Correlation and Path Coefficient Studies in Garlic (Allium sativum L.)

**Abstract**

In order to understand the relationship among the different horticultural and yield traits in garlic, a study with 20 promising lines was carried out at Experimental Farm of Horticultural Research and Training Station, and Krishi Vigyan Kendra, Kandaghat. The experiment was laid down in a Randomized Complete Block Design (RCBD) with three replications. The association between various phenological, morphological, yield-contributing, and quality traits was studied using correlation and path coefficient analysis. The results from correlation analysis indicated that the traits such as equatorial diameter, total soluble solids, clove weight, clove breadth, number of leaves per plant, days to maturity, plant height, dry matter, leaf length, neck thickness and number of cloves per bulb were significantly associated with bulb yield in a positive manner. In addition, path analysis suggested that the bulb equatorial diameter had the greatest direct impact on bulb weight, the strong positive and direct effect of bulb weight resulted in a positive association with yield. Therefore, the results inferred that emphasis should be given on traits *i.e*., equatorial diameter, number of leaves per plant, days to maturity, plant height, dry matter, and neck thickness in making direct selection for improvement of bulb yield in garlic.

**Keywords :** *Allium sativum* L., genotypes, character association studies, yield & yield related traits

**Introduction**

Garlic (*Allium sativum* L.) is the second most frequently cultivated crop after onion. It is an asexually propagated crop and a member of the Amaryllidaceae family. Garlic (2n = 16) is an herbaceous annual bulb crop native to Central Asia and is well known for its medicinal properties. In current scenario, garlic is grown across the globe and United States of America, China, India, Spain, Korea, and Egypt are main producers. India is the world's second-largest producer of garlic and among the Indian states, Madhya Pradesh, Gujarat, Orissa, Rajasthan, Uttar Pradesh, and Maharashtra is leading garlic producing states (NHB, 2021-22). In terms of area, garlic is ranked fifth among vegetable crops in India (Patidar et al. 2018).In India, the crop was cultivated over an area of 3,85,324 hectares with production of 3164.63 thousand tons during the year 2021-22. However, the average garlic productivity varies considerably among states, and it ranged from 4.38 to 7.91 t/ha in 2017–18 (NHRDF, 2020).

Understanding the relationships between various components and their respective contributions has immense value in selection. Yield is a highly complex polygenic trait which controlled by many genes at genetic level and is dependent on a number of attributing traits. According to Pandey et al. (2021), execution of a successful selection program requires an understanding of the relationship between yield and its related contributing traits. In this regard, to increase the potential of garlic varieties for bulb yield, it is important to understand the relationship between different plant characters (Ranjitha et al. 2018). Additionally, knowing the direct and indirect effects of various traits on yield would be very helpful in determining the magnitude of association (Kumar et al. 2017).

The correlation coefficient, in this context, measures the linear relationship between two and more variables. Between various characters, the correlation coefficient can be high or low, positive or negative and it provides an overview on the various associations. Understanding the direction of selection and maximizing yield in a short period of time needs estimation of the correlation coefficient among the different plant’s characteristics. Though correlation coefficient estimates merely illustrate the relationships between the characters; they do not provide information on causes and effects. Therefore, path analysis is necessary to differentiate the correlation coefficient into its direct and indirect effect components. The concept of path analysis was introduced by Wright, although the method was initially applied by Dewey and Lu (1959). The path coefficient analysis is essentially a standardized partial regression coefficient that divides the correlation coefficient into measurements of the independent variable's direct and indirect effects. Path coefficient analysis is helpful for residual effect estimation in addition to indirect selection.

Therefore, the present investigation was undertaken with an object to evaluate the correlation and path analysis among twenty genotypes of garlic with respect to sixteen characters. The present study provides information on association between traits of garlic including the yield and also the effect of one character on the direction and magnitude of other character.

