Received: 17 Mar 2021 | Revised: 28 May 2021 | Accepted: 01 Jun 2021

Electronic Journal of Plant Breeding

Research Article

# Study on genetic parameters in garlic (*Allium sativum* L.) for yield and quality traits

**Santosh Kumari***

Department of Vegetable Science, College of Horticulture & Forestry, Neri, Hamirpur, Dr Y S Parmar University of Horticulture & Forestry, Nauni- 173230 Solan, HP, India
*E-Mail: santoshstpc@gmail.com

**Abstract**
Garlic is an important vegetable crop grown widely throughout the world for its medicinal values and health benefits. Garlic helps to prevent and reduce the severity of common illnesses like the flu and common cold, improves blood pressure and reduces the cholesterol. The present study was undertaken to assess the genetic variability, to determine the correlation of bulb yield and its contributing components and to identify those components with significant effects on yield and using them as selection criteria. The genetic parameters of variability were estimated, comprising thirty-six genotypes in garlic at the Research Farm of Vegetable Science, UHF, Nauni, Solan, HP during the *Rabi* season, 2014-15 and 2015-16. Phenotypic and genotypic coefficients of variation were higher for weight of 100 peeled cloves (35.09 % and 31.07 %), bulb yield per plot (34.87 % and 33.19 %), bulb yield per hectare (34.87 % and 33.19 %), clove weight (34.50 % and 30.83 %), weight of 100 unpeeled cloves (34.22 % and 30.07 %), oleoresin content (32.69 % and 31.79 %), bulb weight (30.65 % and 30.01 %) and the number of bulbs per kg (30.21 % and 30.01 %) indicating further scope of improvement and facilitating the selection for these characters. High heritability was recorded for the characters *viz.,* peeling index (99 %), the number of bulbs per kg (96 %), oleoresin content (95 %), bulb weight (94 %), the number of leaves per plant (92 %), bulb yield per plot (91 %), bulb yield per hectare (91 %), the number of cloves per bulb (90 %), drying percentage (86 %), neck thickness (84 %), clove length (84 %), bulb breadth (83 %), plant height (82 %) and clove weight (80 %). High genetic gain was recorded for characters *viz.*, bulb yield per plot (65.07 %), bulb yield per hectare (65.07 %), oleoresin content (63.70%), the number of bulbs per kg (59.68 %), bulb weight (59.36 %), clove weight (56.76 %), weight of 100 peeled cloves (56.68 %), weight of 100 unpeeled cloves (52.19 %) and the number of cloves per bulb (50.04 %). An idea about interrelationships of bulb yield and its components is very helpful to improve the efficiency of breeding program using appropriate selection indices. Yield per plot was positively and significantly associated with plant height (0.445 and 0.492), the number of leaves per plant (0.381 and 0.407), days to maturity (0.497 and 0.641), neck thickness (0.375 and 0.409), bulb weight (0.966 and 1.00), bulb breadth (0.808 and 0.898), bulb length (0.852 and 0.984), clove weight (0.865 and 0.936), clove breadth (0.726 and 0.787), clove length (0.734 and 0.799), weight of 100 unpeeled cloves (0.800 and 0.873) and weight of 100 peeled cloves (0.796 and 0.861) whereas, negatively and significantly with the number of cloves per bulb (-0.448 and -0.473), the number of bulbs per kg (-0.921 and -0.960) and drying percentage (-0.374 and -0.404). Path coefficient analysis revealed a high positive and direct effect of bulb weight (2.018) on bulb yield per plot followed by weight of 100 unpeeled cloves (0.641), the number of bulbs per kg (0.309), days to maturity (0.154), peeling index (0.139), plant height (0.118), drying percentage (0.115), clove breadth (0.094), neck thickness (0.054), clove weight (0.049) and the number of leaves per plant (0.042).

**Key words**
Garlic, variability, heritability, correlation, path coefficient

## INTRODUCTION

Garlic (*Allium sativum* L.) is one of the most important remunerative bulbous spice and medicinal crops grown in the world. It is the second most widely cultivated bulb

