Original Research Article

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Character Association and Path Analysis for Quantitative Traits in Garlic (*Allium sativum* L.)

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**Abstract**

An experiment was conducted to assess correlation and path analysis in 156 genotypes and 4 checks of garlic grown in Augmented Randomized Block Design at Vegetable Research Station, Junagadh Agricultural University, Junagadh during *rabi* season of 2015-2016. The observations were recorded on 18 characters viz., plant height (cm), number of leaves per plant, leaf length (cm), leaf width at middle portion (cm), days to maturity (days), pseudostem height (cm), collar thickness (cm), bulb collar diameter (cm), bulb equatorial diameter (cm), bulb polar diameter (cm), bulb weight (g), number of cloves per bulb, clove weight (g), clove length (cm), clove collar diameter (cm), clove polar diameter (cm), clove equatorial diameter (cm), total soluble solids (%) and bulb yield (kg/ha). In general, the estimates of genotypic correlation were higher than the corresponding phenotypic correlation coefficient. It may result from the modifying effect of environment on the association of characters at genotypic level. The bulb yield had significant positive correlation with characters like with plant height, number of leaves per plant, leaf width at middle portion, pseudostem length, bulb collar diameter, bulb equatorial diameter, bulb polar diameter, bulb weight and clove length, clove collar diameter and clove equatorial diameter. From these associations, it appears that higher bulb yield can be obtained by increasing these characters. Path coefficient analysis revealed that the characters like plant height and clove polar diameter had high direct effect on bulb yield. These above characters also had positive indirect effect on each other. Plant height, number of leaves per plant, leaf width at middle portion, pseudostem height exhibited positive and indirect effects on bulb yield via plant height, leaf length, leaf length at middle portion, days to maturity, pseudostem height, bulb equatorial diameter, bulb polar diameter, bulb weight, number of cloves per bulb, clove weight and clove collar diameter, clove equatorial diameter and total soluble solids. Bulb collar diameter, bulb equatorial diameter, bulb polar diameter, bulb weight, clove length, clove polar diameter and clove equatorial diameter contributed indirectly by giving positive indirect effects on bulb yield through plant height, leaf width at middle portion, bulb equatorial diameter, bulb polar diameter, bulb weight, number of cloves per bulb, clove polar diameter, clove equatorial diameter and total soluble solids.

**Keywords**

Garlic, Traits, Correlation, Path analysis.

**Article Info**

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**Introduction**

Garlic (*Allium sativum* L.) is one of the most important remunerative bulbous spice and medicinal crop grown commercially. It is the second most widely used spice after onion. It belongs to family *Alliaceae* because of its superior ovary and scapose umbeliate inflorescence. The name garlic is derived from the old English word "gar" meaning spear presumably referring to clove. *Allium longicupis* is considered to be its wild
ancestor, which is extensively found in Central Asia. Garlic (*Allium sativum* L.) has 2n=2x=16 chromosome number. Garlic is a perennial plant, cultivated mainly for bulbs. The edible underground stem is the composite bulb made up of numerous smaller bulbs called clove. Leaves have solid thin blades. Some varieties produce flowers but these flowers do not set seeds. There are some varieties which produce vegetative bulbs on the top called bulbils. They are also used for propagation in some cases.

The basic rationale in any crop improvement programme is the increase in yield potential of the crop. The character bulb yield has got a complex gene action and so, in order to study it properly, different factors affecting the yield must be considered and evaluated with regard to their contribution to yield. Knowledge in respect of nature and magnitude of association with different component characters is a pre-requisite to bring the improvement in desired direction. In order to accumulate optimum combination of bulb yield contributing characters in a single genotype, it is essential to know the relationships among themselves.

Further, the bulb yield is influenced by its various components directly and or indirectly via other traits that create a complex situation before a breeder for making selection. Therefore, path coefficient analysis could provide a more realistic picture of the inter-relationship, as it partitions the correlation in direct and indirect effect of the variables.

