GENETIC VARIABILITY AND INTER RELATIONSHIPS AMONG BULB YIELD AND ASSOCIATED TRAITS IN GARLIC (*Allium sativum* L.)

THESIS

By

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(A-2017-30-064)

Submitted to

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CERTIFICATE – I

This is to certify that the thesis entitled "**Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum L.*)**" submitted in partial fulfillment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Horticulture (Vegetable Science)** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Mr. Shivam Sharma (Admission No. A-2017-30-064)** son of **Sh. Kushmayudh Sharma and Smt. Manjulata Sharma** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Palampur
Dated : 20 June, 2019

(Dr. D.R Chaudhary)
Major Advisor

CERTIFICATE- II

This is to certify that the thesis entitled **"Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum L.*)"** submitted by Mr. Shivam Sharma **(Admission No. A-2017-30-064)** son of **Sh. Kushmayudh Sharma and Smt. Manjulata Sharma** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfillment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Horticulture** (**Vegetable Science)** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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"Pride, Praise and Perfection Belongs to Mata Naina Ugratara and Dev Payindal Rishi

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Place: Palampur
Date: 20 June, 2019

(Shivam Sharma)

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LIST OF ABBREVIATIONS USED

Abbreviation	**Meaning**
et al.	co-workers
i.e.	that is
viz.,	videlicet (namely)
°c	Degree Celsius
G	Gram
Kg	Kilogram
%	Per cent
Fig.	Figure
Cm	Centimeter
M	Meter
Mm	Millimeter
Df	degree of freedom
N	North
E	East
^{0}b	^{0}Brix
etc.	et cetera
m^2	Meter square
t	Tonne
ha	Hectare

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ABSTRACT

The present investigation entitled "Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum* L.)" was undertaken at the Research Farm of Department of Vegetable Science and Floriculture, CSKHPKV, Palampur during *Rabi,* 2017-18. Twenty five genotypes including GHC-1 as standard check, were evaluated in a RBD with three replications to assess various parameters of genetic variability. The data were recorded on ten competitive plants in each entry over the replications for bulb yield and yield related traits. The analysis of variance revealed the presence of sufficient genetic diversity amongst genotypes for all the traits studied. Based on mean performance, Kanaid Local Selection and Chambi Local Selection were the top ranking genotypes for bulb yield per plant which significantly out yielded all the genotypes with a significant increase of 28.74 % and 12.71 %, respectively over standard check, GHC-1. High estimates of PCV and GCV coupled with high heritability and high genetic advance as percentage of mean was observed for bulbils per plant, clove weight, leaf width at middle portion, clove equatorial diameter, cloves per bulb and pseudo stem diameter, suggested the involvement of additive gene action in the inheritance of these traits. The correlation and path coefficients studies revealed that clove weight, bulb equatorial diameter, clove polar diameter, leaf length and clove equatorial diameter were the best selection indices for increasing bulb yield. The Mahalanobis D^2 statistic, categorized 25 genotypes into six clusters with cluster V being the largest containing seven genotypes. The highest inter cluster distances were observed between cluster IV and cluster V followed by cluster IV and cluster VI. The cluster IV was found best for bulb yield per plant, bulb yield per plot, clove weight, clove length, clove polar diameter, clove equatorial diameter, bulb polar diameter, bulb equatorial diameter and leaf width at middle portion. The selection of genotypes based upon large cluster distances may lead to favorable broad spectrum genetic variability. The principal component analysis revealed that 92.93 % variation was explained by first six significant principal components. The traits, plant height (PC1 and PC2), clove polar diameter (PC3), leaf length (PC4), cloves per bulb (PC5) and pseudo stem length (PC6) were the maximum contributors towards genetic divergence

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1. INTRODUCTION

Garlic (*Allium sativum* L.), an asexually propagated crop and member of family Amaryllidaceae (Allen, 2009) is an important spice crop and is the second most widely cultivated *Allium* after onion throughout the world. The primary centre of origin of garlic is Central Asia (India, Afganistan, West China, Russia), whereas 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). The crop has been recognized as a valuable spice and condiment throughout world imparting flavour, aroma and taste to various food stuffs. It is regularly consumed almost in every home, not only for culinary purposes but also in home remedies and flavouring agent in many processed food. Garlic is used for various food preparation, chutney, pickles, curried vegetables, meat preparation and tomato ketchup etc. (Shinde et al. 2003). Garlic has high nutritive value than other bulbous crops and has tremendous export potential both as fresh and dehydrated forms.

Garlic has been considered as ‘Nectar of life’ in Ayurveda as it reduces blood lipids cholesterol concentration and possesses anticancer effects. It possesses antibacterial (Arora and Kaur, 1999), antifungal (Hughes and Lawson, 1991), antiviral (Meng et al. 1993) and antiprotozoal properties (Reuter et al. 1996). Garlic has also medicinal value which is well recognized in the control and treatment of hypertension, worms, germs, bacterial and fungal diseases, diabetes, cancer, ulcer, rheumatism etc. (Kilgori et al. 2007). Similar to green onion, it is eaten as green and blanched tops in different ways as fresh, cooked, leaves as condiment as well as immature bulb consumption is common especially in tropics. Bread and butter obtained from garlic have many uses in homes and restaurant cooking and food preparations (Nonnecke, 1989).

Garlic contains carbohydrates, sugars, dietary fibres, fat, protein, thiamine, riboflavin, niacin, vitamin C, calcium, sulphur and essential oils which impart 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 known to possess the true garlic odour.

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 axillary buds within foliage leaves. Garlic displays considerable variability with respect to morphological traits, yield, quality attributes as well as resistance to important insect pests and diseases. It also shows adaptation to wide range of soil types, temperature and day length, making its farming possible from tropical to temperate regions.

Globally, garlic is grown over an area of 1577.8 hectares with a production of 28164.1 metric tonnes and productivity is 17.85 metric tonnes per hectare. China is leading country in area and production followed by India, Republic of Korea, Egypt and Russian Federation. In India, area under garlic is 321 thousand hectares with annual production of 1693 thousand metric tonnes (Anonymous, 2016). Garlic is cultivated mainly in the states of Madhya Pradesh, Gujarat, Orissa, Maharashtra and Uttar Pradesh. Madhya Pradesh is the leading state in its production, occupying 60,000 hectares area with 270 thousand metric tonnes production. In Himachal Pradesh, garlic has become a major money spinning crop, occupying an area of 4.70 thousand hectares with production of 9.70 thousand tonnes (Anonymous, 2017).

Of late, the cultivation of garlic in Himachal Pradesh has become more popular amongst the farmers of Kullu, Mandi, Sirmaur and Kangra districts on account of its relative ease in cultivation and higher profit margins. The produce is generally sold in the internal markets bringing lucrative returns to the growers. The constraints in garlic production are lack of availability of improved varieties for commercial cultivation, processing and export. Consequently, farmers are restricted to use garlic landraces inferior in yield, prone to most of the diseases and insects with traditional agronomic practices. Most of the cultivated varieties of garlic are indigenous clonal stocks, however, some high yielding exotic genotypes have also been introduced recently. Because of lack of systematic study to improve this crop, very little information is available on genetic variability, association and contribution of characters for bulb yield. Knowledge of association of different components together with their relative contribution are of immense value in selection. Since, estimates of correlation coefficient indicate only the inter relationship of the characters but do not furnish information on the cause and effects, separation of correlation coefficients into the components of direct and indirect effects through path analysis becomes important. The garlic cultivars are mostly sterile and exhibit greater morphological variation between clones and thus genetic improvement is limited only to clonal selection, the effectiveness of this improvement programme therefore, largely depends upon the magnitude of inter clonal variability and further the heritability of this variability being carried forward into subsequent generations. Thus, the information on nature and magnitude of genetic variability present in the genetic stocks, heritability and genetic advance among various traits are of considerable use in selecting the suitable genotypes to include in future breeding programmes.

Genetic diversity plays an important role in plant breeding because hybrids between lines of diverse origin generally display a greater heterosis than the closely related strains. The knowledge of nature and degree of divergence in genotypes and nature of forces operating at different levels through genetic study based on multivariate analysis is extremely valuable for exploiting the genetic variability through effective breeding strategies (Habtamu and Million, 2013). The inclusion of diverse parents in hybridization programmes serves the purpose of combining genes to obtain desirable transgressive recombinants.

Based upon all these considerations, the present study entitled "**Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum* L**.)" was therefore, planned and executed involving 25 genotypes collected from within and outside state with the following broad objectives:

(1) To assess the nature and magnitude of genetic divergence for bulb yield and related traits, and

(2) to determine the correlation coefficients and direct and indirect effects of component traits on bulb yield in garlic.

2. REVIEW OF LITERATURE

In the present investigation entitled, "**Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum* L.)**", an attempt has been made to review the work done on genetic variability, correlation, path analysis and genetic divergence studies in garlic. A brief description of available literature pertaining to the investigation has been presented in this chapter under the following sub heads:

2.1 Genetic variability

2.2 Correlation coefficient

2.3 Path coefficient

2.4 Genetic divergence

2.1 Genetic variability

The presence of genetic variability in any crop is the basis for all crop improvement programmes. Vavilov (1951) was probably the first to realize that a wide range of variability in any crop provides better opportunity for selection of desirable types. The extent of improvement through selection largely depends upon the heritable variations of different traits. A broad spectrum of variability is instrumental in getting success in any plant breeding programme as it provides an opportunity to the breeders to use his skill and art in making desirable selection. Wide range of variability for traits is also necessary to isolate significantly superior varieties for commercial cultivation, to be used as parents in hybridization for recombination breeding to develop high yielding hybrid varieties and to create useful genetic diversity for further selection.

Fisher (1918) partitioned continuous variation of quantitative traits into heritable and non-heritable components, where the heritable components may be the consequence of genotype and are inherited from generation to generations, whereas the non-heritable part is the result of environmental factors. Wright (1921) further partitioned the heritable components into additive and non-additive effects and it is the former which responds to selection. Lush (1940) classified heritability into narrow sense and broad sense. Heritability in narrow sense is the proportion of additive variance to the total variance, whereas heritability in broad sense is the proportion of genetic variance to the total variance. Burton and De Vane (1953) suggested that genetic coefficient of variation in conjunction with heritability estimates provides better indication of the extent of improvement to be expected from selection and it is further remarked that expected genetic gain under a particular system provides a true practical information which is needed by a breeder for effective selection. Johnson et al. (1955) also reported that estimation of heritability values along with genetic advance is more useful in predicting the expected progress to be obtained through selection. Panse (1957) reported that magnitude of heritable variability and its genetic component is the most important aspect of the genetic constitution of the breeding material which has a close bearing on its response to selection.

Kohli and Prabal (2000) observed significant variation for leaf size, plant height, number of cloves per bulb, bulb yield per plot, clove equatorial diameter and bulb equatorial diameter. The heritability estimates were high for bulb equatorial diameter and number of aerial bulbils. Genetic advance was high for bulb weight, bulb yield per plot and number of cloves per bulb.

Singh and Tiwari (2001) evaluated 17 genotypes of garlic for bulb yield and yield attributing characters and reported significant variation amongst the genotypes for number of cloves per bulb, bulb equatorial diameter, bulb weight and bulb yield. Genotypes, LG-1 produced the highest bulb yield (86 q/ha) followed by PUG-1 (84 q/ha) and G-282 (80 q/ha). The genotypes, LG-1, PGS-11, PGS-4 and PUG-1 exhibited more variability for bulb yield and yield attributing traits.

Raj and Khan (2002) reported that the magnitude of phenotypic coefficients of variation (PCV) were higher than the corresponding genotypic coefficients of variation (GCV) for all the characters viz., bulb yield per plot, plant height, clove girth, clove length, number of cloves per bulb, bulb weight and dry leaf weight. High genotypic coefficients of variation (GCV) and heritability values coupled with high genetic advance were recorded for dry leaf weight, bulb yield per plot, number of cloves per bulb and bulb weight, indicated that these characters had additive gene effects and therefore, were more reliable for effective selection.

Shridhar (2002) reported high magnitude of both phenotypic and genotypic coefficients of variation for bulb yield, clove weight and number of cloves per bulb. The estimates of phenotypic coefficients of variation (PCV) were higher than the genotypic coefficients of variation (GCV) for bulb yield, plant height and cloves per bulb. The estimates of heritability were high for days to maturity, bulb weight, clove weight, number of cloves per bulb and plant height. The high heritability coupled with high genetic advance was recorded for bulb yield, bulb weight, clove weight, number of cloves per bulb, clove equatorial diameter and plant height which indicated the involvement of additive gene action for the expression of these traits.

Singh et al. (2002) evaluated sixteen promising advance lines including two checks (G-1 and G-282) of garlic for bulb yield, yield attributes, quality parameters and storage performance. The results revealed that the advance line, 324 performed exceptionally better than the other genotypes for bulb yield and storability as reflected from yield of maximum recovery of bulb after storage.

Tiwari et al. (2002) evaluated the performance of 20 garlic genotypes and reported a wide range of variability for all the characters examined. Maximum plant height and more number of leaves per plant were recorded in DG-1 (74.33 cm) and PGS-4 (7.34), respectively. The genotype, Sel-1 had the longest leaves (39.13 cm), whereas G-41 recorded the highest neck diameter (0.63 cm). The genotypes, G-282 and G-323 recorded the highest bulb weight, whereas G-41 and G-50 were the earliest to mature (158 days). Bulb yield was highest in G-323 (114 q/ha).

Agrawal et al. (2003) reported high phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) for average clove weight, plant height, bulb weight and number of cloves per bulb. High heritability along with high genetic advance was observed for plant height, average clove weight, number of cloves per bulb and bulb weight.