crop after onion, in the world, which belongs to family Amaryllidaceae. The primary centre of origin of garlic is the Central Asia and Southern Europe whereas, the Mediterranean region is considered as its secondary centre of origin (Brewster, 1994). The most probable wild progenitor of garlic is *Allium longicuspis* Regel (Vvedensky, 1944). Garlic crop is a valuable spice and condiment in India imparting flavour, aroma and taste. It is consumed both fresh and in dried form. In India and the other Asian and Middle East countries, garlic is used for food preparation, chutney, pickles, curried vegetables, meat preparation and tomato ketchup etc. (Shinde *et al.*, 2003). In many regions, people use fresh leaves as salad. Garlic has high nutritive value than other bulb crops and has good export potential as fresh bulb as well as in the dehydrated form. Garlic is low in calories and contains carbohydrates, sugars, dietary fibres, fat, proteins, thiamine, riboflavin, niacin, vitamin C, calcium, vitamin B6 and manganese. The crop contains sulphur and essential oils that are often correlated with strong flavour (Memane *et al.*, 2008). The chief constituents of oil are diallyl disulphide, diallyl trisulphide, allyl - propyl disulphide and a small quantity of diethyl disulphide and diallyl polysulphide. Diallyl disulphide is said to possess the true garlic odour (Shankaracharya, 1974). It has also been considered as 'Nectar of life' in Ayurveda (Singh *et al.,* 2015). Garlic contains antioxidants that protects against cell damage and aging. Moreover, garlic has been reported to reduce blood lipids and to have anticancer effects. It has hypocholesterolemic action and reduces the cholesterol concentration in human blood. It has antibacterial (Arora and Kaur, 1999), antifungal (Hughes and Lawson, 1991), antiviral (Meng *et al.*, 1996) and antiprotozoal properties (Reuter *et al.*, 1996). It is beneficial to cardiovascular and immune system. Botanically, economic part of garlic is a compound bulb composed of few to many densely packed elongated side cloves. Garlic bulb does not store food, instead matures as dry scales enclosing cloves which are well developed auxiliary buds within foliage leaves. It also shows adaptation to a wide range of soil types, temperatures and day length making its farming possible from tropics to temperate latitudes. Garlic is grown globally, but China is the leading country in area and production followed by India, Republic of Korea, Egypt and Russian Federation. In India, area under garlic is 317 thousand hectares with an annual production of 1611 thousand MT (NHB, 2018). Garlic is cultivated mainly in the states of Madhya Pradesh, Gujarat, Orissa, Maharashtra and Uttar Pradesh. Madhya Pradesh is the leading state in garlic production contributing, 92.5 thousand hectare area with 405 thousand MT 0f production (NHB, 2018). In Himachal Pradesh, garlic is grown over an area of 4.95 thousand hectares with production of 8.49 thousand MT (NHB, 2018). It is a good foreign exchange earner and large quantity of garlic is exported every year. Major garlic exporting countries are China, France, Spain and Egypt whereas, the major garlic importing countries are Bangladesh, Philippines, Singapore, UK and USA. Garlic displays considerable variability with respect to morphology, yield, quality features as well as resistance to important insect pests and diseases. Though, India ranks the second in terms of area and production, but productivity of garlic is very less (5.42 t/ha). Unavailability of improved varieties, improper cultural practices, post harvest and market related issues are main causes of low production and productivity. Also there are limited numbers of cultivars in the crop owing to lack of variability. This warrants the need to identify the promising genotypes for yield, quality attributes and disease resistance. Assessment of available variability in germplasm through parameters of variability helps to select potential genotypes for their direct use as variety. The present investigation was therefore; carried out in garlic to assess the genetic variability and the relationships among yield, yield contributing attributes and quality attributes.

## MATERIALS AND METHODS

Thirty-six genotypes of garlic were collected from within and outside the state to study the genetic parameters. The experiment was laid out in RCBD with three replications at Research Farm of Department of Vegetable Science, UHF, Nauni, Solan (HP) during the Rabi seasons of 2014-15 and 2015-16. The climate of Experimental Site is generally characterized as sub-temperate with the mild summers and cool winters. Months of May and June are the hottest, while December and January are the coldest. It experiences annual rainfall of 1100-1300 mm, most of which occurs during the monsoon season. Mean temperature during the crop season varied from 9.85 ˚C to 23.50 ˚C and 10.85˚C to 23.6 ˚C, while relative humidity varied from 45 % to 63 % and 45 % to 62 % during the year 2014-15 and 2015-16, respectively. The soil structure of experimental site is gravelly loam to gravelly clay loam with pH ranging from 6.85 - 7.04. Experimental material was planted during the first fortnight of October in 2014 and 2015 at a spacing of 20 x 10 cm in a plot size of 2 x 1 m accommodating 100 plants. The standard cultural practices were followed to raise a healthy garlic crop as advocated in the "Package of Practices for Vegetable Crops" of the university. The observations were recorded on various characters *viz.,* plant height (cm), the number of leaves per plant, days to maturity, neck thickness (cm), bulb weight (g), bulb breadth (cm), bulb length (cm), clove weight (g), cove length (cm), clove breadth (cm), the number of cloves per bulb, the number of bulbs per kg, weight of 100 unpeeled cloves (g), weight of 100 peeled cloves (g), bulb yield per plot (kg), bulb yield per hectare (q), peeling index (%), drying percentage (%), total soluble solids (ºBrix) and oleoresin content (%).
Peeling index was computed as follows:

**Peeling index (%)** =

$$\frac{\text{Weight of 100 peeled cloves}}{\text{Weight of 100 unpeeled cloves}} X100$$

Drying percentage was analyzed as follows:

**Drying percentage (%) =**

$$\frac{\text{Weight after drying}}{\text{Weight before drying}} X100$$

,

Total soluble solids were assessed by an instrument known as hand refractometer, by placing a drop of juice on it. The numbers on the scale were visible when the refractometer was pointed towards a light source which represented the concentration of soluble solids in the garlic extract in ºBrix.

Oleoresin content was determined as per standard procedure (AOAC, 1975).

**Oleoresin content (%) =**

$$\frac{\text{Weight of oleoresinin the sample (g)}}{\text{Weight of the sample (g)}} X100$$

Variability coefficients were analyzed as per methods of Burton and De-Vane (1953) and path analysis by the method given by Dewey and Lu (1959).

Sharma (1994) suggested the following limits, for categorizing the magnitude of different parameters viz., PCV and GCV: > 30% High;15-30% Moderate; < 15% Low; Heritability (H): >80% High; 50-80% Moderate; < 50% Low; Genetic gain (GG) : > 50% High; 25 50% Moderate and <25% Low.