**Material and Methods**

The experiment was conducted during the *rabi* season at the Experimental farm of Horticultural Research and Training Station, and Krishi Vigyan Kendra, Kandaghat. The experimental site falls under the mid-hill zone of Himachal Pradesh and located at an altitude of 1425 meters above mean sea level. The experimental material consisted of a total 20 garlic genotypes (Table 1) which have been collected from different states of India along with the check, Agrifound Parvati. The experiment was laid down in Randomized Complete Block Design (RCBD) with three replications and planting was done at a spacing of 20×10cm in the plot of 1×1m size. The various observations *i.e*., phenological (number of days to maturity) morphological (plant height, number of leaves, leaf length, leaf width), yield contributing (neck thickness, bulb polar diameter, bulb equatorial diameter, bulb weight, number of cloves in each bulb, clove length, clove breadth, clove weight, number of bulbs per kg, bulb yield per plot, total dry matter) and biochemical (total soluble solids) were recorded during crop growth stages, harvest and after harvest. The genotypic and phenotypic correlation coefficients were calculated as per methods suggested by Burton and Devane (1953) and Al-Jibouri et al. (1958), respectively. Likewise, path coefficient analysis to assess the direct and indirect contribution of different traits on bulb yield was calculated by using the method proposed by Dewey and Lu (1959).

**Results and Discussion**

**Correlation Studies**

To understand the prevailing association among different parameters and with bulb yield, correlation analysis was carried out. During the study, both phenotypic and genotypic correlation were estimated (Table 2) as field selection was done through the visual observation of the garlic plants, which can be used as an indirect selection criterion (Gomes et al. 2007; Andrade et al. 2010). In addition, selection at the phenotypic level is important for extrapolating the region of interest of the crop and is, therefore, influenced by genotype and by the environment (Andrade et al. 2019).

The yield is a complicated trait and is influenced by other plant’s trait along with environmental variables; selection based on only yield would be ineffective. Therefore, the relationship among the different traits with yield is crucial for selection in breeding programmes (Adam and Grafius 1971). In present study, estimations of phenotypic and genotypic correlation coefficients revealed that, on average, genotypic correlation coefficients were larger in magnitude than their phenotypic counterparts. The level of significance was mentioned at levels p<0.05 or p<0.01 among the traits. The correlation coefficient among sixteen different phenological, morphological, biochemical, yield and yield traits revealed that bulb weight was positively correlated with days to maturity (0.41 and 0.55), plant height (0.51 and 0.52), dry matter (0.47 and 0.48), leaf length (0.46 and 0.47), number of leaves per plant (0.53 and 0.55), yield contributing traits *viz. ,*bulb equatorial diameter (0.90 and 0.93), clove weight (0.63 and 0.65), clove breadth (0.59 and 0.59), neck thickness (0.42 and 0.44), number of clove per bulb (0.38 and 0.42) and biochemical traits like total soluble solids (0.71 and 0.74). On other hand, a negative association of bulb yield with number of bulbs per kg (-0.89 and -0.90) was also reported. A positive correlation implies that increasing one-character results in an increase in the other. On the other hand, negative correlation is inverse; an increase in one feature results in a commensurate reduction in the magnitude of the other character. It was also observed that bulb diameter is strongly associated with bulb yield, therefore, when genotypes with larger bulb diameters are selected it results in higher commercial bulb yield. Similar to this, Gabriel and Guiñazú (2007); and Rezende and Silva (2015), also concluded that bulbs with larger diameters at planting resulted in increased garlic yield. Furthermore, plant height was also found to be positively correlated with bulb yield which is due to fact that taller plants have a larger photo synthetically active area, resulting in higher vegetative masses and a greater accumulation of photo-assimilates in the shoots also produces larger bulbs. Therefore, the translocation of the nutrients and reserves present in the leaves during the bulbification period causes larger bulbs (Mathew et al. 2011).

In general, the genotypic correlation coefficient was found greater than its phenotypic counterpart (Table 2). The genotypic correlation was comparable to the phenotypic correlation, except that in certain instances, the correlation coefficient was non-significant at the phenotypic level but significant at the genotypic level. However, the degree of the inconsistency between genotypic and phenotypic correlations was less for the aforementioned characteristics, suggesting that environmental variables had a smaller effect on their expression. The correlation analysis revealed positive interrelationships between bulb yield and plant height, number of leaves per plant, bulb polar diameter and bulb weight.The similar results were also noted by earlier researchers such as Singh et al. (2013); Sharma et al. (2016); Prajapati et al. (2016); Chotalia and Kulkarni (2017); Kumar et al. (2017); and Tiwari et al. (2022) in garlic.