Agarwal and Tiwari (2004) studied genetic variability in 21 genotypes of garlic and observed sufficient variability amongst the genotypes for bulb yield and yield attributing traits. High genotypic and phenotypic variances along with higher magnitude of genotypic and phenotypic coefficients of variation were observed for clove weight, bulb yield, number of cloves per bulb, whereas moderate values were recorded for bulb weight and leaf area index. The number of leaves per plant exhibited the lowest estimates.

Jogdande et al. (2004) revealed that the genotype, G-282 exhibited the maximum plant height (75.75 cm), number of leaves per plant (9.14), weight of fresh bulb (31.30 g) and bulb equatorial diameter (3.44 cm). The garlic genotype, G-41 recorded the highest bulb yield (97.14 q/ha) and TSS (41.0 %).

Shrivastava et al. (2004) reported that the genotype, DARL-52 (119.74 q/ha) had the maximum marketable bulb yield followed by DG-1 (112.31 q/ha) and PGS-14 (110.48 q/ha).

Singh and Chand (2004) assessed genetic variability, heritability and genetic advance in thirty genotypes of garlic and revealed that bulb yield per hectare, bulb weight and number of cloves per bulb exhibited maximum diversity. The estimates of phenotypic coefficient of variation (PCV) were slightly higher than the genotypic coefficients of variation (GCV). The environment coefficient of variation (ECV) was low which indicated the less influence of the environment on the expression of these traits. High heritability coupled with high genetic advance was recorded for average clove weight, number of cloves per bulb, bulb weight, bulb yield and leaf breadth.

Jenderek and Zewdie (2005) evaluated the first generation of sexually derived families of garlic and observed significant variation among the sexually derived families for bulb weight, clove weight, number of cloves per bulb, flower stalk length, number of leaves per plant and days to maturity. Similarly, within each family, significant differences were observed among individual plants for all characters except for bulb weight and number of leaves in family P66, and for number of leaves per plant in families, P42 and P52. Individual plants within each family were significantly different from their respective maternal parents for all the traits studied. Bulb weight, number of cloves and clove weight were observed as the main factors contributing towards bulb yield in garlic.

Khar et al. (2005) conducted genetic studies on forty seven genotypes of garlic and observed a wide range of variability for all the traits studied. Phenotypic and genotypic coefficients of variation were high for neck thickness, number of leaves, bulb weight, clove weight and bulb yield. Both heritability and genetic advance estimates were high for bulb yield, clove weight and bulb weight.

Futane et al. (2006) evaluated the performance of eight garlic genotypes and revealed that G-41 had the highest values for number of leaves per plant, bulb fresh weight, bulb equatorial diameter, total soluble solids and bulb yield. The genotypes, G-282 recorded the highest values for plant height, 100 clove weight and clove thickness, while G-50 recorded the highest values for number of cloves per bulb and clove length.

Golani et al. (2006) reported low estimates of heritability coupled with low genotypic coefficients of variation and genetic gain for all the traits viz., plant height, number of leaves per plant, neck thickness, bulb girth, bulb length, bulb weight, bulb yield per plot and TSS.

Khar et al. (2006) evaluated 11 garlic elite lines with 4 checks and reported that average bulb weight was maximum in AC-200 (23.7 g) followed by AC-183 (22 g) over check, G-41 which had 20.6 g bulb weight. The number of cloves per bulb were found less in AC-200 (18.1 per bulb), while it was more in G-41 (20.3 per bulb). Weight of cloves was maximum in AC-38 (57.6 g). However, the TSS ranged from 38.8 to 43.2 % in these lines.

Kumar et al. (2006) conducted genetic variability studies involving 20 diverse lines of garlic in three artificially created environments (40, 80 and 120 kg N/ha). The bulb yield per plant varied from 7.07 to 32.68 g over the environments. Average weight of cloves, clove equatorial diameter and bulb yield per plant exhibited high heritability and genetic advance as per cent of mean which indicated that clonal selection based on phenotypic performance would be more useful to develop plant types with higher yield potential.

Panthee et al. (2006) studied genetic variability in 179 accessions of garlic and reported that number of cloves per bulb, maturity duration, plant height, bulb weight, bulb equatorial diameter, bulb outer scale number and bulb yield exhibited high heritability and genetic advance as per cent of mean.

Tripathi and Lawande (2006) evaluated twenty five garlic accessions and reported that G-323 (33 %) had the highest total soluble solids (TSS) followed by DARL-50 (32.5 %) and G-41(32.4 %).

Yadav et al. (2006) reported higher magnitude of genotypic coefficients of variation (GCV) for number of cloves per bulb, bulb weight, number of leaves per plant, clove width, plant height, bulb length, bulb width and clove length.

Gowda et al. (2007) evaluated 13 genotypes of garlic and reported that the genotypes, G-282 and Call No. 323 produced maximum plant height, stem girth, number of leaves, bulb weight, volume of bulb and bulb yield per hectare.

Gupta et al. (2007) studied fourteen different collections of garlic and reported significant variability for days to sprout, days to harvest, plant height, leaf length, leaf number, neck thickness, neck height, clove equatorial diameter, clove number, bulb weight and bulb yield. High heritability was recorded for all the characters except for days to sprout. High genetic gain was observed for neck thickness, bulb weight, bulb yield, clove number and neck height.

Sengupta et al. (2007) reported that the varieties, ARU-52, G-41, G-50, G-1 and Sel-2 produced significantly higher plant height, pseudo stem diameter, number of leaves, leaf area, dry weight of leaves, bulb equatorial diameter and bulb weight. The significant improvement in morpho-physiological attributes led to significant higher bulb yield in these cultivars. The more number of leaves resulted in production of more chlorophyll that ultimately led to higher amount of photosynthates and increased bulb yield.

Choudhuri and Chattergy (2009) evaluated thirteen diverse genotypes of garlic for bulb yield and its contributing traits and reported that the genotypes, G-323, Jalpaiguri Local and G-282 had different vegetative and yield attributes. The maximum bulb weight, bulb equatorial diameter and number of cloves per bulb was recorded in G-323 followed by Jalpaiguri Local and G-282. Highest bulb yield was recorded in G-323. Based on growth and yield performance, the genotype, G-323 was found promising.

Shigwedha (2009) evaluated eighteen genotypes for bulbils habit, days to maturity, number of leaves per plant, plant height and bulb yield and reported that large segmented genotypes produced the maximum plant height (60.47 cm), bulb yield per plot (7.57 kg) and were late in maturity (243 days), while UHF-4 had the maximum number of leaves per plant (14.60).

Alam et al. (2010) conducted an experiment involving 20 garlic genotypes and reported significant differences amongst genotypes for plant height, number of leaves per plant, fresh and dry bulb weight, bulb length and bulb equatorial diameter, total number of cloves, bulb yield per plot and bulb yield per hectare.

Dubey et al. (2010) reported high estimates of heritability, GCV and genetic advance as per cent of mean for bulb yield, cloves per bulb, polar and equatorial diameter of bulbs which indicated that these traits were genetically controlled by additive genes.

Jabeen et al. (2010) evaluated twenty five genotypes of garlic and recorded significant variation for number of leaves per plants, plant spread, plant height, leaf length, leaf width, average bulb weight, bulb length, bulb equatorial diameter, number of cloves per bulb, clove length, clove equatorial diameter, average clove weight, dry bulb yield per plot and per hectare. The magnitude of phenotypic and genotypic coefficients of variation were highest for plant height, average bulb weight and bulb yield which indicated that selection for these traits may lead to substantial improvement in bulb yield.

Kassahun et al. (2010) carried out variability studies for bulb yield and yield related traits involving 25 local garlic accessions and observed significant differences amongst accessions for bulb yield and its contributing characters. Very little differences were found between genotypic and phenotypic coefficients of variation which indicated that the variability among accessions was mainly due to the genetic constitution. Comparatively, high heritability coupled with high expected genetic advance as per cent of mean was recorded for bulb dry weight, dry weight above ground, yield per plant, biological yield per plant, plant height, leaf length, clove weight and cloves per bulb.

Tsega et al. (2011) evaluated twenty five local garlic accessions for bulb yield and yield related traits and reported significant differences amongst accessions for bulb yield and harvest index. Wide range of variation and less differences were found between genotypic and phenotypic coefficients of variation for all the traits studied. High heritability estimates coupled with high expected genetic advance as per cent of mean were recorded for bulb dry weight, bulb yield per plant, biological yield per plant, plant height, leaf length, clove weight and cloves per bulb.

Singh et al. (2012 a) evaluated 19 advance lines including 4 checks namely, Yamuna Safed (G-1), Agrifound White (G-41), Yamuna Safed-2 (G-50) and Yamuna Safed-3 (G-282) for bulb yield and its contributing traits. The genotypes, G-189 and G-324 were identified promising for bulb yield, bulb weight, cloves per bulb, bulb polar diameter, bulb equatorial diameter and plant height.

Singh et al. (2012 b) conducted a field experiment on thirty two diverse genotypes of garlic and observed wide range of variability for bulb yield, clove weight, cloves per bulb, bulb weight and clove equatorial diameter. Both phenotypic and genotypic coefficients of variation were high for clove weight, cloves per bulb, marketable yield and clove size index. High heritability estimates were recorded for plant height, cloves per bulb, leaves per plant, clove weight, bulb weight, marketable yield, bulb size index and neck thickness.

Sonkiya et al. (2012) studied genetic variability and heritability among ten genotypes for quantitative characters in garlic and observed high heritability coupled with high genetic advance as per cent of mean for leaf area and clove weight, indicated predominance of additive gene effects for these traits.

Yadav et al. (2012) evaluated 56 genotypes of garlic and observed high phenotypic and genotypic coefficients of variation for bulb yield per plant, bulb yield per hectare, bulb yield per plot and average weight of 10 cloves, whereas days to maturity, number of leaves per plant (30, 60 and 90 days after planting), leaf length (4^{th}leaf), plant height (30 and 90 days after planting) and bulb polar diameter exhibited low estimates of phenotypic and genotypic coefficients of variation. High heritability coupled with high genetic advance was observed for bulb equatorial diameter, average weight of 10 cloves and plant height at 60 days after planting. High heritability with moderate genetic advance was recorded for pseudo stem diameter and bulb polar diameter. High heritability associated with low genetic advance as percentage of mean was exhibited for days to maturity.

Dhall and Brar (2013) recorded the highest genotypic and phenotypic coefficients of variation for clove weight, cloves per bulb and clove equatorial diameter. High heritability along with high genetic advance was observed for plant height, bulb weight and cloves per bulb which suggested that these characters were controlled by additive genes.

Mishra et al. (2013) recorded the highest bulb yield of 150.1 q/ha in garlic genotype, G-303, whereas the lowest bulb yield of 133.7 q/ha was obtained in G-4. The lines, G-189, G-176, G-302, G-304, G-369, G-366, G-222 and G-378 were found promising with respect to growth, yield, quality and disease resistance as compared to check varieties (G-1, G-41, G-50, G-323 and G-282).

Panse et al. (2013) recorded significant variation for different traits except leaf width (4^{th} leaf), indicated presence of sufficient genetic variability in the germplasm. High estimates of heritability were obtained for pseudo stem diameter, days to maturity, bulb polar diameter, bulb equatorial diameter, average weight of 10 cloves and plant height. High heritability coupled with high genetic advance as percentage of mean was observed for bulb equatorial diameter, average weight of 10 cloves and plant height at 60 days after planting (DAP), suggested their improvement through selection.

Vatsyayan et al. (2013) studied genetic variability among 45 diverse genotypes of garlic for different characters to identify elite genotypes. The results showed high genotypic and phenotypic coefficients of variation for traits like bulb weight, bulb yield per plot and number of scales per bulb. High heritability estimates coupled with high genetic advance as per cent of mean (genetic gain) were observed for bulb yield per plot, bulb weight, scales per bulb, clove weight and cloves per bulb.

Pervin et al. (2014) carried out an experiment involving twenty five garlic genotypes and reported that heritability in broad sense was high for plant height, leaf length, fresh weight of leaves, bulb yield, fresh and dry weight of root and cloves per bulb. The genotypic and phenotypic variances were found moderate to low for number of leaves per plant, cloves per bulb, fresh and dry weight of roots, plant height and fresh weight of leaves.

Singh et al. (2014) evaluated 35 genotypes of garlic and reported higher magnitude of coefficients of variation at phenotypic as well as genotypic levels for bulb equatorial diameter, clove length, bulb yield per plant and number of cloves per bulb. Moderate coefficients of variation at phenotypic and genotypic levels were observed for plant height, leaf length and neck thickness. High heritability coupled with high genetic advance as per cent of mean was observed for bulb equatorial diameter and bulb yield per plant.

Umamaheswarappa (2014) evaluated different genotypes of garlic and reported that the genotype, G-282 had the highest total yield (61.50 q/ha) and marketable yield (52.77 q/ha), bulb polar diameter (3.72 cm), bulb equatorial diameter (3.04 cm) and bulb weight (15.41 g).

Esho (2015) evaluated five genotypes of garlic and reported the existence of significant variation amongst the genotypes for all the traits except clove equatorial diameter. High estimates of genotypic and phenotypic coefficients of variation coupled with high heritability were obtained for bulb weight, plant height, number of cloves per bulb and TSS. Higher magnitude of genotypic and phenotypic coefficients of variation was observed for plant height, bulb weight, number of cloves per bulb and TSS.

Khar et al. (2015) carried out variability studies in garlic genotypes and revealed significant differences among the genotypes for all the traits studied except for number of leaves per plant, leaf length, dry matter content, total soluble solids and bulb equatorial diameter which indicated sufficient variability in the germplasm evaluated. Both PCV and GCV were high for pseudo stem diameter, plant height, average clove weight, average bulb weight, bulb yield and leaf length. High heritability coupled with high genetic advance as per cent of mean was observed for plant height, average clove weight and bulb yield per plant.