## RESULTS AND DISCUSSION

The pooled analysis of variance of the years 2014-15 and 2015-16, indicated significant differences among the genotypes for all the characters studied (**Table 1**), which revealed the existence of wide variability in the germplasm. The extent of variability in thirty-six genotypes was measured in terms of coefficients of variation *viz*., phenotypic and genotypic coefficient of variation along with the amount of heritability, genetic advance and expected genetic advance as per cent of mean. (**Table 2**) Considerable variation was observed for most of the characters. For determining the magnitude of genotypic and phenotypic variability, the genotypic and phenotypic coefficients of variation were calculated. Phenotypic and genotypic coefficients of variation were higher for weight of 100 peeled cloves, bulb yield per plot, bulb yield per hectare, clove weight, weight of 100 unpeeled cloves, oleoresin content, bulb weight and the number of bulbs/kg indicating further scope of improvement and facilitating the selection for these characters to isolate more promising genotypes. The results are in line with the findings of Tsega *et al*. (2011), Vatsyayan *et al*. (2013) and Khar *et al*. (2015) who recorded the high estimates of phenotypic and genotypic coefficients of variation for characters bulb weight, clove

**Table 1. Pooled analysis of variance of the years 2014-15 and 2015-16 for various horticultural characters in garlic**

| Source | df | Mean Sum of Squares | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Plant height | Leaves/ plant | Days to maturity | Neck thickness | Bulb weight | Bulb breadth | Bulb length | Clove weight | Clove breadth | Clove length | Cloves/ bulb | Bulbs/ Kg | Bulb yield per hectare | Weight of 100 unpeeled cloves | Weight of 100 peeled cloves | Peeling index | Drying percen-tage | TSS (ºB) | Oleoresin content | Yield/ plot |
| Replication | 2.00 | 6.544 | 0.129 | 25.292 | 0.006 | 2.841 | 0.038 | 0.108 | 0.333 | 0.031 | 0.045 | 2.750 | 25.638* | 342.476* | 2778.989* | 1160.295 | 0.001 | 0.655 | 11.286 | 0.001 | 0.169* |
| Genotype | 35.00 | 122.338* | 2.998* | 83.914* | 0.088* | 327.461* | 2.612* | 2.417* | 5.270* | 0.554* | 1.846* | 75.213* | 1461.778* | 6560.755* | 23435.835* | 22380.211* | 0.178* | 42.980* | 57.411* | 0.102* | 3.240* |
| Year | 1.00 | 232.359* | 2.011* | 1.500 | 0.147* | 360.013* | 5.621* | 3.709* | 6.458* | 0.209* | 1.113* | 22.247* | 70.521* | 6288.844* | 2177.479 | 3051.466* | 0.094* | 7.531* | 61.857* | 0.005* | 3.106* |
| Year x Genotype | 35.00 | 12.327* | 1.343* | 8.710 | 0.004 | 5.073* | 0.141* | 0.208* | 0.328* | 0.082* | 0.112* | 2.092* | 12.714* | 154.292* | 1428.571* | 1085.721* | 0.009* | 3.221* | 2.715 | 0.001* | 0.077* |
| Error | 142.00 | 4.601 | 0.065 | 9.771 | 0.003 | 3.345 | 0.091 | 0.128 | 0.215 | 0.031 | 0.060 | 1.338 | 7.963 | 101.916 | 901.443 | 701.372 | 0.000 | 1.168 | 3.753 | 0.001 | 0.050 |
| Total | 215.00 | 378.169 | 6.545 | 129.186 | 0.247 | 698.733 | 8.503 | 6.571 | 12.604 | 0.907 | 3.176 | 103.639 | 1578.614 | 13448.283 | 30722.317 | 28379.065 | 0.281 | 55.556 | 137.021 | 0.110 | 6.642 |

* Significant at 5% level of significance

**Table 2. Estimates of phenotypic and genotypic coefficients of variation, heritability, genetic advance and genetic gain for various characters in garlic**

| Characters | Range | Mean ± SE | Coefficients of variability (%) | | Heritability (%) | Genetic advance | Genetic gain (%) |
|---|---|---|---|---|---|---|---|
| | | | Phenotypic | Genotypic | | | |
| Plant height (cm) | 52.50 - 71.08 | 62.08 ± 0.75 | 8.26 | 7.50 | 82 | 8.71 | 14.04 |
| No. of leaves per plant | 5.70 - 8.30 | 7.06 ± 0.12 | 12.40 | 11.87 | 92 | 1.65 | 23.39 |
| Days to maturity | 215 - 227.67 | 221.11 ± 0.62 | 2.11 | 1.56 | 55 | 5.29 | 2.39 |
| Neck thickness (cm) | 0.52 - 1.07 | 0.72 ± 0.02 | 18.33 | 16.76 | 84 | 0.23 | 31.58 |
| Bulb weight (g) | 11.67 - 40.08 | 25.05 ± 1.23 | 30.65 | 30.01 | 94 | 14.83 | 59.36 |
| Bulb breadth (cm) | 2.89 - 5.51 | 4.28 ± 0.11 | 17.15 | 15.64 | 83 | 1.26 | 30.01 |
| Bulb length (cm) | 2.15 - 4.49 | 3.35 ± 0.11 | 21.80 | 19.01 | 76 | 1.15 | 34.15 |
| Clove weight (g) | 1.13 - 4.63 | 3.03 ± 0.16 | 34.50 | 30.83 | 80 | 1.72 | 56.76 |
| Clove breadth (cm) | 0.70 - 1.88 | 1.35 ± 0.04 | 26.35 | 22.88 | 75 | 0.55 | 40.93 |
| Clove length (cm) | 1.30 - 3.29 | 2.63 ± 0.09 | 23.07 | 21.10 | 84 | 1.04 | 39.75 |
| Number of cloves per bulb | 9.75 - 26.75 | 13.89 ± 0.59 | 26.65 | 25.31 | 90 | 6.88 | 50.04 |
| Number of bulbs per kg | 31.83 - 91.50 | 53.63 ± 2.38 | 30.21 | 30.01 | 96 | 31.10 | 59.68 |
| Weight of 100 unpeeled cloves (g) | 109.72 - 337.62 | 200.26 ± 10.42 | 34.22 | 30.07 | 74 | 104.52 | 52.19 |
| Weight of 100 peeled cloves (g) | 103.50 - 319.10 | 187.72 ± 10.18 | 35.09 | 31.07 | 78 | 106.41 | 56.68 |
| Bulb yield per plot (kg) | 0.88 - 3.74 | 2.46 ± 0.12 | 34.87 | 33.19 | 91 | 1.44 | 65.07 |
| Bulb yield per hectare (q) | 39.60 - 168.30 | 103.95 ± 5.51 | 34.87 | 33.19 | 91 | 64.66 | 65.07 |
| Peeling index (%) | 84.19 - 97.01 | 93.49 ± 0.55 | 3.61 | 3.59 | 99 | 6.88 | 7.36 |
| Drying percentage (%) | 26.99 - 43.47 | 34.26 ± 0.74 | 14.01 | 12.99 | 86 | 8.51 | 25.10 |
| Total Soluble Solids (ºBrix) | 20.31 - 33.90 | 27.00 ± 0.52 | 13.18 | 11.06 | 70 | 5.16 | 19.11 |
| Oleoresin content (%) | 0.16 - 0.61 | 0.41 ± 0.02 | 32.69 | 31.79 | 95 | 0.26 | 63.70 |