**Materials and Methods**

One hundred and fifty six genotypes and four checks of garlic were sown in an Augmented Randomized Block Design (ARBD) (Federer, 1956) during *rabi* season of 2015-2016. The cloves were planted at a distance of 15 cm row to row and 10 cm plant to plant as per spacing. Other recommended agronomical practices and plant protection measures were followed for the successful raising of the crop. The observations were recorded on various quantitative characters viz., plant height (cm), number of leaves per plant, leaf length (cm), leaf width at middle portion (cm), days to maturity (days), pseudostem height (cm), collar thickness (cm), bulb collar diameter (cm), bulb equatorial diameter (cm), bulb polar diameter (cm), bulb weight (g), number of cloves per bulb, clove weight (g), clove length (cm), clove polar diameter (cm), clove equatorial diameter (cm), total soluble solids (%) and bulb yield (kg/ha). were recorded on five competitive plants per genotype in each plot were randomly selected for the purpose of recording observations on different characters (except days to maturity) and their averages were used in the statistical analysis.

Days to maturity was measured on plot basis. The phenotypic and genotypic correlation coefficients of all the characters were worked-out as per Al-Jibouri et al., (1958). The path coefficient analysis was carried out as per the method suggested by Dewey and Lu (1959). Phenotypic correlation coefficients of 17 variables with bulb yield were used to estimate the path coefficients for the direct effects of various independent characters on bulb yield.

**Results and Discussion**

The correlation coefficients were worked out among 18 characters to find out association of bulb yield with its components at genotypic (*r_g*) and phenotypic (*r_p*) levels. The data given in (Table 1) revealed that in general, the genotypic correlation coefficients were higher than the respective phenotypic correlations which might be from modifying effect of environment on the association of characters at genotypic level. Selection of yield as such
may not be effective since there may be
number of genes for bulb yield and bulb yield
may be resultant of interaction among its
various components. Knowledge of relation
between bulb yield and its component is
essential and selection for one component
may bring about a simultaneous change in the
other.

Therefore, for a rational approach to improve
bulb yield, it may be useful to collect
information on character association. Results
of genotypic and phenotypic correlation
analysis of present study are graphically
represented in figures 1 and 2.

The correlation of bulb yield showed positive
and significant at genotypic and phenotypic
level with plant height, number of leaves per
plant, leaf width at middle portion,
pseudostem length, bulb collar diameter, bulb
equatorial diameter, bulb polar diameter, bulb
weight and clove length, clove polar diameter
and clove equatorial diameter, indicating that
selection based on these traits will help
increasing the yield of garlic.

Similar result was found by Moravec et al.,
(1974), Singh (1981), Kalloo et al., (1982),
Singh (1984), Rahman and Das (1985),
Lokhande and Pawar (1988), Kohli and
Fageria (1992), Kohli and Mahajan (1993),
Srivastava et al., (1993), Baiday and Tiwari
(1995), Thakur et al., (1997), Agrawal (1999),
Khan (2002), Agrawal and Tiwari (2009),
Tsega et al., (2010), Singh et al., (2012),
Sonkiya et al., (2012), Idress Al Gehani et al.,
(2013), Panse et al., (2013), Singh et al.,
(2013), Pervin et al., (2014), Samaptika Kar
et al., (2014), Kadam et al., (2016), Prajapati
et al., (2016), Bhatt et al., (2017) in garlic.

Positive association of bulb weight was found
positive and significant at genotypic and
phenotypic level with plant height, number of
leaves per plant, leaf width at middle portion,
pseudostem length, collar thickness, bulb
collar diameter, bulb equatorial diameter, bulb
polar diameter. Similar findings were reported
by Moravec et al., (1974), Singh (1981),
Shaha et al., (1990), Kohli and Mahajan
(1993), Srivastava et al., (1993), Barman et
al., (1996), Dhall et al., (2013), Esho (2015),
Satesh Kumar et al., (2015) and Sharma et al.,
(2016) in garlic.

The correlation of plant height showed
positive and significant at genotypic and
phenotypic level with leaf length, collar
thickness, bulb weight, number of cloves per
bulb, bulb yield indicating that selection
based on these traits will help increasing the
plant height of garlic.

Similar result was found by Singh (1981),
Shaha et al., (1990), Kohli and Fageria
(1992), Kohli and Mahajan (1993), Barman et
al., (1996) and Esho (2015).