Sandhu et al. (2015) evaluated 40 diverse genotypes of garlic and reported that phenotypic coefficients of variability were higher in magnitude than genotypic coefficients of variability for all the traits studied. High heritability coupled with moderate genetic gain was expressed for number of cloves per bulb, leaf width, alcohol insoluble solids and allicin content.

Sharma et al. (2016 a) carried out variability studies involving 131 genotypes of garlic and observed that phenotypic coefficients of variation (PCV) were higher in comparison to the genotypic coefficients of variation (GCV) for plant height, bulb weight, leaf length, number of cloves per bulb and pseudo stem length. High heritability coupled with moderate genetic advance was recorded for clove weight, bulb weight, pseudo stem length, bulb polar diameter, bulb equatorial diameter and number of cloves per bulb. The genotypes viz., PG-20, K-1, GHC-1, TG-1, CFG-3, G-50 were rated as best and can further be utilized for improvement of garlic.

Bhatt et al. (2017) evaluated sixteen diverse indigenous genotypes of garlic for genetic variability, heritability and genetic advance and observed sufficient genetic diversity for bulb yield and associated traits viz., bulb weight, clove length, cloves per bulb, clove equatorial diameter, leaf length and leaf width.

Kumar et al. (2017 a) conducted an investigation to study the genetic variability, heritability and genetic advance in available genotypes of garlic (*Allium sativum* L.) for plant height, number of leaves per plant, leaf length, leaf width, bulb yield per plant, bulb length, bulb equatorial diameter, number of cloves per bulb, clove length, clove equatorial diameter, days to harvest, total soluble solids (TSS), dry matter and acidity. The higher magnitude of phenotypic and genotypic coefficients of variation were observed for bulb yield per plant, number of cloves per bulb and acidity.

Sabir et al. (2017) reported that genotypic and phenotypic coefficients of variation were high for average clove weight, bulb yield per plant, cloves per bulb and plant height. The traits, clove width, plant height, leaf length, yield per plant, cloves per bulb, average clove weight had high heritability coupled with high genetic advance as per cent of mean, indicated additive gene effects. Based on the results obtained, it was concluded that selection on the basis of these characters will be more meaningful for getting higher bulb yield in garlic.

Raja et al. (2017) carried out an investigation to study genetic variability among 80 genotypes of garlic for bulb yield and its contributing characters. Based on mean performance, the genotype, NDG-33 was the highest yielder followed by NDG-32, whereas minimum bulb yield was recorded in NDG-54. The genotypes, NDG-33, NDG-32, NDG-26, NDG-9 and NDG-34 were rated as high yielder which can be utilized in breeding programme for improving bulb yield. Analysis of variance indicated presence of considerable variability for all the twelve characters studied. The estimates of phenotypic coefficients of variation (PCV) were higher than the genotypic coefficients of variation (GCV) for number of cloves per bulb, clove equatorial diameter, clove weight, neck thickness, leaf width and clove length. All the traits studied exhibited high heritability except total soluble solids (TSS) with low heritability estimates. High heritability coupled with high genetic advance as per cent of mean was exhibited for leaf width followed by acidity.

Jethava et al. (2018) carried out an investigation to study the field performance and genetic variation of 260 genotypes of garlic (*Allium sativum* L.) and reported that the analysis of variance revealed significant differences among the genotypes for plant height, pseudo stem length, pseudo stem diameter, days to maturity, number of leaves, leaf length, leaf width, bulb polar diameter, bulb equatorial diameter, number of cloves per bulb, weight of 10 cloves, bulb yield and TSS which indicated greater variability in experimental material studied. In general, the estimates of phenotypic coefficients of variance (PCV) were found higher in magnitude than corresponding genotypic coefficients of variation (GCV). Characters such as pseudo stem diameter and leaf width showed higher phenotypic and genotypic coefficients of variation. High heritability coupled with high genetic advance as per cent of mean was observed for pseudo stem diameter, pseudo stem length and bulb yield per plant, suggested predominant role of additive gene action in the inheritance of these traits.

Mishra et al. (2018) evaluated 80 indigenous garlic genotypes for genetic variability and reported higher magnitude of coefficients of variation for leaf width, clove weight, number of cloves per bulb, number of leaves per plant, plant height, leaf length and bulb equatorial diameter, at phenotypic level. High heritability coupled with high genetic advance as per cent of mean was recorded for number of cloves per bulb, leaf length, total soluble solids (TSS), clove width and bulb yield per plant.

Singh et al. (2018) evaluated 60 genotypes including four check varieties of garlic (*Allium sativum* L.) namely, G-50, G-41, G-282 and Punjab Garlic for genetic variability, heritability and genetic advance and reported that the maximum bulb yield per plant was observed in NDG-26 (29.97 g) followed by NDG-41 (29.30 g) and NDG-5 (28.22 g). The minimum bulb yield per plant was recorded in NDG-31 (15.13 g). The high estimates of genotypic and phenotypic coefficients of variation were recorded as 28.74 and 28.77 per cent, respectively for leaf width. The high magnitude of genotypic and phenotypic coefficients of variation were observed for leaf width, clove length, clove equatorial diameter, indicated substantial scope for improvement of these characters through hybridization and subsequent selection. The high estimates of heritability coupled with high genetic advance as per cent of mean were observed for leaf width, clove width, neck thickness, clove equatorial diameter, indicated ample scope for improvement of these traits through selection.

2.2 Correlation coefficient

The knowledge of the correlation among components of economic importance and between other traits can help to improve the efficiency of selection by making possible use of suitable combination of characters in such selection. An unfavourable association between desired characters under selection may result in genetic sippage. Therefore, knowledge of association between important characters is essential before planning purposive breeding programme. Galton (1889) was the pioneer in the development of basic concepts of correlation. Phenotypic correlation does not give true picture of the relationship between two characters, as it includes environmental correlation as well. Hence, study of genetic correlation is essential to understand the real association among traits. Robinson et al. (1951) stated that most of the traits of economic importance including yield are complex involving several related traits. Therefore, knowledge of the degree of phenotypic and genotypic correlations of the traits is indeed important. Johnson et al. (1955) revealed that the estimates of genotypic and phenotypic correlations among characters are useful in planning and evaluating breeding programmes. Hayes et al. (1955) stated that correlation coefficient is a measure of degree of association between the two traits worked out at the same time. The study of correlation coefficient between various economic traits of crop plant is very important to display the degree of union between characters. Therefore, the knowledge of nature of association between yield and its component characters is of great interest in the selection programme.

Kohli and Prabal (2000) revealed that the correlation between bulb yield, leaf size and bulb equatorial diameter was positive and significant.

Figliuolo et al. (2001) evaluated 50 accessions of garlic and observed that plant height was significantly correlated with bulb weight, bulb polar diameter and leaf length. Bulb weight was positively correlated with bulb equatorial diameter, whereas number of cloves per bulb was negatively correlated with bulb weight.

Narayan and Khan (2002) revealed that plant height and leaf weight were positively correlated with clove girth and clove length. The traits, dry leaf weight, clove length and bulb weight should be considered in the selection for improvement of bulb yield in garlic.

Shridhar (2002) reported that the magnitude of genotypic correlations was higher than the phenotypic correlations for all the traits studied. The weight of 10 bulbs showed positive phenotypic correlation with bulb polar and equatorial diameters, whereas the weight of 50 cloves was positively correlated with weight of 10 bulbs and clove equatorial diameter. The number of cloves was negatively correlated with clove polar diameter, clove equatorial diameter and weight of 50 cloves. Plant height exhibited a significant negative correlation with days to maturity and number of cloves.

Singh and Chand (2003) conducted a field experiment involving 30 diverse clones of garlic and reported positive and significant association of days to maturity with TSS and negative significant association of dry matter with bulb yield and days to maturity.

Naruka and Dhaka (2004) evaluated 30 genotypes of garlic and reported that plant height, number of leaves per plant, chlorophyll content, fresh weight of leaves, maturity period and neck thickness exhibited positive and significant correlation with number of cloves per bulb, weight of 20 cloves, harvest index and bulb yield per hectare. However, bulb: leaf ratio had negative and significant correlation with harvest index and bulb yield per hectare.

Shrivastava et al. (2004) reported that bulb weight had a significant and positive correlation with plant height followed by leaves per plant, pseudo stem diameter, top weight and bulb equatorial diameter; plant height showed significant positive correlation with leaves per plant, pseudo stem diameter, top weight and bulb equatorial diameter. Significant and positive correlation was exhibited amongst leaves per plant, pseudo stem diameter and top weight. Pseudo stem diameter had a significant positive correlation with top weight and bulb equatorial diameter. However, negative correlation was observed between cloves per bulb and clove weight biomass.

Singh et al. (2004) revealed that bulb equatorial diameter, leaf breadth, number of cloves per plant, average clove weight, days to maturity, clove length and clove equatorial diameter displayed significant positive association with bulb yield per plant.

Wani (2004) computed phenotypic correlation coefficients amongst 12 characters of garlic and revealed that bulb yield was positively and significantly associated with number of leaves, bulb volume, bulb weight and number of cloves per bulb. These characters appeared as key traits which require special emphasis during selection programmes for genetic improvement to obtain higher bulb yield in garlic.

Baghalian et al. (2006) evaluated 24 garlic genotypes and reported that bulb yield had significant and positive correlation with leaf number, clove weight and bulb weight.

Kambiz et al. (2006) evaluated 24 garlic genotypes and reported that bulb yield had significant and positive correlation with leaves per plant, cloves per bulb and bulb weight.

Singh et al. (2006) evaluated 30 genotypes of garlic and observed significant positive correlation of bulb equatorial diameter, leaf breadth, leaves per plant, average clove weight, days to maturity, clove length and clove equatorial diameter with bulb yield.

Meena et al. (2007) revealed that the bulb yield showed significant positive correlation with plant height, number of leaves per plant, bulb equatorial diameter, bulb polar diameter and bulb weight.

Kalra et al. (2008) evaluated 38 accessions of garlic and observed that bulb yield was positively correlated with days taken to maturity. Accessions, CIMAP 2549 and CIMAP 2550 were early maturing, tolerant to purple blotch and produced bulb yield greater than 10 t/ha. These accessions can therefore, be planted late and harvested at the normal time of maturity.

Agarwal and Tiwari (2009) observed significant and positive correlation of bulb yield both at genotypic and phenotypic levels with bulb weight, clove weight, bulb polar diameter, clove length, leaf area index and neck diameter. Significant negative correlations of bulb yield at genotypic level were observed with purple blotch severity index and number of cloves per bulb.

Dubey et al. (2010) observed that bulb yield was positively and significantly correlated with neck thickness, bulb equatorial diameter, bulb size index, cloves per bulb, bolter, total soluble solids, dry matter, days for harvest and gross yield at genotypic and phenotypic levels, indicated that selection based on these traits will be helpful in increasing bulb yield of garlic.

Tsega et al. (2010) expressed that bulb yield per plant showed positive and significant phenotypic correlation with all characters except for harvest index and days to maturity. Genotypic correlations were higher in magnitude than phenotypic correlations for these traits.

Singh et al. (2011) revealed that marketable yield was positively and significantly correlated with leaves per plant, bulb equatorial diameter, bulb size index, weight of 20 bulbs and cloves per bulb at genotypic and phenotypic levels and negatively correlated with weight of 50 cloves at both levels. Gross yield was positively and significantly correlated with plant height, neck thickness and negatively correlated with clove equatorial diameter and clove size index at genotypic and phenotypic levels.

Barad et al. (2012) conducted an experiment comprising of 41 genotypes of garlic and observed higher estimates of genotypic correlation coefficients than phenotypic correlation coefficients. The bulb weight was positively and significantly correlated with bulb polar diameter, bulb equatorial diameter and number of cloves per bulb.

Patil et al. (2012) carried out an investigation involving 45 genotypes of garlic and reported that neck thickness, average bulb weight, bulb length, bulb equatorial diameter, average clove weight and days to maturity were positively and significantly correlated with bulb yield. The trait like number of cloves per bulb exhibited positive and non-significant correlation with bulb yield per hectare and days to maturity.

Sonkiya et al. (2012) reported that bulb yield (q/ha) both at genotypic and phenotypic levels was positively correlated with number of leaves, neck thickness, weight of five bulbs, number of cloves per bulb, length of cloves, clove equatorial diameter, days to maturity, TSS and sulphur content. The improvement in the characters like weight of hundred cloves, neck thickness, sulphur content may bring improvement in bulb yield of garlic.

Dhall and Brar (2013) conducted an experiment with twenty five genotypes of garlic and observed that bulb weight was positively and significantly correlated with bulb equatorial diameter, clove weight, clove length, bulb polar diameter and plant height at both genotypic and phenotypic levels.

Gehani and Kanbar (2013) reported that bulb yield was positively and significantly correlated with 5th leaf length, leaf width, pseudo stem weight, leaf area, total dry weight, bulb equatorial diameter and bulb height.

Singh et al. (2013 a) reported that total bulb yield showed positive and significant genotypic and phenotypic associations with plant height, number of leaves per plant, pseudo stem length, bulb weight and number of cloves per bulb which indicated that selection based on these traits will be helpful in increasing bulb yield of garlic.

Wang et al. (2014) evaluated 212 accessions of garlic and suggested that bulb yield was significantly and positively correlated with bulb weight (r = 0.99), bulb equatorial diameter (r = 0.73), bulb polar diameter (r = 0.53), clove per bulb (r = 0.52) and leaf width (r = 0.52). The trait, pseudo stem diameter was found significantly and positively correlated with allicin content (r = 0.23).

Esho (2015) reported that bulb yield was positively and significantly correlated with plant height, bulb weight, bulb equatorial diameter, bulb polar diameter, clove weight, clove equatorial diameter and TSS, whereas plant height and bulb equatorial diameter were positively and significantly correlated with all the traits except for number of cloves per bulb.