weight and bulb yield per hectare. High PCV and GCV for bulb weight were reported by Sharma *et al*. (2016) and Meena *et al.* (2020). Moderate phenotypic and genotypic coefficients of variation were recorded for the number of cloves per bulb, clove breadth, clove length, bulb length, neck thickness and bulb breadth. These characters can be improved by vigorous selection. Moderate estimates of phenotypic and genotypic coefficients of variation for the number of cloves per bulb have been reported by Tsega *et al*. (2011), Singh *et al*. (2012a), Yadav *et al.* (2012) and Panse *et al*. (2013). Low estimates of phenotypic and genotypic coefficients of variation were recorded for drying percentage, the total soluble solids, the number of leaves per plant, plant height, peeling index and days to maturity. For improving these traits, breeder should go to source of high variability. Low phenotypic and genotypic coefficients of variation for drying percentage has been reported by Vatsyayan *et al*. (2013), for the total soluble solids by Khar *et al*. (2005) and Sandhu *et al*. (2015) and for peeling index by Tsega *et al*. (2011) in garlic.

The genotypic coefficient of variation does not offer full scope to estimate the variations that are heritable and therefore, estimation of heritability becomes necessary. Genetic heritability is heritable from one generation to another. But heritability alone cannot assess the expected gain in next generation, so should be considered with genetic advance. In the present study, estimates of heritability (broad sense) varied from 55- 99 per cent. High heritability was recorded for the characters *viz.,* peeling index, the number of bulbs per kg, oleoresin content, bulb weight, the number of leaves per plant, bulb yield per plot, bulb yield per hectare, the number of cloves per bulb, drying percentage, neck thickness, clove length, bulb breadth, plant height and clove weight. Estimates of heritability were recorded moderate for weight of 100 peeled cloves, bulb length, clove breadth, weight of 100 unpeeled cloves, the total soluble solids and days to maturity. Genetic gain (genetic advance expressed as per cent of population mean) ranged from low to high. High genetic gain was recorded for bulb yield per plot, bulb yield per hectare, oleoresin content, the number of bulbs per kg, bulb weight, clove weight, weight of 100 peeled cloves, weight of 100 unpeeled cloves and the number of cloves per bulb. Moderate genetic gain was obtained for clove breadth, clove length, bulb length, neck thickness, bulb breadth and drying percentage. Minimum values were recorded for the number of leaves per plant, total soluble solids, plant height, peeling index and days to maturity. Selection should be done for the characters *viz*.,

