0.24</td>
<td>-0.02</td>
<td>0.23</td>
<td>0.44</td>
<td>0.01</td>
<td>0.04</td>
<td>0.33*</td>
</tr>
<tr>
<td>BD</td>
<td>0.00</td>
<td>-0.09</td>
<td>0.05</td>
<td>-0.09</td>
<td>0.00</td>
<td>0.25</td>
<td>0.19</td>
<td>0.02</td>
<td>0.15</td>
<td>0.49**</td>
</tr>
<tr>
<td>BL</td>
<td>0.00</td>
<td>0.10</td>
<td>0.01</td>
<td>-0.09</td>
<td>0.00</td>
<td>0.07</td>
<td>0.08</td>
<td>0.01</td>
<td>0.25</td>
<td>0.44**</td>
</tr>
</tbody>
</table>

\(DM = \) number of days from emergence to physiological maturity, \(PH = \) Plant Height, \(LN = \) Leaf Number, \(LL = \) Leaf length, \(ND = \) Neck Diameter, \(PSL = \) Pseudo stem Length, \(LW = \) Leaf Width, \(BD = \) Bulb Diameter, \(BL = \) Bulb Length

Table 3: Estimates of direct (bold and diagonal) and indirect effect (off diagonal) of nine traits on bulb yield of 49 garlic genotypes at phenotypic level at Fogera in 2017/2018

<table>
<thead>
<tr>
<th>Traits</th>
<th>DM</th>
<th>PH</th>
<th>LN</th>
<th>LL</th>
<th>ND</th>
<th>PSL</th>
<th>LW</th>
<th>BD</th>
<th>BL</th>
<th>(r_{ph})</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>-0.04</td>
<td>-0.32</td>
<td>0.03</td>
<td>0.13</td>
<td>0.01</td>
<td>-0.01</td>
<td>0.13</td>
<td>0.00</td>
<td>-0.05</td>
<td>-0.11</td>
</tr>
<tr>
<td>PH</td>
<td>-0.03</td>
<td>-0.44</td>
<td>0.04</td>
<td>0.11</td>
<td>0.01</td>
<td>0.10</td>
<td>0.20</td>
<td>0.00</td>
<td>-0.03</td>
<td>-0.03</td>
</tr>
<tr>
<td>LN</td>
<td>-0.02</td>
<td>-0.31</td>
<td>0.06</td>
<td>0.09</td>
<td>0.01</td>
<td>0.11</td>
<td>0.19</td>
<td>0.00</td>
<td>-0.03</td>
<td>0.10</td>
</tr>
<tr>
<td>LL</td>
<td>-0.03</td>
<td>-0.33</td>
<td>0.04</td>
<td>0.15</td>
<td>0.01</td>
<td>-0.02</td>
<td>0.14</td>
<td>0.00</td>
<td>-0.06</td>
<td>-0.11</td>
</tr>
<tr>
<td>ND</td>
<td>-0.03</td>
<td>-0.33</td>
<td>0.04</td>
<td>0.11</td>
<td>0.02</td>
<td>0.03</td>
<td>0.19</td>
<td>0.00</td>
<td>-0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>PSL</td>
<td>0.00</td>
<td>-0.17</td>
<td>0.03</td>
<td>-0.01</td>
<td>0.00</td>
<td>0.25</td>
<td>0.13</td>
<td>0.01</td>
<td>0.02</td>
<td>0.26*</td>
</tr>
<tr>
<td>LW</td>
<td>-0.02</td>
<td>-0.28</td>
<td>0.04</td>
<td>0.07</td>
<td>0.01</td>
<td>0.11</td>
<td>0.30</td>
<td>0.01</td>
<td>0.04</td>
<td>0.28**</td>
</tr>
<tr>
<td>BD</td>
<td>0.00</td>
<td>-0.04</td>
<td>0.02</td>
<td>-0.02</td>
<td>0.00</td>
<td>0.12</td>
<td>0.11</td>
<td>0.02</td>
<td>0.19</td>
<td>0.40**</td>
</tr>
<tr>
<td>BL</td>
<td>0.00</td>
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<td>-0.01</td>
<td>-0.03</td>
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<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.34</td>
<td>0.41**</td>
</tr>
</tbody>
</table>

\(r_{ph} = \) phenotypic correlation, \(DM = \) number of days from emergence to physiological maturity, \(PH = \) Plant Height, \(LN = \) Leaf Number, \(LL = \) Leaf length, \(ND = \) Neck Diameter, \(PSL = \) Pseudo stem Length, \(LW = \) Leaf Width, \(BD = \) Bulb Diameter, \(BL = \) Bulb Length
CONCLUSION

The study of associations among various traits at genotypic and phenotypic levels showed that bulb yield per plant had positive and highly significant association with pseudo stem length, leaf width, bulb diameter and bulb length which is considered significant to breeder because component breeding would be very effective under such situation. Selection for these traits may be essential for improvement of bulb yield in garlic.

Path coefficient analysis showed that pseudo stem length, leaf width, leaf length, bulb length, leaf number and bulb diameter had positive direct effects on bulb yield per plant, whereas, a negative direct effect was observed for plant height and days to maturity at both levels. Bulb length had a positive indirect effect on bulb yield per plant via bulb diameter followed by leaf width and pseudo stem length. In contrast, the negative indirect effect on bulb yield per plant was exhibited by days to maturity, leaf length, plant height, leaf number and neck diameter. Therefore, the present study indicated that pseudo stem length, leaf width, leaf length, bulb length, leaf number and bulb diameter had a significant positive influence on bulb yield of garlic.

Conflict of Interests

The authors have not declared any conflict of interests.

Acknowledgements

The authors acknowledged Ethiopian Institute of Agricultural Research (EIAR) and Fogera National Rice Research and Training Center (FNRRRTC) for supporting during study period. The authors obliged to extend deepest gratitude to Dr. Tilahun Tadesse, Mr. Desta Abayechaw, Mrs. Helen Asaminew, Mr. Desalegn Sisay and Mr. Maru Adugna who helped us throughout our research period.

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