Khar et al. (2015) reported that average bulb weight showed positive and significant correlation with number of leaves per plant, leaf length, average clove weight, clove equatorial diameter, while it was negative and significantly correlated with total soluble solids which indicated that genetic improvement of bulb yield may be undertaken by selection of various characters like number of leaves per plant, leaf length, average clove weight and bulb equatorial diameter.

Prajapati et al. (2016) revealed that total yield (rp = 0.824), leaf length (rp = 0.634), bulb equatorial diameter (rp = 0.559), leaf width (rp = 0.544), plant height (rp = 0.498) pseudo stem diameter (rp = 0.476), bulb polar diameter (rp = 0.460), average weight of bulb (rp = 0.459) and days to maturity (rp = 0.435) were positively and significantly associated with bulb yield per plant.

Sharma et al. (2016 b) carried out character association studies involving 131 genotypes of garlic and reported that bulb weight per plant had significant positive correlation with plant height (0.541, 0.508), leaf length (0.461, 0.419), pseudo stem height (0.430, 0.417), pseudo stem diameter (0.562, 0.509), bulb polar diameter (0.733, 0.714), bulb equatorial diameter (0.858, 0.827), number of cloves per bulb (0.322, 0.317), clove length (0.581, 0.545) and clove weight (0.713,0.706) at both genotypic and phenotype levels, respectively.

Bhatt et al. (2017) evaluated 16 diverse indigenous genotypes of garlic for assessment of genetic variability and character association including path coefficient analysis, heritability and genetic advance for twelve yield contributing traits and revealed that both at genotypic and phenotypic levels, the gross bulb yield was significantly and positively associated with number of cloves per bulb (rp = 0.803, rg = 0.807), ascorbic acid (rp = 0.549, rg = 0.572) and weight of 10 uniform cloves (rp = 0.486, rg = 0.487).

Chotaliya and Kulkarni (2017) assessed the correlation and path coefficient in 156 genotypes and 4 checks of garlic and reported that in general, the estimates of genotypic correlations were higher than the corresponding phenotypic correlation coefficients for plant height, number of leaves per plant, leaf length, leaf width at middle portion, days to maturity, pseudo stem height, collar thickness, bulb collar diameter, bulb equatorial diameter, bulb polar diameter, bulb weight, number of cloves per bulb, clove weight, clove length, clove polar diameter, clove equatorial diameter, total soluble solids and bulb yield. This could be due to modifying effect of environment on the association of characters at genotypic level. The bulb yield had significant positive correlation with plant height, number of leaves per plant, leaf width at middle portion, pseudo stem length, bulb collar diameter, bulb equatorial diameter, bulb polar diameter, bulb weight, clove length, clove polar diameter and clove equatorial diameter.

Kumar et al. (2017 b) reported that the magnitude of genotypic correlations was higher than phenotypic correlations for plant height, leaves per plant, leaf length, leaf width, neck thickness, cloves per bulb, clove weight, clove length, bulb length, clove width, bulb equatorial diameter, total soluble solids and bulb yield per plant. The bulb yield per plant had significant and positive correlation with cloves per bulb and leaves per plant, while plant height was significantly and positively correlated with bulb yield per plant which indicated that selection for these traits would be effective for the improvement of bulb yield in garlic.

Singh et al. (2017) studied 60 genotypes including four check varieties (G-50, G-41, G-282 and Punjab Garlic) of garlic (*Allium sativum* L.) to assess the association of different yield traits and reported that number of cloves per bulb exhibited significant and positive phenotypic correlation with bulb yield per plant and significant negative correlation with clove weight. The total soluble solids exhibited significant and positive correlation with bulb yield per plant.

Zakari et al. (2017) revealed that bulb yield per hectare had significant and positive correlation with plant height, number of leaves, total dry matter, bulb weight, bulb equatorial diameter, number of cloves per bulb and clove weight.

Mishra et al. (2018) evaluated 80 indigenous garlic genotypes for genetic variability and reported that leaf length had significant and positive correlation with plant height, number of leaves per plant, bulb equatorial diameter and bulb yield per plant which indicated that selection for these traits would be more effective in the improvement of bulb yield.

Raja et al. (2018) evaluated 30 genotypes of garlic and observed that the bulb yield per plant exhibited significant and positive correlation with number of cloves per bulb which indicated that selection for these traits would be effective in the improvement of bulb yield in garlic.

2.3 Path coefficient

The estimates of correlation coefficient indicates only the inter-relationship amongst different characters but do not furnish information on the causes and effects. Therefore, under such a situation, path analysis helps in separating the correlation coefficient into components of direct and indirect effects. The detail technique of path coefficient analysis for partitioning of correlation coefficients into direct and indirect effects was first published by Wright (1921) and further illustrated as a mean of analysis of correlation coefficients by Dewey and Lu (1959).

Rajalingam and Harapriya (2001) studied the path coefficient analysis and reported that plant height, leaf breath, bulb weight, bulb length, shape index, days to maturity and harvest index had direct positive effects on bulb yield.

Khar et al. (2005) conducted path analysis involving 47 elite lines of garlic and reported that the indirect effects of total yield had masked the direct or indirect effects of most characters except total number of cloves where the indirect effects were in the negative direction via plant height, number of leaves, bulb equatorial diameter, neck thickness, bulb weight and weight of cloves. Total yield, number of leaves, weight of bulb and weight of cloves should be given due emphasis in selection programmes for bringing substantial yield improvement in garlic.

Golani et al. (2006) reported direct effects of number of leaves per plant and bulb girth and indirect effects of bulb length and bulb weight on bulb yield. However, significant and positive association of bulb yield with number of leaves per plant, bulb length, bulb girth and bulb weight was also observed.

Singh et al. (2006) evaluated 30 genotypes and revealed maximum direct effects of leaf breadth on bulb weight per plant followed by average clove weight, cloves per bulb, plant height, clove length and dry matter content, suggested that these traits should be considered for selection.

Yadav et al. (2007) conducted path coefficient analysis and reported that clove length had the highest direct effects on bulb weight followed by number of leaves per plant, plant height, bulb width, number of cloves per bulb, clove width and bulb length. Clove length had the highest negative indirect effects followed by bulb length and number of leaves per plant. The indirect effects of the some of characters on bulb weight were negative. However, bulb weight had positive and desirable indirect effects on plant height followed by bulb width, clove width and number of cloves per bulb.

Nourba et al. (2008) showed that clove weight and number of cloves per bulb had maximum direct effects on bulb yield of garlic.

Singh et al. (2008) revealed that plant height, bulb equatorial diameter and clove length had direct positive effects on bulb weight in garlic.

Agarwal and Tiwari (2009) reported positive direct effects of bulb weight, clove length and leaf area index on bulb yield.

Meena (2010) evaluated 25 genotypes of garlic and reported that the traits *viz.*, bulb weight, fresh weight of leaves, dry weight of bulb, circumference of bulb, neck thickness, volume of bulb, sulphur content and vitamin C had positive direct effects on bulb yield.

Kassahun et al. (2010) conducted path coefficient analysis and revealed that all characters except leaf length, dry weight above ground and bulb dry weight exerted positive direct effects on bulb yield per plant at phenotypic level. The low residual values indicated that the characters used were enough to explain their contribution and effects on bulb yield per plant.

Tsega et al. (2010) studied path coefficient analysis in 25 garlic genotypes and revealed that all characters except leaf length, dry weight above ground and bulb dry weight exerted positive direct effects on bulb yield per plant at phenotypic level.

Singh et al. (2011) carried out path coefficient analysis involving 32 promising genotypes of garlic and reported that leaves per plant, clove equatorial diameter, cloves per bulb and weight of 50 cloves showed positive direct effects on bulb yield. Clove equatorial diameter had maximum positive direct effect (0.744) followed by weight of 50 cloves (0.547), cloves per bulb (0.313) and leaves per plant (0.288). The highest negative direct effects were recorded for clove size index (-0.874) followed by neck thickness (-0.341), weight of 20 bulbs (-0.264) and plant height (-0.057). The estimates of direct and indirect effects on bulb yield were more pronounced in genotypic path than phenotypic path coefficient. The results indicated that weight of 20 bulbs, bulb size index, weight of 50 cloves and cloves per bulb produced highest positive direct effects on bulb yield and should be given more emphasis during selection for improvement.

Barad et al. (2012) conducted a field experiment comprising of 41 genotypes of garlic and observed positive and direct effects of number of cloves per bulb, whereas indirect effects via plant height, number of leaves per plant, bulb weight and bulb equatorial diameter on bulb yield.

Patil et al. (2012) conducted a field experiment on 45 genotypes of garlic and reported that number of cloves, bulb weight, plant height, average bulb equatorial diameter and clove weight had positive indirect effects on bulb yield.

Sonkiya et al. (2012) studied path analysis in garlic and observed that bulb yield had high positive direct effects on number of leaves, neck thickness, bulb weight, number of cloves per bulb, clove length, clove equatorial diameter, days to maturity, TSS and sulphur content.

Dhall and Brar (2013) reported that bulb polar diameter (0.658), bulb equatorial diameter (0.228), plant height (0.274), number of leaves per plant (0.763), clove equatorial diameter (0.224) had greater direct influence on bulb weight and hence selection of genotype on basis of these characters may be effective for improvement of bulb yield in garlic.

Panse et al. (2013) observed that plant height, bulb polar diameter, average weight of cloves, cloves per bulb and pseudo stem diameter had positive direct effects on bulb yield in garlic.

Singh et al. (2013 a) carried out path analysis studies involving 20 genotypes of garlic and observed direct effects of bulb weight and bulb equatorial diameter and indirect effects of plant height, number of leaves per plant, pseudo stem length, bulb polar diameter, number of cloves per bulb and clove weight on total bulb yield. Total bulb yield exhibited positive and significant genotypic and phenotypic association with plant height, number of leaves per plant, pseudo stem length, bulb weight and number of cloves per bulb, indicated that selection based on these traits will help increasing the bulb yield of garlic. Bulb weight showed positive and direct effects and significant positive correlation with total bulb yield. Therefore, bulb with more weight should be considered as selection criteria for increasing the total bulb yield and emphasis should be given for selecting the genotypes with higher bulb weight. Overall, the path analysis indicated that direct effects of bulb weight and bulb equatorial diameter and indirect effects of plant height, number of leaves per plant, pseudo stem length, bulb polar diameter, bulb equatorial diameter, number of cloves per bulb and average weight of 50 cloves should be considered simultaneously for amenability of total bulb yield.

Pervin et al. (2014) studied the field performance and genetic variation of 25 genotypes of garlic and revealed that high and positive direct effects on bulb yield were observed for dry weight of roots (0.281) and number of cloves per bulb (0.277).

Ijaz et al. (2015) studied genetic association between yield and its related traits and reported that bulb yield was associated with plant biomass, bulb equatorial diameter, number of bulbils and number of cloves. The plant traits viz., leaf area, number of leaves and plant height had minor effects on bulb yield.

Kumar et al. (2015) carried out genetic variability studies involving 41 genotypes of garlic collected from different agro climatic zones for bulb yield and other agronomic characters. The analysis of variance revealed greater variability for all the traits studied except for number of leaves per plant, leaf length, dry matter content, total soluble solids and bulb equatorial diameter. Positive direct effects on average weight of bulb were observed for average weight of 10 cloves per bulb (0.950), dry matter (0.575), bulb equatorial diameter (0.419), leaf length (0.127) and plant height (0.222).

Prajapati et al. (2016) conducted path coefficient analysis and revealed that number of cloves per bulb (0.820) followed by pseudo stem diameter (0.315), number of leaves per plant (0.163), leaf width (0.132), pseudo stem length (0.091), bulb equatorial diameter (0.050) and days to maturity (0.034) had the highest positive direct effects on bulb yield per plant. The maximum negative direct effects were exerted by leaf length (–0.124), plant height (–0.118), average weight of 10 cloves (–0.049) and bulb polar diameter (–0.033).

Sharma et al. (2016 b) conducted an experiment involving 131 genotypes of garlic to identify the characters which mainly contributed to bulb yield per plant. The character association analysis revealed that bulb weight per plant showed positive significant correlation with plant height (0.541, 0.508), leaf length (0.461, 0.419), pseudo stem height (0.430, 0.417), pseudo stem diameter (0.562, 0.509), bulb polar diameter (0.733, 0.714), bulb equatorial diameter (0.858, 0.827), number of cloves per bulb (0.322, 0.317), clove length (0.581, 0.545) and clove weight (0.713, 0.706) both at genotypic and phenotype levels, respectively. The maximum direct effects with significant positive correlation were showed by bulb equatorial diameter (0.828), bulb polar diameter (0.714), clove weight (0.706), clove length (0.545) and pseudo stem diameter (0.510). The characters like bulb equatorial diameter, clove weight, number of cloves per bulb were the most important bulb weight determinants as these exhibited high direct and indirect effects via many other yield contributing characters.

Bhatt et al. (2017) studied 16 diverse indigenous genotypes of garlic for assessment of genetic variability and character association including path coefficient analysis for bulb yield and contributing traits and revealed that the maximum negative direct effects on bulb yield were exhibited by sulphur content (-0.329) followed by volume of bulb (-0.215), plant height at 90 days after sowing (-0.064), neck thickness (-0.045), TSS (-0.017) and weight of 10 uniform cloves (-0.001). The selection for number of cloves per bulb, dry weight of bulb, circumference of bulb and number of leaves per plant should be given more emphasis for getting an ideal genotype with increased bulb yield.

Chotaliya and Kulkarni (2017) assessed correlation and path analysis in 156 genotypes and 4 checks of garlic between bulb yield and related traits viz., plant height, number of leaves per plant, leaf length, leaf width at middle portion, days to maturity, pseudo stem height, collar thickness, bulb polar diameter, bulb equatorial diameter, bulb weight, number of cloves per bulb, clove weight, clove length, clove polar diameter, clove equatorial diameter, total soluble solids and revealed that the traits like plant height and clove polar diameter exhibited maximum direct effects on bulb yield. These characters also had positive indirect effects on each other. The traits viz., plant height, number of leaves per plant, leaf width at middle portion, pseudo stem height exhibited positive and indirect effects on bulb yield via plant height, leaf length, leaf width at middle portion, days to maturity, pseudo stem height, bulb equatorial diameter, bulb polar diameter, bulb weight, number of cloves per bulb, clove weight, clove polar diameter, clove equatorial diameter and total soluble solids. The characters namely, 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.