https://doi.org/10.37992/2021.1202.067

**Table 3. Phenotypic and genotypic correlation among different characters in garlic**

| Traits | | Plant height | Leaves/ plant | Days to maturity | Neck thickness | Bulb weight | Bulb breadth | Bulb length | Clove weight | Clove breadth | Clove length | Cloves/ bulb | Bulbs/ Kg | Weight of 100 unpeeled cloves | Weight of 100 peeled cloves | Peeling index | Drying percentage | TSS | Oleoresin content | Yield/ plot |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant height | P | 1.000 | 0.013 | 0.128 | 0.303* | 0.447* | 0.461* | 0.365* | 0.450* | 0.384* | 0.385* | -0.364* | -0.430* | 0.436* | 0.405* | -0.302* | -0.438* | -0.212 | 0.103 | 0.445* |
| | G | 1.000 | 0.021 | 0.195 | 0.351* | 0.485* | 0.507* | 0.434* | 0.493* | 0.449* | 0.433* | -0.374* | -0.445* | 0.473* | 0.430* | -0.317* | -0.486* | -0.278 | 0.114 | 0.492* |
| Leaves/ plant | P | | 1.000 | 0.230* | 0.540* | 0.394* | 0.414* | 0.419* | 0.361* | 0.327* | 0.351* | -0.184 | -0.319* | 0.498* | 0.504* | 0.180 | 0.150 | 0.199 | -0.226 | 0.381* |
| | G | | 1.000 | 0.295* | 0.575* | 0.408* | 0.455* | 0.467* | 0.379* | 0.344* | 0.375* | -0.205 | -0.343* | 0.542* | 0.537* | 0.185 | 0.154 | 0.234 | -0.239 | 0.407* |
| Days to maturity | P | | | 1.000 | 0.101 | 0.527* | 0.546* | 0.519* | 0.496* | 0.377* | 0.319* | -0.020 | -0.462* | 0.528* | 0.557* | 0.384* | -0.116 | -0.039 | 0.002 | 0.497* |
| | G | | | 1.000 | 0.137 | 0.632* | 0.698* | 0.675* | 0.595* | 0.502* | 0.393* | -0.032 | -0.562* | 0.660* | 0.686* | 0.463* | -0.159 | -0.076 | 0.032 | 0.641* |
| Neck thickness | P | | | | 1.000 | 0.378* | 0.425* | 0.394* | 0.374* | 0.230 | 0.344* | -0.183 | -0.385* | 0.389* | 0.390* | 0.067 | 0.121 | 0.316 | -0.319* | 0.375* |
| | G | | | | 1.000 | 0.397* | 0.471* | 0.442* | 0.406* | 0.275* | 0.373* | -0.199 | -0.404* | 0.435* | 0.423* | 0.066 | 0.124 | 0.365 | -0.339* | 0.409* |
| Bulb weight | P | | | | | 1.000 | 0.828* | 0.862* | 0.852* | 0.714* | 0.729* | -0.440* | -0.930* | 0.783* | 0.789* | 0.154 | -0.361* | -0.061 | -0.017 | 0.966* |
| | G | | | | | 1.000 | 0.901* | 0.976* | 0.927* | 0.774* | 0.784* | -0.457* | -0.955* | 0.871* | 0.854* | 0.154 | -0.388* | -0.067 | -0.022 | 1.000* |
| Bulb breadth | P | | | | | | 1.000 | 0.763* | 0.696* | 0.507* | 0.471* | -0.186 | -0.776* | 0.705* | 0.724* | 0.278* | -0.209 | -0.073 | -0.016 | 0.808* |
| | G | | | | | | 1.000 | 0.876* | 0.769* | 0.579* | 0.548* | -0.196 | -0.841 | 0.795* | 0.790* | 0.293* | -0.204 | -0.097 | -0.022 | 0.898* |
| Bulb length | P | | | | | | | 1.000 | 0.807* | 0.667* | 0.681* | -0.368* | -0.824* | 0.759* | 0.751* | 0.156 | -0.238 | -0.004 | -0.100 | 0.852* |
| | G | | | | | | | 1.000 | 0.939* | 0.777* | 0.803* | -0.407* | -0.923* | 0.880* | 0.875* | 0.178 | -0.298* | -0.012 | -0.122 | 0.984* |
| Clove weight | P | | | | | | | | 1.000 | 0.839* | 0.801* | -0.626* | -0.847* | 0.898* | 0.893* | 0.112 | -0.403* | -0.050 | -0.078 | 0.865* |
| | G | | | | | | | | 1.000 | 0.923* | 0.888* | -0.685* | -0.906* | 0.925* | 0.908* | 0.117 | -0.439* | -0.050 | -0.078 | 0.936* |
| Clove breadt | P | | | | | | | | | 1.000 | 0.745* | -0.661* | -0.702* | 0.755* | 0.736* | 0.017 | -0.438* | -0.080 | -0.029 | 0.726* |
| | G | | | | | | | | | 1.000 | 0.836* | -0.742* | -0.777* | 0.832* | 0.814* | 0.023 | -0.498* | -0.067 | -0.040 | 0.787* |
| Clove lengt | P | | | | | | | | | | 1.000 | -0.671* | -0.762* | 0.659* | 0.623* | -0.195 | -0.337* | -0.014 | -0.223 | 0.734* |
| | G | | | | | | | | | | 1.000 | -0.739* | -0.810* | 0.742* | 0.702* | -0.206 | -0.367* | -0.008 | -0.246 | 0.799* |
| Cloves/ bulb | P | | | | | | | | | | | 1.000 | 0.480* | -0.504* | -0.481* | 0.199 | 0.496* | 0.274* | -0.042 | -0.448* |
| | G | | | | | | | | | | | 1.000 | 0.498* | -0.563* | -0.525* | 0.206* | 0.539* | 0.313* | -0.046 | -0.473* |
| Bulbs/ Kg | P | | | | | | | | | | | | 1.000 | -0.719* | -0.713* | -0.096 | 0.337* | 0.089 | 0.025 | -0.921* |
| | G | | | | | | | | | | | | 1.000 | -0.776* | -0.760* | -0.097 | 0.366* | 0.101 | 0.028 | -0.960* |
| Weight of 100 unpeeled cloves | P | | | | | | | | | | | | | 1.000 | 0.986* | 0.234 | -0.260* | 0.061 | -0.078 | 0.800* |
| | G | | | | | | | | | | | | | 1.000 | 1.002* | 0.255* | -0.282* | 0.099 | -0.078 | 0.873* |
| Weight of 100 peeled cloves | P | | | | | | | | | | | | | | 1.000 | 0.318* | -0.246 | 0.067 | -0.075 | 0.796* |
| | G | | | | | | | | | | | | | | 1.000 | 0.337* | -0.271* | 0.104 | -0.071 | 0.861* |
| Peeling index | P | | | | | | | | | | | | | | | 1.000 | 0.087 | 0.095 | -0.006 | 0.147 |
| | G | | | | | | | | | | | | | | | 1..000 | 0.089 | 0.107 | -0.008 | 0.151 |
| Drying percentage | P | | | | | | | | | | | | | | | | 1.000 | 0.501* | -0.328* | -0.374* |
| | G | | | | | | | | | | | | | | | | 1.000 | 0.586* | -0.340* | -0.404* |
| TSS | P | | | | | | | | | | | | | | | | | 1.000 | -0.339* | -0.066 |
| | G | | | | | | | | | | | | | | | | | 1.000 | -0.381* | -0.049 |
| Oleoresin content | P | | | | | | | | | | | | | | | | | | 1.000 | -0.036 |
| | G | | | | | | | | | | | | | | | | | | 1.000 | -0.033 |
| Yield/plo | P | | | | | | | | | | | | | | | | | | | 1.000 |
| | G | | | | | | | | | | | | | | | | | | | 1.000 |