Selection on the basis of these characteristics will definitely result in an increase in yield. Significant correlation coefficients between the majorities of the characteristics in this research indicated that these characters were controlled by certain genetic systems of coupling linkage in an equilibrium phase, implying that selection on their genetic linkage would increase garlic production.

**Path Coefficient Analysis**

The path coefficient analysis illustrates the impact of several independent characteristics on the expression of yield, both alone and in conjunction with other characters. It is a critical technique for decomposing correlation coefficients into their direct and indirect effects on a dependent variable by independent factors. It enables a rigorous analysis of particular force action in order to generate a specified correlation and quantify the proportional significance of each component. The bulb yield per plot was used as the dependent variable in this study, while the remaining characteristics were used as independent factors.

The path coefficient analysis (Table 3) showed that bulb equatorial diameter (0.729) had a significant positive and direct impact on bulb yield per plot, followed by clove length (0.320), number of leaves per plant (0.290), leaf length (0.190), dry matter (0.110), number of cloves per bulb (0.080), days to maturity (0.60), bulb polar diameter (0.040), plant height (0.030) and leaf width at middle portion (0.040). Whereas maximum negative direct effect on bulb weight was recorded maximum by clove breadth (-0.450) followed by number of bulbs per kg (-0.170), total soluble solids (-0.110), neck thickness (-0.090) and clove weight (-0.030).

Bulb equatorial diameter had shown the greatest direct effect on bulb weight. The strong positive and direct effect of bulb weight (13.12) resulted in a positive association with yield. Yadav et al. (2007); Dubey et al. (2010) and Singh et al. (2013) also found that bulb weight had the greatest direct impact on bulb production per plot. Agarwal and Tiwari (2009) reported that clove length has a direct beneficial impact on bulb production. Sonkiya et al. (2012) observed that neck thickness had a favorable and direct impact on bulb production. Whereas, Singh et al. (2008) and Singh et al. (2011) noticed a negative direct impact of plant height, number of leaves per plant, clove weight, and cloves per bulb on total bulb output. Panse et al. (2013) reported that days to maturity had a negative direct impact on overall bulb yield. Bhatt et al. (2017) also found that clove weight and cloves per bulb had a negative direct impact on overall bulb production.Bulb equatorial diameter had a strong positive and direct impact on bulb weight in this study, followed by clove length, number of leaves per plant, leaf length, dry matter, number of cloves per bulb, days to maturity, bulb polar diameter, plant height and leaf width at middle portion. Therefore, these characteristics should be considered while selecting genotypes to eventually increase garlic yield.

**Conclusion**

The present study highlighted the association between yield and different morphological, yield contributing and biochemical traits in 20 garlic genotypes. The correlation and path analysis was performed to understand the degree and magnitude of association. The results from present study showed that the phenotypic correlation coefficients were higher in magnitude than genotypic correlation coefficient. The phenotypic and genotypic correlation coefficient among different characters showed that bulb weight was correlated positively and significantly with equatorial diameter, total soluble solids, clove weight, clove breadth, number of leaves per plant, days to maturity, plant height, dry matter, leaf length, neck thickness and number of cloves per bulb. Furthermore, the findings from path analysis suggested that the maximum positive and direct effect on bulb weight was contributed by bulb equatorial diameter, clove length, number of leaves per plant, leaf length, dry matter, number of cloves per bulb, days to maturity, bulb polar diameter, plant height and leaf width at middle portion. Therefore, main emphasis should be given on these characters, while making selection for higher bulb yield in garlic.