Raja et al. (2018) evaluated 30 genotypes of garlic in an augmented design for plant height, leaves per plant, leaf length, leaf width, neck thickness, cloves per bulb, clove weight, clove length, clove width, bulb equatorial diameter, total soluble solids and bulb yield per plant and reported that the maximum positive direct effects on bulb yield per plant was exerted by number of cloves per bulb, number of leaves per plant and leaf length, suggested that selection for these traits will directly increase bulb yield per plant.

Yadav et al. (2018) evaluated 80 genotypes for plant height, number of leaves per plant, leaf length, leaf width, neck thickness, bulb equatorial diameter, bulb yield per plant, number of cloves per bulb, clove length, clove weight, clove equatorial diameter and reported that the maximum positive direct effects on bulb yield per plant was displayed by number of cloves per bulb, clove weight, total soluble solids, neck thickness, leaf width and number of leaves per plant which suggested that selection for these traits will directly increase bulb yield.

2.4 Genetic divergence

The choice of germplasm is an essential and crucial step in any plant breeding program, whether for the development of varieties or to produce hybrids and can determine the success or failure of the selection process. The study of genetic divergence can assist in the selection of genotypes to be used in breeding programs for the development of new populations. Assessment of the genetic diversity is an essential first step for identifying appropriate parents for hybridization and generating a broad spectrum of variability in segregating generations. Genetic divergence is related to the degree of distance between populations in the set of genetic characters that differs between the populations. Mahalanobis D^2 analysis is

very useful tool in studying the nature and magnitude of diversity prevalent in the available germplasm. It quantifies the degree of divergence between biological populations at genotypic level and assess relative contribution of different components to the total divergence both at intra and inter cluster levels.

Several methods of divergence analysis based on quantitative traits have been proposed to suit various objectives, of which Mahalanobis generalized distance (Mahalanobis, 1936) occupy a unique place in plant breeding. The concept of Mahalanobis's D^2 statistic is based on the technique of utilising the measurements in respect of aggregate of characters. The D^2 statistic as a measure of genetic divergence was used for the first time in the field of plant breeding by Nair and Mukherjee (1960) in the classification of natural and plantation teak.

Kumar and Mukherjee (2005) evaluated genetic diversity using Mahalanobis statistic (D^2) and grouped the genotypes into three clusters. High D^2 values within a constellation indicated high divergence.

Shashidhar and Dharmatti (2005) categorized 27 genotypes of garlic into 4 clusters. Cluster I was the largest which consisted 13 genotypes followed by cluster II with 12 genotypes, whereas cluster III and IV were solitary clusters. Yield per hectare contributed maximum towards divergence followed by leaf area and leaf size. The maximum intra-cluster distance was recorded for cluster II (D^2 =18.03) followed by cluster I (D^2 = 17.04). Higher inter cluster distance was recorded between cluster I and cluster IV (D^2 = 53.21) followed by cluster III and IV (D^2 = 48.23). Based on cluster mean analysis, cluster IV, having single genotype was categorized under high yielding groups (63.72 q/ha).

Khar et al. (2006) studied genetic divergence and reported that 47 garlic genotypes were grouped into six clusters. The cluster II had the maximum number of genotypes followed by clusters III, I, V, IV and VI. The magnitude of intra-cluster values ranged from 7.34 to 20.50. Cluster IV had maximum intra-cluster distance. The maximum inter cluster values were observed between clusters IV and VI. Cluster VI recorded the highest mean values for bulb polar diameter, bulb equatorial diameter, average weight of five bulbs, average weight of 50 cloves, marketable yield and total yield. Cluster IV registered the highest mean values for plant height, lowest neck thickness and lowest number of cloves per bulb. Cluster V had the highest number of leaves per plant. The relative contribution of different plant traits towards diversity revealed that the highest contribution was from marketable yield followed by weight of five bulbs and plant height.

Panthee et al. (2006) estimated genetic diversity among one hundred and seventy nine garlic accessions. All accessions were characterized based on morphological characters. Four principal components were identified explaining more than 86% of total variation. Major characters included in the principal components were bulb weight, diameter, yield, number of cloves per bulb, maturity, plant height, number of green leaves at 135 days after planting and bulbing period.

Singh et al. (2012 b) revealed significant differences among 32 garlic advance lines for different traits which indicated the presence of sufficient genetic diversity amongst the cultivars. The cluster VII had highest values for plant height (109.11 cm), gross yield (239.19 q/ha) and minimum for *Stemphylium* intensity (2.08 %); Cluster VI was promising for leaves per plant (9.51), bulb size index (15.88 cm^2), weight of 20 bulbs (0.696 g) and marketable yield (159.05 q/ha) and cluster X was observed best for bulb equatorial diameter (4.63 cm), clove equatorial diameter (1.33 cm), clove size index (3.58 cm^2) and weight of 50 cloves (85.0 g). The results suggested that selection of genotypes based upon the large cluster distances from all the clusters may lead to broad spectrum favorable genetic variability.

Patil et al. (2013) grouped 45 genotypes of garlic into seven clusters with cluster II having maximum genotypes (19) followed by cluster I, cluster IV, cluster VI and cluster VII. Maximum inter cluster distance was recorded between cluster II and VII (5487.84) and maximum intra-cluster distance was recorded in cluster III (155.75). The bulb yield contributed maximum towards genetic diversity followed by days to harvest and bulb weight. Selection of genotypes based on these characters may contribute to broaden genetic diversity in the existing gene pool.

Singh et al. (2013 b) observed significant divergence in 15 garlic clones with checks viz., Yamuna Safed (G-1), Agrifound White (G-41), Yamuna Safed-2 (G-50) and Yamuna Safed-3 (G-282) for bulb yield and related traits which indicated sufficient genetic diversity among the cultivars evaluated. Cluster-III had highest values for plant height (93.05 cm), bulb equatorial diameter (4.71 cm), bulb size index (16.08 cm^2), bulb weight (700 g), clove equatorial diameter (1.75 cm), clove size index (4.43 cm^2), weight of 50 cloves (97.50 g) and gross yield (159.63 t/ha) and minimum for neck thickness (1.45 cm), number of cloves per bulbs (17), days for bulb initiation (61.66 days) and days to harvesting (149.83). The traits, total soluble solids contributed maximum (20.46 %) toward genetic divergence followed by gross bulb yield (16.37 %), bolters (12.86 %), marketable yield (11.11 %), number of cloves per bulb (10.52 %), weight of 50 cloves (10.52 %), days for bulb initiation (10.52 %) and days to harvest (4.09 %) which suggested that selection of genotypes based on these traits may contribute to wider genetic diversity in the existing gene pool of garlic genotypes.

Mohammadi et al. (2014) studied variation among landraces of garlic and their relationship with geographical regions for sixteen agro-morphological characters. Sufficient genetic diversity was observed amongst the germplasm. Differences in germplasm were predominantly due to genotypes. Based on cluster analysis, there was a relationship between genetic divergence and geographical origin, genotypes from the same or nearby locations were grouped in the same cluster and vice-versa.

Sandhu et al. (2014) evaluated genetic diversity amongst 40 garlic genotypes for morphological and quality parameters and reported that divergence analysis grouped the genotypes into seven clusters with variable number of genotypes in each cluster, indicated the presence of genetic diversity in the genotypes. The genotypes of cluster V and III exhibited maximum divergence as indicated by their inter cluster distance (192.516) followed by cluster IV and III (123.642), cluster III and I (116.349) and cluster VII and II (102.254). The remaining clusters I and VI were least divergent as revealed by their inter cluster distance (46.47), indicated that the genotypes in these clusters had dissimilarity for morphological features and performance. The allicin content recorded was maximum in cluster III (1.2 %) followed by cluster VI (0.79 %), cluster II (0.78 %), cluster I (0.70 %), cluster VII (0.65 %), cluster VI (0.54 %) and cluster V (0.30 %).

Singh et al. (2014) carried out an investigation to identify the extent of genetic divergence that existed for the yield and yield contributing characters of 15 genotypes of garlic using Mahalanobis D^2 analysis. All the 15 genotypes of garlic (*Allium sativum* L.) were grouped into three clusters on the basis of morphological diversity. Maximum intra-cluster distance was observed in cluster III (5.654), whereas maximum inter cluster distance was observed between cluster II and I (6.294) which indicated significant differences among parental lines for all the agro-morphological characters studied. These traits should be taken into consideration either simultaneously or alone for selecting high yielding genotypes.

Ijaz et al. (2015) reported that elite garlic clone, Wv had the highest garlic bulb yield and the principal component analysis reduced the original eight quantitative characters to three principal components that explained 100 % of variation among four accessions of garlic. The proportions of the total variance attributable to the first three principal components were 60.8 %, 25.4 %, and 13.4 %. The clones, 'Wv' and 'Wn' grouped under first cluster had diversity for plant height, leaf area, and bulb yield, whereas 'Lahsan Gulabi' had diversity for bulb equatorial diameter and number of bulbs per square meter.

Kaushik et al. (2016) carried out genetic diversity studies amongst 40 genotypes of garlic (*Allium sativum* L.) for different morphological traits and reported that divergence analysis grouped the genotypes into seven clusters which indicated the presence of sufficient genetic diversity in the genotypes. The maximum inter cluster distance (2349.16) was recorded between cluster II and VI followed by cluster

II and VII (2009.54). However, the minimum inter cluster distance (217.3) was found between cluster III and IV which suggested that the genotypes in these clusters have dissimilarity for morphological traits. The different clusters had higher mean values for yield related traits viz., bulb weight per plant, clove length and clove weight. The genotypes, PG-20 and Punnur Local from cluster II and Chechena and Bhima Omkar from cluster I proved better for further improvement programme.

Islam et al. (2017) assessed genetic diversity amongst 13 genotypes of garlic (*Allium sativum* L) using morphological traits. Based on D^2 analysis, all 13 garlic lines were grouped into four clusters. The inter cluster distance was larger than the intra-cluster distances. Maximum inter cluster distance was found between cluster I and II (11.433) followed by cluster III and IV (11.420) and cluster I and IV (11.146). The lines grouped under cluster II (5) and cluster IV (4, 6 10, 11 and 12) were superior to all other clusters and could be used for future breeding programme.

Sabir et al. (2017) conducted an experiment on morphological characterization of garlic genotypes on the basis of Mahalanobis D^2 values and reported that all the 27 genotypes were grouped into six clusters. Cluster III (8), cluster V (6) and cluster VI (6) contained maximum number of genotypes; cluster I (4) and cluster II (2) comprised minimum number of genotypes and cluster IV contained single genotype.

Sharma et al. (2018) revealed that more than 75 % of diversity out of total 131 garlic germplasm was present in first 4 principal components out of 12 and had Eigen values recorded more than 1. The first PC explained characters viz., plant height, pseudo stem height, bulb polar diameter, bulb equatorial diameter, bulb weight and number of cloves per bulb were positively related to bulb yield. In case of PC2, characters like plant height, pseudo stem height, bulb equatorial diameter, number of cloves per bulb showed positive correlation. Bi-plot displayed lot of variability present in the genotypes evaluated. The genotypes viz., K1, TG-F1, PG-20, GHC-1 and Punnur Local were identified as the best genotypes. Therefore, the above mentioned variables might be taken into consideration for effective selection of parents in genetic improvement program for broadening the genetic base of the population as well as to develop elite garlic lines.

3. MATERIALS AND METHODS

The present investigation entitled **"Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum L.*)"** was undertaken at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalya, Palampur during *Rabi*, 2017-2018. The details of materials used and methods employed in the present studies are presented below:

3.1 Experimental site

3.2 Experimental material and layout plan

3.3 Observations recorded

3.4 Statistical analysis

3.5 Genetic diversity analysis

3.6 Principal component analysis

3.1 Experimental site

3.1.1 Location

The experimental farm of Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya Palampur is located at an elevation of 1290 meters above mean sea level with 32^0 6' N latitude and 76^0 3' E longitude.

3.1.2 Climate and weather conditions

The experimental area is characterized by severe winters and mild summers with very high rainfall during monsoon season. Agro climatically, the location represents mid hill zone of Himachal Pradesh and is characterized by humid sub-temperate climate with high rainfall of 2500 mm annually, of which 80 per cent is received during June to September. The soil is acidic in nature with pH ranging from 5.0 to 5.6 and soil texture is silty clay loam. Mean temperature during the crop season varied from 13.5 to 25.8 ^{0}C, while relative humidity varied from 52 to 84.36 %, respectively. The mean monthly meteorological data pertaining to temperature, relative humidity, rainfall and sun shine hours during the cropping season *Rabi* 2017-2018 is given in Fig. 3.1 and Appendix- I.