* Significant at 5% level of significance

https://doi.org/10.37992/2021.1202.067

**Table 4. Estimates of direct and indirect effects of different characters on bulb yield of garlic**

| | Plant height | Leaves/ plant | Days to maturity | Neck thickness | Bulb weight | Bulb breadth | Bulb length | Clove weight | Clove breadth | Clove length | Cloves/ bulb | Bulbs/ Kg | Weight of 100 unpeeled cloves | Weight of 100 peeled cloves | Peeling index | Drying percentage | TSS | Oleoresin content | Genotypic correlation coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plant height | 0.118 | 0.001 | 0.030 | 0.019 | 0.979 | -0.205 | -0.127 | 0.024 | 0.042 | -0.048 | 0.024 | -0.138 | 0.303 | -0.427 | -0.044 | -0.056 | 0.000 | -0.004 | 0.492* |
| Leaves/ plant | 0.003 | 0.042 | 0.045 | 0.031 | 0.823 | -0.184 | -0.136 | 0.019 | 0.032 | -0.041 | 0.013 | -0.106 | 0.347 | -0.532 | 0.026 | 0.018 | 0.000 | 0.009 | 0.407* |
| Days to maturity | 0.023 | 0.013 | 0.154 | 0.007 | 1.276 | -0.283 | -0.197 | 0.029 | 0.047 | -0.043 | 0.002 | -0.174 | 0.423 | -0.681 | 0.064 | -0.018 | 0.000 | -0.001 | 0.641* |
| Neck thickness | 0.042 | 0.024 | 0.021 | 0.054 | 0.801 | -0.191 | -0.129 | 0.020 | 0.026 | -0.041 | 0.013 | -0.125 | 0.279 | -0.420 | 0.009 | 0.014 | 0.000 | 0.012 | 0.409* |
| Bulb weight | 0.057 | 0.017 | 0.097 | 0.021 | 2.018 | -0.365 | -0.284 | 0.045 | 0.072 | -0.087 | 0.030 | -0.295 | 0.558 | -0.847 | 0.021 | -0.045 | 0.000 | 0.001 | 1.000* |
| Bulb breadth | 0.060 | 0.019 | 0.107 | 0.025 | 1.819 | -0.405 | -0.255 | 0.038 | 0.054 | -0.061 | 0.013 | -0.260 | 0.509 | -0.783 | 0.041 | -0.023 | 0.000 | 0.001 | 0.898* |
| Bulb length | 0.051 | 0.020 | 0.104 | 0.024 | 1.969 | -0.355 | -0.291 | 0.046 | 0.073 | -0.089 | 0.026 | -0.285 | 0.564 | -0.868 | 0.025 | -0.034 | 0.000 | 0.004 | 0.984* |
| Clove weight | 0.058 | 0.016 | 0.092 | 0.022 | 1.871 | -0.312 | -0.274 | 0.049 | 0.087 | -0.098 | 0.045 | -0.280 | 0.592 | -0.900 | 0.016 | -0.050 | 0.000 | 0.003 | 0.936* |
| Clove breadth | 0.053 | 0.015 | 0.077 | 0.015 | 1.561 | -0.235 | -0.226 | 0.045 | 0.094 | -0.092 | 0.048 | -0.240 | 0.533 | -0.808 | 0.003 | -0.057 | 0.000 | 0.001 | 0.787* |
| Clove length | 0.051 | 0.016 | 0.060 | 0.020 | 1.582 | -0.222 | -0.234 | 0.043 | 0.078 | -0.111 | 0.048 | -0.250 | 0.475 | -0.697 | -0.029 | -0.042 | 0.000 | 0.009 | 0.799* |
| Cloves/ bulb | -0.044 | -0.009 | -0.005 | -0.011 | -0.922 | 0.080 | 0.119 | -0.034 | -0.070 | 0.082 | -0.065 | 0.154 | -0.361 | 0.521 | 0.029 | 0.062 | 0.000 | 0.002 | -0.473* |
| Bulbs/ Kg | -0.053 | -0.015 | -0.086 | -0.022 | -1.928 | 0.341 | 0.269 | -0.044 | -0.073 | 0.090 | -0.032 | 0.309 | -0.497 | 0.753 | -0.013 | 0.042 | 0.000 | -0.001 | -0.960* |
| Weight of 100 unpeeled cloves | 0.056 | 0.023 | 0.102 | 0.024 | 1.757 | -0.322 | -0.256 | 0.045 | 0.078 | -0.082 | 0.037 | -0.240 | 0.641 | -0.994 | 0.035 | -0.032 | 0.000 | 0.003 | 0.873* |
| Weight of 100 peeled cloves | 0.051 | 0.023 | 0.106 | 0.023 | 1.723 | -0.320 | -0.255 | 0.044 | 0.076 | -0.078 | 0.034 | -0.235 | 0.642 | -0.992 | 0.047 | -0.031 | 0.000 | 0.003 | 0.861* |
| Peeling index | -0.037 | 0.008 | 0.071 | 0.004 | 0.311 | -0.119 | -0.052 | 0.006 | 0.002 | 0.023 | -0.013 | -0.030 | 0.163 | -0.334 | 0.139 | 0.010 | 0.000 | 0.000 | 0.151 |
| Drying percentage | -0.057 | 0.007 | -0.024 | 0.007 | -0.782 | 0.083 | 0.087 | -0.021 | -0.047 | 0.041 | -0.035 | 0.113 | -0.181 | 0.269 | 0.012 | 0.115 | 0.000 | 0.012 | -0.404* |
| TSS | -0.033 | 0.010 | -0.012 | 0.020 | -0.136 | 0.039 | 0.003 | -0.002 | -0.006 | 0.001 | -0.020 | 0.031 | 0.063 | -0.103 | 0.015 | 0.067 | -0.001 | 0.014 | -0.049 |
| Oleoresin content | 0.013 | -0.010 | 0.005 | -0.018 | -0.044 | 0.009 | 0.035 | -0.004 | -0.004 | 0.027 | 0.003 | 0.009 | -0.050 | 0.071 | -0.001 | -0.039 | 0.000 | -0.036 | -0.033 |