Generally, the value of correlation
coefficients lies between -1.0 to 1.0. In the
present study all the values of correlation
coefficient ranged from -1.0 to 1.0 except one
case, the value of correlation coefficient was
more than 1; it may be due to when
covariance is over estimated whereas variance
is under estimated (Roy, 2000).

When two or more variables are included in
the correlation studies, it becomes difficult to
determine which characters enhance the yield.
The technique of path coefficient analysis
overcomes this situation which partitions the
forces of association and examines the
relative contribution of direct and indirect
effects of the independent variables on the
dependent variables. The direct and indirect
effects of variance characters along with bulb
yield are executed in table 2.

The characters, which had shown significant
phenotypic correlation with bulb yield, were
considered for the results as well as
discussion.
### Table 1: Phenotypic (P) and genotypic (G) correlation coefficients between different characters in garlic

| Characters          | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    | 11    | 12    | 13    | 14    | 15    | 16    | 17    | 18    |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Plant height (cm)   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| No. of leaves per plant |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Leaf length (cm)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Leaf width at collar |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Bulb collar diameter (cm) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Bulb equatorial diameter (cm) |     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Bulb polar diameter (cm) |     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Bulb weight (g)     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| No. of cloves per bulb |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Clove weight (g)    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Clove length (cm)   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Clove polar diameter |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Clove equatorial diameter (cm) |     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Total Soluble Solids (%) |     |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Bulb yield (kg/ha)  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |