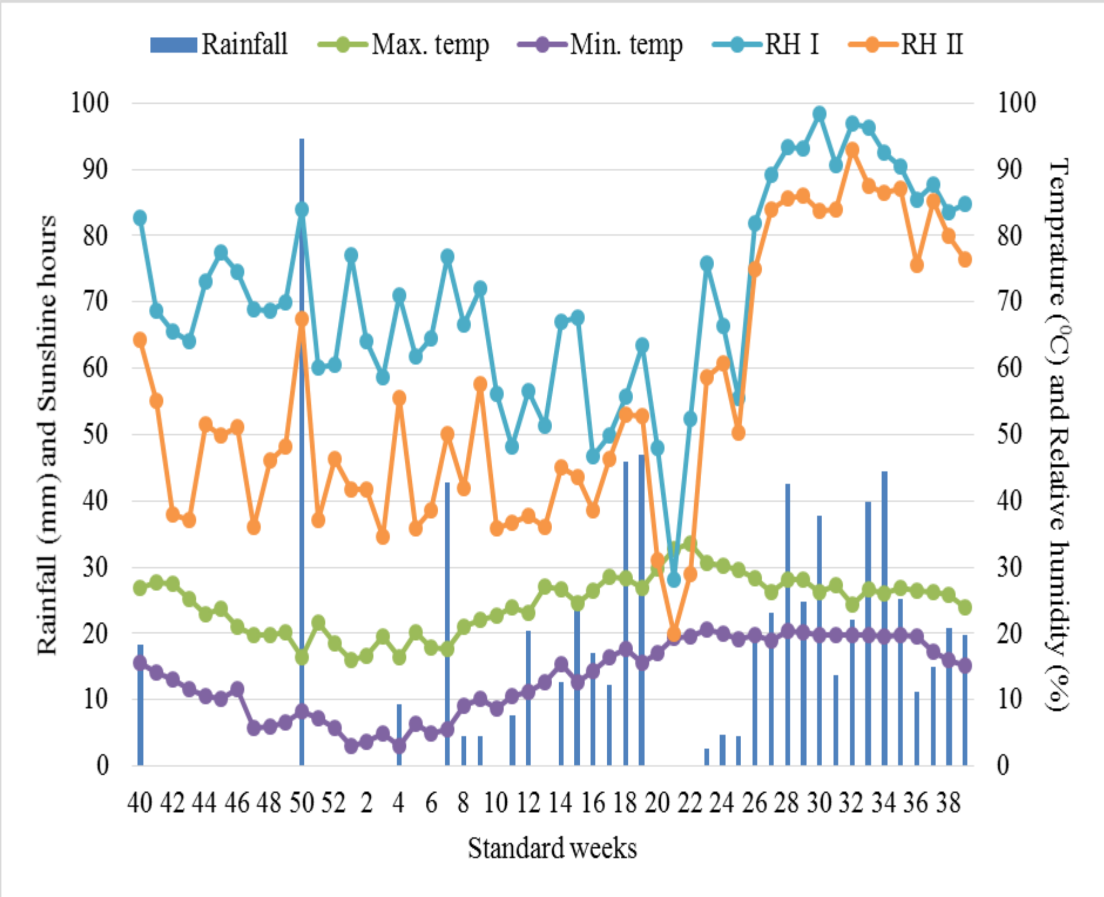


Fig. 3.1 Mean weekly meteorological data during crop season (*Rabi* 2017-18)

3.2 Experimental material and layout plan

3.2.1 Experimental material

The present investigation was carried out involving twenty five diverse genotypes of garlic collected both within and outside the State. The different genotypes of garlic along with their sources of collection have been presented in Table 3.1.

Table 3.1 List of garlic genotypes along with their source

Genotypes	Code	Source
Yamuna Safed-1	G-9	NHRDF, Karnal (Haryana)
Yamuna Safed-2	G-12	NHRDF, Karnal (Haryana)
Yamuna Safed-3	G-8	NHRDF, Karnal (Haryana)
Yamuna Safed-4	G-2	NHRDF, Karnal (Haryana)
Yamuna Safed-5	G-5	NHRDF, Karnal (Haryana)
Yamuna Safed-8	G-13	NHRDF, Karnal (Haryana)
Yamuna Safed-9	G-1	NHRDF, Karnal (Haryana)
Agrifound Parvati	G-11	NHRDF, Karnal (Haryana)
Agrifound Parvati-2	G-10	NHRDF, Karnal (Haryana)
Agrifound White	G-7	NHRDF, Karnal (Haryana)
GHC-1	G-3	CSKHPKV, Palampur
Leda Local Selection	G-4	Local Collection (HP)
Bijni Local Selection	G-6	Local Collection (HP)
Ner Chowk Local Selection	G-14	Local Collection (HP)
Mahadev Local Selection	G-15	Local Collection (HP)
Kangra Local Selection	G-16	Local Collection (HP)
Kanaid Local Selection	G-17	Local Collection (HP)
Gheru Local Selection	G-18	Local Collection (HP)
Chambi Local Selection	G-19	Local Collection (HP)
Biara Local Selection	G-20	Local Collection (HP)
Kasharala Local Selection	G-21	Local Collection (HP)
Jhungi Local Selection	G-22	Local Collection (HP)
Chakar Local Selection	G-23	Local Collection (HP)
Pungh Local Selection	G-24	Local Collection (HP)
Badraina Local Selection	G-25	Local Collection (HP)

3.2.2 Layout plan

The experiment was laid out in Randomized Complete Block Design (RBD) with three replications during *Rabi*, 2017-2018. Each experimental plot consisted of 4 rows each of 0.6 m length, accomodating 6 plants per row. The standard agronomic practices and plant protection measures were followed for raising the healthy crop of garlic as per the Package of Practices for Vegetable Crops by CSKHPKV, Palampur.

3.3 Observations recorded

The observations were recorded on ten randomly selected competitive plants from each entry per plot in each replication and their means were worked out for statistical analysis. Observations were recorded for the following characters:

A. Quantitative traits

3.3.1 Plant height (cm)

Plant height of ten randomly selected plants was measured from the neck of the bulb to the tip of the longest leaf of plant with measuring scale at harvesting and mean values were expressed in centimetres.

3.3.2 Leaves per plant

Total number of leaves from ten randomly selected plants from each genotype were counted and average values were calculated.

3.3.3 Leaf length (cm)

Leaf length of ten randomly selected leaves from the selected plants in each genotype was measured from base to tip of the leaf at final harvest and average worked out.

3.3.4 Leaf width at middle portion (cm)

Leaf width at middle portion of ten randomly selected leaves was measured from center of each leaf and average values were computed and expressed in centimetres.

3.3.5 Pseudo stem length (cm)

Pseudo stem length of ten randomly selected plants from the base of plant (Neck) to the point where scales unfold was measured and averaged out.

3.3.6 Pseudo stem diameter (cm)

Pseudo stem diameter of ten randomly selected plants from the middle portion was measured with the help of Vernier Calliper and average was worked out.

3.3.7 Bulb polar diameter (mm)

Bulb polar diameter of ten randomly selected bulbs was measured with Vernier Calliper and average was worked out.

3.3.8 Bulb equatorial diameter (mm)

Bulb equatorial diameter of ten randomly selected bulbs was measured with Vernier Calliper and average was worked out.

3.3.9 Cloves per bulb

Number of cloves were counted from randomly selected five bulbs and average number of cloves per bulb was computed.

3.3.10 Clove weight (g)

Clove weight of ten randomly selected cloves from selected bulbs was measured and average values calculated.

3.3.11 Clove length (cm)

Clove length of ten randomly selected cloves from selected bulbs was measured with centimeter scale and average values were calculated.

3.3.12 Clove polar diameter (mm)

Clove polar diameter of ten randomly selected cloves was measured with Vernier Calliper and average values were worked out.

3.3.13 Clove equatorial diameter (mm)

Clove equatorial diameter of ten randomly selected cloves was measured with Vernier Calliper and averaged out.

3.3.14 Bulb yield per plant (g)

Bulb yield of ten randomly selected plants was recorded in grams and average values were computed.

3.3.15 Bulb yield per plot (kg)

Bulb yield of all plants per plot was recorded and average yield per plot was worked out.

3.3.16 Total soluble solids (^{0}b)

Two garlic cloves of each genotype were ground in Pestle and Mortar. The extract was squeezed with muslin cloth and a drop of juice was placed on the refractometer. The numbers on the scale were visible when the refractometer was pointed towards a light source represented the concentration of soluble solids and expressed in ^{o}brix.

3.3.17 Bulbils per plant

Number of bulbils per plant of ten randomly selected plants were counted and average number of bulbils were computed.

B. Qualitative traits:

3.3.2.1 Bulb skin colour

Skin colour of bulbs was recorded on the basis of garlic colour chart for different genotypes evaluated and genotypes were organized in 4 categories namely, Purplish, Purplish white, Whitish purple and Creamish white colour.

3.3.2.2 Clove skin colour

Skin colour of cloves was observed on the basis of garlic colour chart for different genotypes and genotypes were arranged into 7 categories namely, Purplish, Purplish white, Creamish white, Whitish purple, Light pink, Light brown and Reddish brown.

3.3.2.3 Foliage colour

Foliage colour was recorded on the basis of garlic colour chart for different genotypes and categorized as green, light green and dark green.

3.3.2.4 Leaf waxiness

Leaf waxiness of ten randomly selected plants was observed for its presence or absence in different garlic genotypes evaluated.

3.3.2.5 Bolting/Non bolting

Garlic genotypes were observed for presence or absence of bolting at the time of final harvest and recorded.

3.3.2.6 Plant growth habit

Plant growth habit of ten randomly selected plants was recorded in different genotypes and classified as spreading, semi-spreading and erect growth habit.

3.4 Statistical analysis

Mean values of each genotype in each replication for all the traits were subjected to statistical analysis as per the standard statistical procedures for analysis of randomized complete block design (Panse and Sukhatme, 1987). The Parameters of variability were calculated as per the formulae given by Burton and De Vane (1953). The correlation coefficients both at phenotypic and genotypic levels were computed as suggested by Al-Jioubri et al. (1958). The path coefficient analysis to assess the direct and indirect contribution of different traits on bulb yield was calculated by employing the method suggested by Dewey and Lu (1959). The genetic diversity utilizing Mahalanobis D^2 statistic was computed as suggested by Mahalanobis (1936), Rao (1952) and Ward (1963).

3.4.1 Analysis of variance

The data to different traits was analyzed as per the procedure given by Panse and Sukhatme (1987). The analysis of variance was based on the following model:

$$Yij = m + gi + rj + eij$$

Where,

Yij= Phenotypic observation of i^{th} genotype grown in j^{th} replication

m = general population mean

gi = effect of i^{th} genotype

rj = effect of j^{th} replication

eij = error associated with i^{th} genotype in j^{th} replication

On the basis of this model, the analysis of variance was done as follows:

Source of variance	**df**	**Sum of squares (SS)**	**Mean squares (MS)**	**Variance ratio (VR)**	**Expected mean squares (MS)**
Replications (r)	r-1	Sr	Sr / (r-1) = Mr	Mr / Me	$\sigma^2e + g\,\sigma^2r$
Genotypes (g)	g-1	Sg	Sg / (g-1) = Mg	Mg/ Me	$\sigma^2e + r\,\sigma^2g$
Error (e)	(r-1) (g-1)	Se	Se/ (r-1) (g-1)= Me	-	σ^2e
Total	(rg-1)	-	-	-	-

Where,

r = Number of replications

g = Number of genotypes

Sr = Sum of squares due to replications

Sg = Sum of squares due to genotypes

Se = Sum of squares due to error

Mr = Mean squares due to replications = σ^2r

Mg = Mean squares due to genotypes = σ2g

Me = Mean squares due to error = σ^2e

σ^2p = $\sigma^2g + \sigma^2e$

The standard error of mean SE (m) and critical differences (CD) for comparing the means of any two genotypes were calculated as follows:

SE (m) ± = $\sqrt{Me/r}$

SE (d) ± = $\sqrt{2Me/r}$

CD (P=0.05) = S.E. (d) x $t_{(P=0.05)}$ at error degree of freedom

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference

CD (P=0.05) = Critical difference at 5 per cent level of significance

The calculated ‘F’ values were compared with the tabulated ‘F’ values at 5% level of significance. If the calculated ‘F’ value was higher than the tabulated, it was considered to be significant. All the traits, which showed significant differences among genotypes were further subjected to the estimation of following genetic parameters:

3.4.2 Mean performance and genetic variability

3.4.3 Heritability in broad sense (h^2_{bs})

3.4.4 Genetic advance (GA)

3.4.5 Genetic gain

3.4.6 Correlation coefficient

3.4.7 Path analysis

3.5 Diversity analysis

3.6 Principal Component Analysis (PCA)

3.4.2 Mean performance and genetic variability

The genotypic, phenotypic and environmental coefficients of variability (GCV, PCV and ECV) were estimated as per the formulae outlined by Burton and De Vane (1953).

a) **Genotypic coefficient of variation (GCV)**

$$GCV (\%) = \frac{\sqrt{\text{Genotypic variance } (\sigma^2 g)}}{\text{General mean } (\bar{x})} \times 100$$

b) **Phenotypic coefficient of variation (PCV)**

$$PCV (\%) = \frac{\sqrt{\text{Phenotypic variance } (\sigma^2 p)}}{\text{General mean } (\bar{x})} \times 100$$

3.4.3 Heritability in broad sense (h^2_{bs})

Heritability in broad sense (h^2_{bs}) was calculated as per the formula suggested by Burton and De Vane (1953) and Johnson et al. (1955).

$$\text{Heritability (\%)} = \frac{Vg}{Vp} \times 100 = \frac{\sigma^2 g}{\sigma^2 g + \sigma^2 e} \times 100$$

Where,

Vg = genotypic variance (Vg) = σ^2g

Vp = phenotypic variance (Vg + Ve) = σ^2g + σ^2e

Ve = environmental variance (Me) = σ^2e

3.4.4 Genetic advance (GA)

The expected genetic advance (GA) resulting from selection of five per cent superior individuals was worked out as suggested by Burton and De Vane (1953) and Johnson et al. (1955).