Diagonal figures represent the direct effect

Residual effect: : 0.04083

* Significant at 5 % level of significance

the number of bulbs per kg, oleoresin content, bulb weight, the number of leaves per plant, bulb yield per plot, bulb yield per hectare, the number of cloves per bulb and clove weight, as these characters recorded high heritability and high genetic gain and are governed by additive genes and are less influenced by the environment. High heritability and genetic gain for cloves per bulb has been observed by Singh *et al*. (2012b). High heritability and high genetic gain for the number of cloves per bulb and high heritability and low genetic gain for plant height and the number of leaves per plant has been observed by Singh *et al*. (2012b). High heritability and high genetic gain for clove weight, bulb weight and the number of cloves per bulb was reported by Sharma *et al.* (2016) and for bulb weight and the number of cloves per bulb by Meena *et al*. (2020).

Correlation coefficient was estimated between yield and other characters at genotypic and phenotypic levels to know the inter relationship among the characters. It provides information about the nature, extent and direction of selection pressure to be applied. Yield is complex character controlled by several yield contributing components and is highly influenced by environmental factors, consequently selection based on yield will not be much effective. It suggests the advantage of a scheme of selection for more than one character at a time. In the present study, the estimates of phenotypic and genotypic correlation coefficients imparted that in general, the values of genotypic correlation coefficient were higher in magnitude than their corresponding phenotypic ones, as also reported by Barad *et al*. (2012). The correlation coefficients among different characters were worked out at both phenotypic and genotypic levels (**Table 3**). Yield per plot was positively and significantly associated with plant height, the number of leaves per plant, days to maturity, neck thickness, bulb weight, bulb breadth, bulb length, clove weight, clove breadth, clove length, weight of 100 unpeeled cloves and weight of 100 peeled cloves. Direct selection for these characters would be fruitful for improving the yield. Yield was negatively and significantly correlated with the number of cloves per bulb, the number of bulbs per kg and drying percentage. A positive and significant correlation of bulb weight, bulb diameter, clove weight, plant height and the number of leaves per plant with bulb yield has been observed by Singh *et al*. (2013) and Khar *et al.* (2015). A negative correlation of the number of cloves per bulb with cloves weight was recorded by Singh *et al*. (2008) and Patil *et al*. (2012).

Path coefficient analysis (**Table 4**) revealed a high positive and direct effect of bulb weight on bulb yield per plot followed by weight of 100 unpeeled cloves, the number of bulbs per kg, days to maturity, peeling index, plant height, drying percentage, clove breadth, neck thickness, clove weight and the number of leaves per plant. Whereas, weight of 100 peeled cloves had a maximum negative direct effect followed by bulb breadth, bulb length, clove length, the number of cloves per bulb, oleoresin content and total soluble solids. The highest positive direct effect of bulb weight on bulb yield per plot was observed by Singh *et al*. (2013) and Thakur and Sharma (2020). Adequate variability was present among the genotypes for growth, yield and quality characters. High coefficients of variation suggested scope of further improvement and selection for the characters to isolate more promising genotypes. Moderate to high heritability values for important yield and quality characters along with high genetic gain suggested additive gene effects of such characters involved in inheritance and selection should be done for such characters. Bulb weight, bulb breadth, bulb length, clove weight, clove breadth, clove length, weight of 100 unpeeled cloves and weight of 100 peeled cloves exhibited high genotypic correlation with bulb yield and selection can directly be done for these characters to improve the bulb yield in garlic.

## ACKNOWLEDGEMENT

Author is thankful to Department of Vegetable Science, UHF, Solan, HP for providing necessary facilities for carrying out the study.

## REFERENCES

AOAC. 1975. Official methods of analysis. *Association of Official Analytical Chemists Washington*. D. C. 12th ed. pp. 554-555.

Arora, S. D. and Kaur, J. 1999. Antimicrobial activity of spices. *J. Antimicr. Agents,* **12**: 257-262. [Cross Ref]

Barad, Y. M., Kathiria, K. B. and Modha, K. G. 2012. Correlation and path coefficient studies in garlic (*Allium sativum* L.) over different environments. *Veg. Sci.*, **39**: 79-82.

Brewster, J. L. 1994. Onion and other vegetables. **In**: *Alliums.* UK: CABI. 236p.

Burton, G. W. and DeVane, E. H. 1953. Estimating heritability in tall fescue (*Festuca arundiancea*) from replicated clonal material. *Agron. J.*, **45**: 478-481. [Cross Ref]

Dewey, D. R. and Lu, K. H. 1959. A correlation and path coefficient analysis of components of crested wheat grass seed production. *Agron. J.,* **51**: 515-518. [Cross Ref]

Hughes, B. G. and Lawson, L. D. 1991. Antimicrobial effect of *Allium sativum* L. (garlic), *Allium ampeloprasum* (elephant garlic) and *Allium cepa* L. (onion), garlic compound and commercial garlic supplement products. *Phytol Res.,* **5**: 154-158. [Cross Ref]

Khar, S., Kumar, S., Samnotra, R. K., Kumar, M., Chopra, S., Kumar, M. and Gupta, S. 2015. Variability and correlation studies in garlic (*Allium sativum* L.). *Ind. J. Pl. Gen. Res.*, **28**: 229-236. [Cross Ref]

Khar, A., Mahajan, V., Devi, A. A. and Lawande, K. E. 2005. Genetic studies in elite lines of garlic ( *Allium sativum* L.). *J. Maharashtra Agri. Univ*., **30**:277-280.