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### Table 1: List of genotypes along with their sources

|  |  |  |
| --- | --- | --- |
| S. No. | GENOTYPE | SOURCE |
| 1 | Kashmir Collection | Sundipora, Badgam, Kashmir |
| 2 | Afghanistan Collection | Saibugh, Kashmir |
| 3 | Jammu Collection | Marh, Jammu |
| 4 | PG-17 | PAU Ludhiana, Punjab |
| 5 | GT Selection | NHRDF, Nasik (MH) |
| 6 | Sapni Collection | Sapni, Kinnaur |
| 7 | Kail Collection | Kail, Shimla |
| 8 | Bhuira Collection | Bhuira, Sirmaur |
| 9 | Haripurdhar Collection | Haripurdhar, Sirmaur |
| 10 | Chausa Collection | Chausa, Kandaghat, Solan |
| 11 | Ded Collection | Ded, Kandaghat, Solan |
| 12 | Dolag Collection | Dolag, Kandaghat, Solan |
| 13 | Mahi Collection | Mahi, Kandaghat, Solan |
| 14 | Baniya Devi Collection | Kunihar, Solan |
| 15 | Malkeet Collection | Nalagarh, Solan |
| 16 | Nalagarh Collection | Nalagarh, Solan |
| 17 | Ramshehar Collection | Ramshehar, Nalagarh, Solan |
| 18 | Deothi Collection | Deothi, Solan |
| 19 | Kandaghat Selection | UHF, Solan |
| 20 | Agrifound Parvati (Check) | UHF, Solan |

**Table 2: Phenotypic and genotypic coefficients of correlation among different characters in garlic.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Traits** |  | **DM** | **TSS** | **BPK** | **CW** | **CB** | **CL** | **CPB** | **BED** | **BPD** | **NT** | **LW** | **LL** | **LPP** | **PH** | **DTM** |
| **BW** | **G** | **0.48\*** | **0.74\*** | **-0.91\*** | **0.65\*** | **0.59\*** | **0.52\*** | **0.42\*** | **0.93\*** | **0.20** | **0.44\*** | **0.14** | **0.47\*** | **0.55\*** | **0.52\*** | **0.55\*** |
|  | **P** | **0.47\*** | **0.71\*** | **-0.89\*** | **0.63\*** | **0.59\*** | **0.51\*** | **0.38\*** | **0.90\*** | **0.19** | **0.42\*** | **0.14** | **0.46\*** | **0.53\*** | **0.51\*** | **0.41\*** |
| **DM** | **G** |  | 0.45\* | -0.49\* | 0.59\* | -0.03 | -0.07 | 0.02 | 0.38\* | 0.35\* | 0.18 | 0.62\* | 0 | 0.07 | 0.40\* | 0.42\* |
|  | **P** |  | 0.42\* | -0.48\* | 0.56\* | -0.03 | -0.06 | 0.01 | 0.37\* | 0.33\* | 0.16 | 0.60\* | 0.02 | 0.09 | 0.38\* | 0.30\* |
| **TSS** | **G** |  |  | -0.82\* | 0.27\* | 0.59\* | 0.51\* | 0.23 | 0.70\* | -0.07 | 0.42\* | 0.25\* | 0.11 | 0.80\* | 0.26\* | 0.38\* |
|  | **P** |  |  | -0.79\* | 0.25\* | 0.56\* | 0.50\* | 0.21 | 0.66\* | -0.06 | 0.39\* | 0.24 | 0.11 | 0.74\* | 0.23 | 0.32\* |