*Significant at p=0.05 or at 5% and **Significant at p=0.01 or at 1% (1) Plant height (cm) (2) No. of leaves per plant (3) Leaf length (cm) (4) Leaf width at middle portion (cm) (5) Days to maturity (6) Pseudostem height (cm) (7) Collar thickness (cm) (8) Bulb collar diameter (cm) (9) Bulb equatorial diameter (cm) (10) Bulb polar diameter (cm) (11) Bulb weight (g) (12) No. of cloves per bulb (13) Clove weight (g) (14) Clove length (cm) (15) Clove polar diameter (cm) (16) Clove equatorial diameter (cm) (17) Total Soluble Solids (%) (18) Bulb yield (kg/ha)
| Characters | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1         | 0.3108 | -0.0068 | -0.0321 | 0.0656 | -0.001 | 0.0180 | -0.1151 | -0.0197 | 0.0129 | 0.0051 | 0.0284 | 0.0028 | 0.0022 | -0.0161 | 0.0214 | -0.0082 | -0.0005 | 0.2685** |
| 2         | 0.0452 | -0.0464 | 0.0033 | 0.0550 | -0.0023 | 0.0024 | -0.0088 | -0.0080 | 0.0177 | 0.0073 | 0.0267 | 0.0005 | -0.0091 | -0.1028 | 0.1892 | 0.0292 | 0.0097 | 0.2090** |
| 3         | 0.2000 | 0.0031 | **-0.0499** | 0.0585 | 0.0015 | -0.0370 | -0.0973 | -0.0139 | 0.0017 | -0.0019 | 0.0092 | 0.0024 | 0.0130 | 0.0345 | -0.0568 | -0.0188 | -0.0058 | 0.0426 |
| 4         | 0.1369 | -0.0171 | -0.0196 | **0.1489** | -0.0039 | -0.0013 | -0.0625 | -0.0324 | 0.0196 | 0.0120 | 0.0223 | 0.0008 | -0.0021 | -0.0816 | 0.1105 | 0.0179 | -0.0024 | 0.2459** |
| 5         | 0.0017 | -0.0042 | 0.0030 | 0.0228 | -**0.0253** | -0.0005 | -0.0078 | -0.0064 | 0.0039 | 0.0036 | 0.0008 | -0.0003 | 0.0034 | -0.0231 | 0.0396 | 0.0043 | 0.0050 | 0.0204 |
| 6         | 0.0497 | -0.0010 | 0.0164 | -0.0017 | 0.0001 | **0.1123** | -0.0128 | 0.0029 | 0.0045 | 0.0056 | 0.0115 | -0.0003 | -0.0122 | -0.0344 | 0.0443 | 0.0095 | -0.0086 | 0.1858* |
| 7         | 0.1835 | -0.0021 | -0.0249 | 0.0478 | -0.0010 | 0.0074 | **-0.1950** | -0.0226 | 0.0111 | 0.0026 | 0.0200 | 0.0019 | -0.0008 | -0.0053 | 0.0083 | -0.0041 | -0.0074 | 0.0195 |
| 8         | 0.0835 | -0.0051 | -0.0094 | 0.0658 | -0.0022 | -0.0044 | -0.0601 | **-0.0733** | 0.0251 | 0.0179 | 0.0245 | 0.0007 | -0.0094 | -0.0876 | 0.1528 | 0.0215 | 0.0208 | 0.1609* |
| 9         | 0.0854 | -0.0175 | -0.0018 | 0.0622 | -0.0021 | 0.0109 | -0.0462 | -0.0393 | **0.0468** | 0.0246 | 0.0454 | 0.0008 | -0.0211 | -0.1453 | 0.2538 | 0.0390 | 0.0090 | 0.3047** |
| 10        | 0.0478 | -0.0101 | 0.0029 | 0.0536 | -0.0027 | 0.0190 | -0.0152 | -0.0392 | 0.0344 | **0.0334** | 0.0243 | -0.0004 | -0.0155 | -0.1283 | 0.2147 | 0.0379 | 0.0010 | 0.2575** |
| 11        | 0.1276 | -0.0179 | -0.0067 | 0.0480 | -0.0003 | 0.0187 | -0.0565 | -0.0260 | 0.0307 | 0.0117 | **0.0692** | 0.0029 | -0.0177 | -0.1067 | 0.1918 | 0.0186 | 0.0131 | 0.3006** |
| 12        | 0.1592 | -0.0045 | -0.0215 | 0.0219 | 0.0012 | -0.0069 | -0.0669 | -0.0090 | 0.0069 | -0.0024 | 0.0358 | **0.0056** | 0.0111 | -0.0041 | -0.0042 | -0.0223 | 0.0129 | 0.1127 |
| 13        | -0.0102 | -0.0064 | 0.0098 | 0.0047 | 0.0013 | 0.0207 | -0.0022 | -0.0104 | 0.0149 | 0.0078 | 0.0185 | -0.0009 | **-0.0661** | -0.0557 | 0.1097 | 0.0344 | 0.0086 | 0.0785 |
| 14        | 0.0202 | -0.0193 | 0.0070 | 0.0492 | -0.0024 | 0.0157 | -0.0042 | -0.0260 | 0.0275 | 0.0174 | 0.0299 | 0.0001 | -0.0149 | **-0.2469** | 0.3750 | 0.0437 | 0.0083 | 0.2801** |
| 15        | 0.0160 | -0.0211 | 0.0068 | 0.0396 | -0.0024 | 0.0120 | -0.0039 | -0.0270 | 0.0286 | 0.0173 | 0.0319 | -0.0001 | -0.0175 | -0.2229 | **0.4153** | 0.0463 | 0.0099 | 0.3289** |
| 16        | -0.0318 | -0.0170 | 0.0118 | 0.0333 | -0.0013 | 0.0133 | 0.0099 | -0.0197 | 0.0228 | 0.0159 | 0.0161 | -0.0015 | -0.0285 | -0.1350 | 0.2408 | **0.0799** | 0.0161 | 0.2251** |
| 17        | -0.0017 | -0.0046 | 0.0030 | -0.0036 | -0.0013 | -0.0100 | 0.0148 | -0.0156 | 0.0043 | 0.0004 | 0.0093 | 0.0007 | -0.0059 | -0.0210 | 0.0420 | 0.0132 | **0.0975** | 0.1214 |

*Significant at p=0.05 or at 5 % and **Significant at p=0.01 or at 1%
Residual effect: Phenotypic = 0.8664
N.B.: Values at diagonal and bold indicated direct effects of respective character.
(1) Plant height (cm) (2) No. of leaves per plant (3) Leaf length (cm) (4) Leaf width at middle portion (cm) (5) Days to maturity (6) Pseudostem height (cm) (7) Collar thickness (cm) (8) Bulb collar diameter (cm) (9) Bulb equatorial diameter (cm) (10) Bulb polar diameter (cm) (11) Bulb weight (g) (12) No. of cloves per bulb (13) Clove weight (g) (14) Clove length (cm) (15) Clove polar diameter (cm) (16) Clove equatorial diameter (cm) (17) Total Soluble Solids (%) (18) Bulb yield (kg/ha)
Fig. 1 Genotypic correlation coefficient of seventeen component characters with bulb yield