Meena, M. L., Yadav, S. K., Sanjay, S., Rajmani, A., Ruchika and Mandal, R. K. 2020. Genetic variability, heritability and genetic advance in the garlic, *Allium sativum* genotypes. *Biosc. Biotech. Res. Comm*., **13**(1): 335-339. [Cross Ref]

Memane, P. G., Tomar, R. S., Kakade, D. K., Kulkarni, G. U. and Chovatia, R. S. 2008. Effect of clove weight and plant growth regulators on growth and yield of garlic (*Allium satiuvm* L.). *The Asian J. Hort.,* **3** (1): 82-86.

Meng, Y., Lu, D., Guo, N., Zhang, L. and Zhou, G. 1996. Anti-Human Cytomegalovirus (HCMV) effect of garlic Components. *Virol. Sinica,* **8**: 147-150.

NHB. 2018. http://www.nhb.gov.in/statistics.

Panse, R., Jain, P. K., Gupta A. and Singh, S. D. 2013. Morphological variability and character association in diverse collection of garlic germplasm. *Afri. J. Agri. Res.*, **8**: 2861-2869.

Patil, B. T., Gidmare, P. P., Bhalekar, M. N. and Shinde, K. G. 2012. Correlation and path coefficient studies in garlic (*Allium sativum* L.). *Veg. Sci.*, **39**: 98-100.

Reuter, H. D., Koch, H. P. and Lawson, L. D. 1996. Therapeutic effects and applications of garlic and its preparations. **In**: *Garlic: The Science and Therapeutic Applications of Allium sativum L. and Related Species* (H P Koch and L D Lawson). Williams and Wilkins. pp. 135-213.

Sandhu, S. S., Brar, P. S. and Dhall, R. K. 2015. Variability of agronomic and quality characteristics of garlic (*Allium sativum* L.) ecotypes. *SABRAO J. Plant Breed. Gen*., **47**: 133-142.

Shankaracharya, N. B. 1974. Symposium on Spice Industry in India, Association of Food Scientists and Technologists, Central Food Technological Research Institute, Mysore. pp. 24-36.

Sharma, P. 1994. Genetic variability and path corfficient analysis in cabbage (*Brassica oleracea* var. *capitata* L.). M.Sc. thesis, HPKVV, Palampur.

Sharma, R., Omotayo, K., Kattula, N., Malik, S., Kumar, M. and Sirohi, A. 2016. Genetic variability, heritability and genetic advance in garlic genotypes. *Int. J. Agri. Sci*., **8**(54): 2894-2898.

Shinde, N. N., Sanyal, D. and Sontakke, M. B. 2003. Garlic. **In**: *Vegetable Crops* (T K Bose, J Kabir , T K Maity ,V A Parthasarathy and M G Som.eds.). Vol.3.3rd rev ed. Naya udyog. pp. 121-171.

Singh, G., Mishra, D. P., Vimlesh, K., Pandey, D. P. and Singh, S. 2015. Genetic diversity in genotypes of garlic ( *Allium sativum* L.) for growth, yield and its attributing traits. *Biosc. Biot. Res. Comm.,* **8** (2): 149-152.

Singh, S. K., Srivastva, J. P., Dubey, A. K. and Singh, S. K. 2008. Correlation and path coefficient analysis studies in garlic (*Allium sativum* L.). *Annals Hort.,* **1**: 96-97.

Singh, R. K., Dubey, B. K. and Gupta, R. P. 2012a. Studies on variability and genetic divergence in elite lines of garlic (*Allium sativum* L.). *J. Spices and Arom. Cr.*, **21**: 136-144.

Singh, R. K., Dubey, B. K., Bhonde, S. R. and Gupta, R. P. 2012b. Studies on variability, heritability and genetic advance in garlic (*Allium sativum* L.*). Veg. Sci*., **39**: 86-88.

Singh, S. R., Ahmed, N. A., Lal, S., Amin A., Amin M., Ganie, S. A. and Jan N. 2013. Character association and path analysis in garlic (*Allium sativum* L) for yield and its attributes. *SAARC J. of Agri.*, **11**: 45-52. [Cross Ref]

Thakur, U. K. and Sharma, H. R. 2020. Correlation coefficient and path analysis studies in diverse garlic (*Allium sativum* L.) genotypes. *Annals Hort*., **13** (1): 29-33. [Cross Ref]

Tsega, K., Tiwari, A. and Woldetsadik, K. 2011. Genetic variability among bulb yield and yield related traits in Ethiopian garlic (*Allium sativum* L.) germplasm. *Pantnagar J. Res.*, **9**: 97-102.

Vatsyayan, S., Brar, P. S. and Dhall, R. K. 2013. Genetic variability studies in garlic (*Allium sativum* L.). *Annals Hort.*, **6**: 315-320.

Vvedensky, A. 1944. The genus *Allium* in the USSR. *Herbertia,* **11**: 65-218.

Yadav, N. K., Singh, K. P., Naidu, A. K. and Nair, B. 2012. Estimation of genetic variability for yield and its components in garlic (*Allium Sativum* L.). *Progr. Agri.*, **12**: 26.