| **BPK** | **G** |  |  |  | -0.56\* | -0.60\* | -0.51\* | -0.27\* | -0.90\* | -0.15 | -0.45\* | -0.23 | -0.25 | -0.58\* | -0.44\* | -0.55\* |
|  | **P** |  |  |  | -0.55\* | -0.59\* | -0.51\* | -0.24 | -0.87\* | -0.15 | -0.43\* | -0.22 | -0.24 | -0.55\* | -0.42\* | -0.40\* |
| **CW** | **G** |  |  |  |  | 0.22 | 0.16 | -0.11 | 0.67\* | 0.64\* | 0.35\* | 0.14 | 0.35\* | -0.02 | 0.72\* | 0.69\* |
|  | **P** |  |  |  |  | 0.21 | 0.16 | -0.1 | 0.64\* | 0.61\* | 0.34\* | 0.14 | 0.34\* | -0.02 | 0.69\* | 0.49\* |
| **CB** | **G** |  |  |  |  |  | 0.98\* | 0.23 | 0.66\* | -0.08 | 0.1 | -0.14 | 0.32\* | 0.51\* | 0.26\* | 0.21 |
|  | **P** |  |  |  |  |  | 0.97\* | 0.21 | 0.63\* | -0.08 | 0.1 | -0.13 | 0.30\* | 0.49\* | 0.25 | 0.17 |
| **CL** | **G** |  |  |  |  |  |  | 0.18 | 0.58\* | -0.07 | 0.04 | -0.15 | 0.31\* | 0.46\* | 0.26\* | 0.11 |
|  | **P** |  |  |  |  |  |  | 0.15 | 0.56\* | -0.06 | 0.05 | -0.14 | 0.30\* | 0.44\* | 0.25 | 0.09 |
| **CPB** | **G** |  |  |  |  |  |  |  | 0.33\* | -0.33\* | 0.02 | 0.04 | 0.16 | 0.42\* | -0.11 | -0.1 |
|  | **P** |  |  |  |  |  |  |  | 0.28\* | -0.28\* | 0.03 | 0.04 | 0.16 | 0.35\* | -0.08 | -0.12 |
| **BED** | **G** |  |  |  |  |  |  |  |  | 0.14 | 0.31\* | 0.09 | 0.31\* | 0.41\* | 0.39\* | 0.59\* |
|  | **P** |  |  |  |  |  |  |  |  | 0.12 | 0.28\* | 0.08 | 0.29\* | 0.39\* | 0.36\* | 0.44\* |
| **BPD** | **G** |  |  |  |  |  |  |  |  |  | 0.49\* | 0.28\* | 0.33\* | -0.17 | 0.83\* | 0.24 |
|  | **P** |  |  |  |  |  |  |  |  |  | 0.45\* | 0.26\* | 0.30\* | -0.17 | 0.79\* | 0.15 |
| **NT** | **G** |  |  |  |  |  |  |  |  |  |  | 0.16 | 0.51\* | 0.48\* | 0.72\* | 0.24 |
|  | **P** |  |  |  |  |  |  |  |  |  |  | 0.16 | 0.49\* | 0.46\* | 0.68\* | 0.15 |
| **LW** | **G** |  |  |  |  |  |  |  |  |  |  |  | -0.08 | -0.15 | 0.24 | -0.06 |
|  | **P** |  |  |  |  |  |  |  |  |  |  |  | -0.08 | -0.15 | 0.24 | -0.06 |
| **LL** | **G** |  |  |  |  |  |  |  |  |  |  |  |  | 0.26\* | 0.67\* | 0.22 |
|  | **P** |  |  |  |  |  |  |  |  |  |  |  |  | 0.26\* | 0.63\* | 0.15 |
| **LPP** | **G** |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.18 | 0.03 |
|  | **P** |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.16 | 0.06 |
| **PH** | **G** |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.40\* |
|  | **P** |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.25 |
| **\*Significance at 5% level of significance** | | | | | | | | | | | | | | | | |