| Characters                              | $r_{ge}$ |
|----------------------------------------|----------|
| 1. Plant height (cm)                   | 0.702**  |
| 2. No. of leaves per plant             | 0.346**  |
| 3. Leaf length (cm)                    | 0.379**  |
| 4. Leaf width at middle portion (cm)   | 0.632**  |
| 5. Days to maturity                    | 0.129    |
| 6. Pseudostem height (cm)              | 0.046    |
| 7. Collar thickness (cm)               | 0.210**  |
| 8. Bulb collar diameter (cm)           | 0.462**  |
| 9. Bulb equatorial diameter (cm)       | 0.429**  |
| 10. Bulb polar diameter (cm)           | 0.401**  |
| 11. Bulb weight (g)                    | -0.123   |
| 12. No. of cloves per bulb             | 0.056    |
| 13. Clove weight (g)                   | 0.288**  |
| 14. Clove length (cm)                  | 0.333**  |
| 15. Clove polar diameter (cm)          | 0.225**  |
| 16. Clove equatorial diameter          | 0.136    |
| 17. Total soluble solids (%)           |          |
**Fig. 2** Phenotypic correlation coefficient of seventeen component characters with bulb yield

| No. | Character                                | R<sub>p</sub> Value |
|-----|------------------------------------------|-------------------|
| 1.  | Plant height (cm)                        | 0.269**           |
| 2.  | No. of leaves per plant                  | 0.209**           |
| 3.  | Leaf length (cm)                         | 0.186*            |
| 4.  | Leaf width at middle portion (cm)        | 0.246**           |
| 5.  | Days to maturity                         | 0.161*            |
| 6.  | Pseudostem height (cm)                   | 0.305**           |
| 7.  | Collar thickness (cm)                    | 0.257**           |
| 8.  | Bulb collar diameter (cm)                | 0.113             |
| 9.  | Bulb equatorial diameter (cm)            | 0.078             |
| 10. | Bulb polar diameter (cm)                 | 0.301**           |
| 11. | Bulb weight (g)                          | 0.280**           |
| 12. | No. of cloves per bulb                   | 0.043             |
| 13. | Clove weight (g)                         | 0.329**           |
| 14. | Clove length (cm)                        | 0.020             |
| 15. | Clove polar diameter (cm)                | 0.225**           |
| 16. | Clove equatorial diameter                | 0.020             |
| 17. | Total soluble solids (%)                 | 0.121             |

The table shows the phenotypic correlation coefficients (R<sub>p</sub>) of the seventeen component characters with the bulb yield. The characters are ranked from highest to lowest based on their correlation coefficients, with asterisks indicating significance levels: * for p < 0.05 and ** for p < 0.01.
The phenotypic path coefficient analysis revealed that plant height (0.3108) followed by clove polar diameter (0.4153) exhibited high and positive direct effect on bulb yield and was found to be the most important yield components. The characters leaf width at middle portion (0.1489) and pseudostem height (0.1123) had low and positive direct effect on bulb yield, while bulb equatorial diameter (0.0468), bulb polar diameter (0.0334), bulb weight (0.0692), number of cloves per bulb (0.0056), clove equatorial diameter (0.0799), and total soluble solids (0.0975) had very low or negligible and positive direct effect on bulb yield. High and positive direct effect of plant height on bulb yield has also been reported in garlic by Srivastava et al., (1993), Barman et al., (1996), Agrawal (1999), Shaha and Kale (1999), Agrawal and Tiwari (2009), Meena (2010), Tsega et al., (2010), Singh et al., (2012), Dhall et al., (2013), Idress Al Gehani et al., (2013), Singh et al., (2013), Pervin et al., (2014) and Satesh Kumar et al., (2015), of clove polar diameter on bulb yield by Sharma et al., (2016). Thus, these characters viz., plant height and clove polar diameter turned out to be the major components of bulb yield and direct selection for these traits will be rewarding for yield improvement.

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