DTM: Days to Maturity, PH: Plant Height, LPP: No of leaves per Plant, LL: Leaf Length, LW: Leaf Width, NT: Neck Thickness, BPD: Bulb Polar Diameter, BED: Bulb Equatorial Diameter, CPB: No of Cloves per Bulb, CL: Clove Length, CB: Clove Breadth, CW: Clove Weight, BPK: No of Bulbs per kg, TSS: Total Soluble Solids, DM: Dry Matter (%) and BW: Bulb Weight.

**Table 3: Estimates of direct and indirect effects of different characters on bulb yield of garlic.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **DTM** | **PH** | **LPP** | **LL** | **LW** | **NT** | **BPD** | **BED** | **CPB** | **CL** | **CB** | **CW** | **BPK** | **TSS** | **DM** | **BW** |
| **DTM** | **0.060** | 0.010 | 0.010 | 0.040 | 0.000 | -0.020 | 0.010 | 0.430 | -0.010 | 0.030 | -0.090 | -0.020 | 0.090 | -0.040 | 0.050 | **0.55** |
| **PH** | 0.030 | **0.030** | 0.050 | 0.130 | 0.010 | -0.060 | 0.030 | 0.280 | -0.010 | 0.080 | -0.050 | -0.020 | 0.070 | -0.090 | 0.040 | **0.52** |
| **LPP** | 0.000 | 0.000 | **0.290** | 0.050 | -0.010 | -0.040 | -0.010 | 0.300 | 0.030 | 0.150 | -0.230 | 0.000 | 0.100 | -0.090 | 0.010 | **0.55** |
| **LL** | 0.010 | 0.020 | 0.070 | **0.190** | 0.000 | -0.050 | 0.010 | 0.220 | 0.010 | 0.100 | -0.130 | -0.010 | 0.040 | -0.010 | 0.000 | **0.47** |
| **LW** | 0.000 | 0.010 | -0.040 | -0.020 | **0.040** | -0.010 | 0.010 | 0.070 | 0.000 | -0.050 | 0.050 | 0.000 | 0.040 | -0.030 | 0.070 | **0.14** |
| **NT** | 0.020 | 0.020 | 0.140 | 0.100 | 0.010 | **-0.090** | 0.020 | 0.220 | 0.000 | 0.010 | -0.050 | -0.010 | 0.080 | -0.050 | 0.020 | **0.44** |
| **BPD** | 0.020 | 0.020 | -0.050 | 0.060 | 0.010 | -0.040 | **0.040** | 0.100 | -0.030 | -0.020 | 0.040 | -0.020 | 0.030 | 0.010 | 0.040 | **0.21** |
| **BED** | 0.040 | 0.010 | 0.120 | 0.060 | 0.000 | -0.030 | 0.010 | **0.720** | 0.030 | 0.180 | -0.300 | -0.020 | 0.150 | -0.080 | 0.040 | **0.93** |
| **CPB** | -0.010 | 0.000 | 0.120 | 0.030 | 0.000 | 0.000 | -0.010 | 0.240 | **0.080** | 0.060 | -0.110 | 0.000 | 0.050 | -0.030 | 0.000 | **0.42** |
| **CL** | 0.010 | 0.010 | 0.130 | 0.060 | -0.010 | 0.000 | 0.000 | 0.420 | 0.010 | **0.320** | -0.440 | 0.000 | 0.090 | -0.060 | -0.010 | **0.53** |
| **CB** | 0.010 | 0.010 | 0.150 | 0.060 | -0.010 | -0.010 | 0.000 | 0.480 | 0.020 | 0.310 | **-0.450** | -0.010 | 0.100 | -0.070 | 0.000 | **0.59** |
| **CW** | 0.040 | 0.020 | -0.010 | 0.070 | 0.010 | -0.030 | 0.030 | 0.480 | -0.010 | 0.050 | -0.100 | **-0.030** | 0.090 | -0.030 | 0.070 | **0.65** |
| **BPK** | -0.040 | -0.010 | -0.170 | -0.050 | -0.010 | 0.040 | -0.010 | -0.630 | -0.020 | -0.160 | 0.270 | 0.020 | **-0.170** | 0.090 | -0.060 | **-0.91** |
| **TSS** | 0.020 | 0.010 | 0.230 | 0.020 | 0.010 | -0.040 | 0.000 | 0.500 | 0.020 | 0.160 | -0.260 | -0.010 | 0.140 | **-0.110** | 0.050 | **0.74** |
| **DM** | 0.030 | 0.010 | 0.020 | 0.000 | 0.020 | -0.020 | 0.010 | 0.300 | 0.000 | -0.020 | 0.010 | -0.020 | 0.080 | -0.050 | **0.110** | **0.48** |
| **Residual =** **0.019** | | | | | | | | | | | | | | | | |

DTM: Days to Maturity, PH: Plant Height, LPP: No of leaves per Plant, LL: Leaf Length, LW: Leaf Width, NT: Neck Thickness, BPD: Bulb Polar Diameter, BED: Bulb Equatorial Diameter, CPB: No of Cloves per Bulb, CL: Clove Length, CB: Clove Breadth, CW: Clove Weight, BPK: No of Bulbs per kg, TSS: Total Soluble Solids, DM: Dry Matter (%) and BW: Bulb Weight.