Genetic advance (GA) = h^2_{bs} x σp x K

Where,

h^2_{bs} = heritability in broad sense

σp = phenotypic standard deviation

K = 2.06 (Selection differential at 5 per cent selection index

3.4.5 Genetic gain

Genetic gain expressed as per cent of population mean, was calculated by the method given by Johnson et al. (1955).

$$\text{Genetic gain} = \frac{\text{Genetic Advance}}{\text{General population mean}} \times 100$$

For categorizing the magnitude of different parameters, Sharma (1994) suggested the following limits:

PCV and GCV	> 30 %	-	High
	20-30 %	-	Moderate
	< 20 %	-	Low
Heritability (h^2_{bs})	> 80 %	-	High
	50-80 %	-	Moderate
	< 50 %	-	Low
Genetic gain	> 50%	-	High
	25-50%	-	Moderate
	< 25%	-	Low

3.4.6 Correlation coefficients

The genotypic and phenotypic correlations were calculated as per Al-Jibouri et al. (1958) by using analysis of variance and covariance matrix in which total variability split into replications, genotypes and errors. All the components of variance were estimated from the analysis of covariance as given below:

3.4.4.1 Analysis of variance and covariance

The data were subjected to analysis of variance adopting standard statistical methods (Singh and Choudhary, 1985). The analysis of variance including source of variation, degree of freedom (df) and expected mean squares are given below:

Source of variation	Degree of freedom (df)	Mean sum of squares		Mean sum of products	Variance
		X	**Y**		
Replications (r)	r-1				
Genotypes (g)	g-1	Mg X	Mg Y	Mg XY = MP_1	MP_1/MP_2
Error (e)	(r-1) (g-1)	Me X	Me Y	Me XY = MP_2	

Genotypic, phenotypic and environmental covariances between X and Y characters were worked out as under:

Ve XY = MP_2

Vg XY = $(MP_1 - MP_2)/ r$

Vp XY = Vg XY + Ve XY

Where,

Ve XY = environmental covariance between character X and Y

Vg XY = genotypic covariance between character X and Y

Vp XY = phenotypic covariance between character X and Y

3.4.6.2 Coefficients of correlation

a) Genotypic correlation coefficient between X and Y

$$r_g = \frac{\text{Vg XY}}{\sqrt{\text{Vg X x Vg Y}}}$$

Where,

Vg XY = genotypic covariance between character X and Y

Vg X = genotypic variance of character X

Vg Y = genotypic variance of character Y

b) Phenotypic correlation coefficient between X and Y

$$r_p = \frac{Vp\ XY}{\sqrt{Vp\ X \times Vp\ Y}}$$

Where,

Vp XY	=	phenotypic covariance between character X and Y
Vp X	=	phenotypic variance of character X
Vp Y	=	phenotypic variance of character Y
Genotypic variance (Vg)	=	(Mg - Me) / r
Phenotypic variance (Vp)	=	(Vg + Ve)

Environmental variance (Ve) = Me

Test of significance

The significance of phenotypic coefficient of correlation at (g-2) degrees of freedom and environmental coefficient of correlation at [(r-1) (g-1) -1] degrees of freedom, where r and g stand for number of replications and number of genotypes, respectively, were tested at 5 per cent level of significance against the table values of correlation coefficient (Fisher and Yates, 1963).

To test the significance of genotypic coefficient of correlation, the F value was calculated using:

$F = [(g-2)\ r^2]/\ (1-r^2)$ and compared with the F-distribution at 1 and (g-2) degrees of freedom, where g and r stand for number of genotypes and genotypic coefficient of correlation, respectively (Mead and Curnow, 1983).

3.4.7 Path coefficient analysis

Path coefficient is a standardized partial regression coefficient and as such it is a measure of direct and indirect effects of a set of variables (component traits) on a dependent variable such as bulb yield. The genotypic and phenotypic correlation coefficients were used to find out their direct and indirect contribution towards bulb yield. The direct and indirect paths were obtained by employing the formulae suggested by Dewey and Lu (1959). The path coefficients were obtained by simultaneous selection of the following equations, which express the basic relationship between genotypic correlation 'r' and path coefficients (P).

$Py_1 + py_2r_{12} + py_3r_{13} \ldots\ldots + py_nr_{1n} = ry_1$

$Py_1r_{12} + py_2 + py_3r_{23} + \ldots\ldots + py_nr_{2n} = ry_2$

$py_1r_{13} + py_2r_{23} + py_3 + \ldots\ldots + py_nr_{3n} = ry_3$

:

:

$py_1r_{n1} + py_2r_{n2} + py_3r_{n3} + \ldots\ldots + py_n = ry_n$

Where,

py_1, py_2, py_3---------------, py_n are the directs path effects of 1, 2, 3---------, n variables on the dependent variable "y"

r_{12}, r_{13}, ---------------------, $r_{(n-1)\,n}$, are the possible coefficient of correlation between various independent variables with dependent variables "y"

The variation in the dependent variables which remained undetermined by including the other variables was assumed to be due to the variables (s) not included in the present investigation. The degree of the determination (P^2xR) of such variables was calculated as follows:

Residual effect (P x R) = $(1-R^2)^{1/2}$

Where

$R^2 = py_1ry_1 + py_2ry_2 +$----------------------------- $+ py_nry_n$

Where

R^2 is the square multiple correlation coefficient and is the amount of variation in yield that can be accounted by the yield component characters included in the present studies.

3.5 Genetic diversity analysis

3.5.1 D^2statistic

The concept of D^2 statistic for measuring of group distance based on multiple characters was developed by P. C. Mahalanobis in 1936. The estimation of D^2 values is as under:

$D^2 = wij\ (xi^{-1} - xi^{-2})\ (xi^{-1} - xi^{-2})$

Where, wij = inverse of estimated variance covariance matrix.

3.5.2 Computation of D^2 values and their significance

For each combination, the mean deviation i.e. $Yi1 - Yi2$ was computed and the D^2 value was computed as sum of squares of these deviations.

$D^2 = \Sigma\ (Yi1 - Yi2)$

Where, i= 1, 2,…………. p-number of characters

$Yi1$= Transformed uncorrelated mean of i^{th} character for genotype 1

$Yi2$= transformed uncorrelated mean of i^{th} character for genotype 2

The significance of D^2 values was tested against the table value of X^2 at p degree of freedom, where, p is total number of characters included in the study. If the calculated D^2 values was higher than the table X^2 values, it was considered as significant and vice-versa.

3.5.3 Grouping of genotypes into various clusters

Using D^2 values, different genotypes were grouped into various clusters following Tocher’s method as suggested by Rao (1952).

The first step in grouping the genotypes into distinct clusters was to arrange the genotypes in order of their relative distances from each other. After this, a method (Ward's minimum variance method) suggested by Ward (1963) was used for cluster formation. He suggested a general agglomerative hierarchical clustering procedure, where the criterion for choosing the pair of clusters to merge at each step is based on the optimal value of an objective function. To illustrate the procedure, Ward used the example where the objective function is the error sum of squares.

Ward's minimum variance criterion minimizes the total within-cluster variance. At each step, the pair of clusters with minimum between cluster distance is merged. To implement this method, at each step find the pair of clusters that leads to minimum increase in total within cluster variance after merging. This increase is a weighted squared distance between cluster centres. At the initial step, all clusters are singletons (clusters containing a single point). To apply a recursive algorithm under this objective function, the initial distance between individual objects must be (proportional) to squared Euclidean distance. The initial cluster distances in Ward's minimum variance method are therefore defined to be the squared Euclidean distance between points:

3.5.4 Intra and inter cluster distance

Average intra-cluster $D^2 = \Sigma D_i^2/n$

where,

ΣD_i^2 = sum of all distances between all possible combinations (n) of the genotypes included in the cluster.

Average inter cluster distance $D^2 = \Sigma D_{ij}^2/n_i \ldots . n_j$

where,

ΣD_{ij}^2 = sum of all distances between all possible combinations ($n_i.n_j$) of the genotypes between the clusters.

n_i = number of genotypes in i^{th} cluster

n_j= number of genotypes in j^{th} cluster

3.5.5 Cluster Diagram

With the help of D^2 values between (inter cluster distance) and within (intra-cluster distance) clusters, a diagram showing the relationship between different genotypes can be drawn. Such a diagram is not exactly to the scale.

3.5.6 Contribution of individual characters towards total divergence

In all the combination of genotypes, (n−1) 2, each character is ranked on the basis of mean difference, *i.e.*, di = Yi1 – Yi2 value, rank 1 is given to the highest mean difference and rank p to the lowest mean difference where, p is the total number of characters. The contribution of individual character to the divergence has been worked out in terms of 'n' number of times it appeared first.

3.6 Principal Component Analysis

PCA was performed using the statistical software XLSTAT (Anonymous, 2015).

4. RESULTS AND DISCUSSION

The present investigation entitled **"Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum* L.)"** was conducted at the experimental farm of Department of Vegetable Science and Floriculture, CSKHPKV, Palampur (HP) during *Rabi*, 2017-2018. Twenty five garlic genotypes, collected from within and outside state, were evaluated for bulb yield, and yield contributing characters. The experimental results so obtained are presented here after under the following sub-heads:

4.1 Analysis of variance for the experimental design

4.2 Mean performance of genotypes for quantitative traits

4.3 Parameters of variability

4.4 Correlation coefficient studies

4.5 Path coefficient analysis

4.6 Genetic divergence studies using D^2 statistics

4.7 Principal component analysis

4.1 Analysis of variance for the experimental design

The analysis of variance revealed that mean squares due to genotypes were significant (Table 4.1) for all the traits studied, viz., plant height, leaves per plant, leaf length, leaf width at middle portion, pseudo stem length, pseudo stem diameter, bulb polar diameter, bulb equatorial diameter, cloves per bulb, clove weight, clove length, clove polar diameter, clove equatorial diameter, bulb yield per plant, bulb yield per plot, total soluble solids (TSS) and bulbils per plant indicated thereby, the presence of sufficient genetic variability among the genotypes for these traits. The results are in confirmation with the findings of Raja et al. (2018) and Mishra et al. (2018) who observed sufficient genetic diversity amongst the experimental material evaluated.

Table 4.1 Analysis of variance for experimental design

Source of variation/ Trait	Mean squares		
	Replication	**Genotype**	**Error**
df	**2**	**24**	**48**
Plant height	10.06	227.75*	3.52
Leaves per plant	0.0001	1.57*	0.58
Leaf length	8.88	126.68*	1.96
Leaf width at middle portion	0.12	0.67*	0.03
Pseudo stem length	24.28	66.15*	1.40
Pseudo stem diameter	0.06	0.33*	0.02
Bulb polar diameter	9.67	50.81*	2.42
Bulb equatorial diameter	15.34	130.84*	1.86
Cloves per bulb	3.98	32.32*	1.35
Clove weight	0.10	2.47*	0.05
Clove length	0.56	0.90*	0.03
Clove polar diameter	8.52	107.03*	2.07
Clove equatorial diameter	5.12	61.87*	1.54
Bulb yield per plant	11.60	101.59*	3.07
Bulb yield per plot	0.006	0.058*	0.002
TSS	0.50	26.0*	3.74
Bulbils per plant	0.31	3.82*	0.03

*Significant at 5 % level of significance

4.2 Mean performance of genotypes for quantitative traits

In the present investigation, a total of 25 garlic genotypes were evaluated for bulb yield and yield contributing traits against the best check, GHC-1. The results obtained are interpreted separately against the best check for all the traits studied. The mean performance of all the genotypes for different traits are given in Table 4.2 and described here after:

Table 4.2 Mean performance of garlic genotypes for different traits

Genotype	Plant height (cm)	Leaves per plant	Leaf length (cm)	Leaf width at middle portion (cm)	Pseudo stem length (cm)	Pseudo stem diameter (cm)	Bulb polar diameter (mm)	Bulb equatorial diameter (mm)	Cloves per bulb	Clove weight (g)	Clove length (cm)	Clove polar diameter (mm)	Clove equatorial diameter (mm)	Bulb yield per plant (g)	Bulb yield per plot (kg)	TSS (°b)	Bulbils per plant
Yamuna Safed-9	54.27	8.47	39.52	1.08	28.69	1.01	34.40	36.47	7.53	3.09	4.10	32.27	18.59	23.21	0.56	44.44	4.18
Yamuna Safed-4	56.94	7.13	29.59	0.84	24.88	0.91	37.44	32.65	17.60	1.01	3.31	22.07	11.21	17.71	0.42	43.02	3.17
Leda Local Sel.	55.80	8.23	33.36	1.30	20.21	1.00	33.47	39.53	10.37	2.50	4.85	27.39	13.87	22.87	0.62	37.89	0.00
Yamuna Safed-5	54.71	7.67	38.60	1.17	23.88	0.93	27.12	31.31	20.85	1.08	3.33	26.51	10.93	22.51	0.54	40.53	3.77
Bijni Local Sel.	58.60	9.17	32.75	1.16	27.67	1.25	36.23	39.66	16.00	1.90	3.59	37.03	11.61	30.46	0.73	41.49	0.00
Agrifound White	41.61	7.87	28.28	0.93	23.24	0.63	29.33	28.37	10.67	1.47	3.62	31.44	11.73	15.67	0.38	44.77	4.07
Yamuna Safed-3	56.75	7.00	28.21	1.02	24.26	1.00	28.45	34.04	11.00	1.87	3.41	23.71	12.51	20.46	0.49	41.44	3.67
Yamuna Safed-1	50.90	8.37	29.74	1.05	26.26	1.10	30.59	36.66	12.07	1.52	3.41	21.86	10.99	18.40	0.44	42.35	2.83
Agrifound Parvati-2	53.88	9.87	37.34	1.14	17.67	1.16	35.36	40.87	9.87	3.13	3.64	23.25	16.59	30.60	0.73	37.15	3.97
Agrifound Parvati	56.27	8.30	35.54	1.14	13.94	1.24	35.58	40.65	9.20	2.65	3.99	26.39	15.19	24.33	0.59	37.58	3.83
Yamuna Safed-2	37.79	7.77	18.27	0.89	17.16	0.90	25.47	26.65	12.40	1.50	3.27	20.73	9.66	18.51	0.44	42.33	3.67
Yamuna Safed-8	45.00	7.47	24.32	0.85	17.02	1.00	25.69	31.73	11.07	1.77	3.19	18.71	10.40	19.56	0.47	37.47	3.60
Ner Chowk Local Sel.	33.49	7.70	28.36	0.91	17.45	0.90	29.67	26.45	9.70	1.80	3.81	26.33	10.42	17.26	0.41	44.63	3.58
Mahadev Local Sel.	40.46	7.87	28.70	1.05	12.71	0.94	30.78	29.46	7.87	2.38	3.59	24.72	11.54	18.63	0.45	39.16	0.00
Kangra Local Sel.	41.21	7.37	20.26	0.76	15.25	0.95	26.67	25.01	9.33	1.76	2.93	18.45	11.90	16.38	0.39	40.43	2.97
Kanaid Local Sel.	57.85	8.93	35.10	2.70	16.54	2.32	41.04	50.86	6.53	5.37	5.56	46.75	29.93	38.07	0.91	34.00	0.00
Gheru Local Sel.	41.57	7.67	35.98	2.41	25.77	1.21	29.64	27.74	8.67	2.03	3.47	24.74	11.13	17.44	0.42	38.75	3.48
Chambi Local Sel.	52.04	8.37	40.22	1.54	24.21	1.32	33.61	45.93	10.80	3.12	3.83	25.39	17.18	33.33	0.80	41.64	3.83
Biara Local Sel.	42.86	8.40	27.88	1.25	19.02	1.37	30.86	37.07	8.93	2.99	3.57	28.94	18.45	26.20	0.63	41.95	3.51
Kasharala Local Sel.	43.15	7.57	24.68	0.95	19.09	0.96	30.08	27.58	11.20	1.83	3.25	26.24	19.66	20.57	0.49	46.42	3.15
Jhungi Local Sel.	50.59	8.53	38.99	1.42	19.02	1.45	32.99	40.25	11.20	2.32	4.20	31.73	15.95	25.97	0.62	37.02	3.08
Chakar Local Sel.	49.18	9.10	30.79	1.37	22.36	1.39	35.67	39.00	14.93	1.58	3.69	29.72	13.90	23.57	0.57	40.00	0.00
Pungh Local Sel.	60.08	7.83	30.69	1.26	26.39	1.57	33.57	38.96	12.00	2.14	3.45	26.66	18.84	25.43	0.61	42.91	3.37
Badraina Local Sel.	57.50	7.73	31.83	1.29	28.24	1.53	37.39	38.66	7.73	2.50	3.68	26.52	16.54	19.32	0.46	42.60	3.64
GHC-1 (Check)	71.30	9.40	46.37	2.03	23.97	1.32	37.04	40.87	9.65	3.06	3.83	30.65	19.14	29.57	0.71	39.92	0.00
Mean	**50.55**	**8.15**	**31.81**	**1.26**	**21.40**	**1.17**	**32.32**	**35.45**	**11.09**	**2.25**	**3.70**	**27.13**	**14.71**	**23.16**	**0.55**	**40.80**	**2.69**
Range	33.49-71.30	7.00-9.87	18.27-46.37	0.76-2.70	12.71-28.69	0.63-2.32	25.47-41.04	25.01-50.86	6.53-20.85	1.01-5.37	2.93-5.56	18.45-46.75	9.66-29.93	15.67-38.07	0.38-0.91	34.00-46.42	0.00-4.18
SE (m) ±	1.08	0.44	0.81	0.09	0.68	0.08	0.90	0.78	0.67	0.13	0.11	0.83	0.72	1.01	0.02	1.12	0.11
CD (5%)	3.08	1.25	2.30	0.27	1.94	0.23	2.50	2.24	1.91	0.37	0.30	2.36	2.04	2.88	0.07	3.18	0.31
CV (%)	3.71	9.31	4.41	13.04	5.53	12.16	4.81	3.83	10.47	10.21	4.97	5.31	8.44	7.57	7.67	4.74	6.97

4.2.1 Plant height (cm)

The analysis of variance indicated significant variation among the genotypes for plant height with mean values ranging from 33.49 to 71.30 cm. None of the genotypes could excel the standard check variety (GHC-1) for plant height. Maximum plant height was recorded in the genotype, GHC-1 (71.30 cm) followed by Pungh Local Selection (60.08 cm), Bijni Local Selection (58.60 cm), Kanaid Local Selection (57.85 cm), Badraina Local Selection (57.50 cm) and Yamuna Safed-4 (56.94 cm), while minimum plant height was found in Ner Chowk Local Selection (33.49 cm). The mean plant height for genotypes was 50.55 cm. Variability in plant height was due to the inherent genetic make up of the different genotypes. Similar trend for the observations on plant height was earlier reported by Panse et al. (2013) with mean plant height of 62.63 cm and 68.04 cm, respectively in garlic. Bhatt et al. (2017) and Kumar et al. (2017 a) also observed mean plant height of 53.22 cm and 58.70 cm, respectively in the experimental material evaluated.

4.2.2 Leaves per plant

Among the genotypes, number of leaves per plant ranged between 7.00 to 9.87. Maximum number of leaves were recorded in Agrifound Parvati-2 (9.87) which was statistically at par with GHC-1 (9.40), Bijni Local Selection (9.17), Chakar Local selection (9.10) and Kanaid Local Selection (8.93), while minimum number of leaves were recorded in Yamuna Safed-3 (7.00). The genotypes, Kanaid Local Selection (8.93), Jhungi Local Selection (8.53), Yamuna Safed-9 (8.47), Biara Local Selection (8.40), Chambi Local Selection (8.37), Yamuna Safed-1 (8.37) and Agrifound Parvati (8.30) were at par with check, GHC-1 (9.40). The mean number of leaves per plant were 8.15. The variation in number of leaves per plant was due to different genetic architecture of the genotypes used in the present investigation. Enhanced number of leaves may be due to activated physiological process by stimulating factors in the metabolism and growth of the plant. The results are in agreement with the findings of Yadav et al. (2012), Pervin et al. (2014), Khar et al. (2015) and Bhatt et al. (2017) who reported that mean number of leaves per plant were 7.75, 6.16, 7.13, 7.20 and 7.52, respectively in garlic germplasm. Significant variation for mean number of leaves per plant was also reported by Sandhu et al. (2015).

4.2.3 Leaf length (cm)

Leaf length revealed significant variation among the genotypes and ranged between 18.27 to 46.37 cm. None of the genotype could excel the standard check, GHC-1 for leaf length. Maximum leaf length was recorded in GHC-1 (46.37 cm) followed by Chambi Local Selection (40.22 cm), Yamuna Safed-9 (39.52 cm), Jhungi Local Selection (38.99 cm), Yamuna Safed-5 (38.60 cm), Agrifound Parvati-2 (37.34 cm) and Gheru Local Selection (35.98 cm), while minimum was recorded in Yamuna Safed-2 (18.27 cm). The mean leaf length of genotypes was 31.81 cm. Similar observations on leaf length were reported by Panse et al. (2013), Bhatt et al. (2017) and Kumar et al. (2017 a).

4.2.4 Leaf width at middle portion (cm)

Among the genotypes, leaf width at middle portion varied between 0.76 to 2.70 cm. Two genotypes viz., Kanaid Local Selection (2.70 cm) and Gheru Local Selection (2.41 cm) gave significantly higher performance than that of standard check variety, GHC-1 for leaf width at middle portion. Maximum leaf width at middle portion was recorded in Kanaid Local Selection (2.70 cm) followed by Gheru Local Selection (2.41 cm), GHC-1 (2.03 cm), Chambi Local Selection (1.54 cm) and Jhungi Local selection (1.42 cm). Minimum leaf width at middle portion was recorded in Kangra Local Selection (0.76 cm). The mean leaf width at middle portion of the genotypes was 1.26 cm. The results are in accordance with the findings of Panse et al. (2013), Bhatt et al. (2017) and Kumar et al. (2017 a) who observed similar results for leaf width at middle portion in garlic genotypes.

4.2.5 Pseudo stem length (cm)

Among the genotypes, pseudo stem length ranged between 12.71 to 28.69 cm. Maximum pseudo stem length was recorded in Yamuna Safed-9 (28.69 cm) which was statistically at par with Badraina Local Selection (28.24 cm) and Bijni Local Selection (27.67 cm). The genotypes, Yamuna Safed-9 (28.69 cm), Badraina Local Selection (28.24 cm), Bijni Local Selection (27.67 cm), Pungh local Selection (26.39 cm) and Yamuna Safed-1 (26.26 cm) were found significantly superior in performance for pseudo stem length as compared to standard check, GHC-1 (23.97 cm), while check variety, GHC-1 (23.97 cm) was found statistically at par with Gheru

Local Selection (25.77 cm), Yamuna Safed-3 (24.26 cm), Chambi Local Selection (24.21 cm), Yamuna Safed-5 (23.88 cm), Agrifound White (23.24 cm) and Chakar Local Selection (22.36 cm). Minimum pseudo stem length was recorded in Mahadev Local Selection (12.71 cm). The mean pseudo stem length of genotypes was 21.40 cm. These findings are in accordance with the work of Alam et al. (2010), Tsega et al. (2011), Panse et al. (2013) and Vatsyayan et al. (2013) who reported significant variation among the genotypes for pseudo stem length in garlic.

4.2.6 Pseudo stem diameter (cm)

The pseudo stem diameter ranged between 0.63 to 2.32 cm amongst the genotypes evaluated. Maximum pseudo stem diameter was recorded in Kanaid Local Selection (2.32 cm) followed by Pungh Local Selection (1.57 cm), Badraina Local Selection (1.53 cm), Jhungi Local Selection (1.45 cm), Chakar Local Selection (1.39 cm) and Biara Local Selection (1.37 cm). Minimum pseudo stem diameter was recorded in Agrifound White (0.63 cm). The genotypes, Kanaid Local Selection (2.32 cm) and Pungh Local Selection (1.57 cm) were found significantly superior to standard check variety, GHC-1 (1.32 cm), while check variety GHC-1 (1.32 cm) was statistically at par with Badraina Local Selection (1.53 cm), Jhungi Local Selection (1.45 cm), Chakar Local Selection (1.39 cm), Biara Local Selection (1.37 cm) and Chambi Local selection (1.32 cm). The mean pseudo stem diameter of genotypes was 1.17 cm. The findings of Yadav et al. (2012) and Panse et al. (2013) are in close harmony with the results of present study. The mean pseudo stem diameter of 0.88 cm was also recorded by Bhatt et al. (2017) in garlic genotypes.

4.2.7 Bulb polar diameter (mm)

Among the genotypes, bulb polar diameter ranged between 25.47 to 41.04 mm. Maximum bulb polar diameter was recorded in Kanaid Local Selection (41.04 mm) followed by Yamuna Safed-4 (37.44 mm), Badraina Local Selection (37.39 mm), GHC-1 (37.04 mm) and Bijni Local Selection (36.23 mm). Minimum bulb polar diameter was recorded in Yamuna Safed-2 (25.47 mm). The genotype, Kanaid Local Selection (41.04 mm) was significantly superior to standard check variety, GHC-1 (37.04 mm), while Yamuna Safed-4 (37.44 mm), Badraina Local Selection (37.39 mm), Bijni Local Selection (36.23 mm), Chakar Local Selection (35.67 mm) and

Agrifound Parvati-2 (35.36 mm) were found statistically at par with GHC-1 (37.04 mm). The mean bulb polar diameter of genotypes was 32.32 mm. These findings are in accordance with the work of Alam et al. (2010), Tsega et al. (2011), Panse et al. (2013) and Vatsyayan et al. (2013) who reported significant variation among the genotypes for bulb polar diameter in garlic. Yadav et al. (2012) and Kumar et al. (2017 a) recorded mean bulb polar diameter of 36.9 mm and 42.4 mm, respectively in garlic genotypes evaluated.

4.2.8 Bulb equatorial diameter (mm)

The range of bulb equatorial diameter existed between 25.01 to 50.86 mm among the genotypes. Maximum bulb equatorial diameter was recorded in Kanaid Local Selection (50.86 mm) followed by Chambi Local Selection (45.93 mm), GHC-1 (40.87 mm), Agrifound Parvati-2 (40.87 mm), Agrifound Parvati (40.65 mm), Bijni Local Selection (39.66 mm) and Yamuna Safed-1 (36.66 mm). The genotypes, Kanaid Local Selection (50.86 mm) and Chambi Local Selection (45.93 mm) were statistically superior to check, GHC-1 (40.87 mm), while the performance of genotypes, Agrifound Parvati-2 (40.87 mm), Agrifound Parvati (40.65 mm), Jhungi Local Selection (40.25 mm), Bijni Local Selection (39.66 mm), Leda Local Selection (39.53 mm), Chakar Local Selection (39.0 mm), Pungh Local Selection (38.96 mm) and Badraina Local Selection (38.66 mm) were found statistically at par with GHC-1 (40.87 mm). Minimum bulb equatorial diameter was recorded in Kangra Local Selection (25.01 mm), while mean bulb equatorial diameter of genotypes was 35.45 mm. These findings are in conformity with the results of Alam et al. (2010), Tsega et al. (2011), Yadav et al. (2012), Vatsyayan et al. (2013), Panse et al. (2013), Khar et al. (2015) and Sandhu et al. (2015)

4.2.9 Cloves per bulb

Among the genotypes, number of cloves per bulb ranged between 6.53 to 20.85. Maximum number of cloves per bulb was recorded in Yamuna Safed-5 (20.85) followed by Yamuna Safed-4 (17.60), Bijni Local Selection (16.0), Chakar Local Selection (14.93) and Yamuna Safed-2 (12.40), while minimum number of cloves per bulb were recorded in Kanaid Local Selection (6.53). The genotypes, Yamuna Safed-5 (20.85), Yamuna Safed-4 (17.60), Bijni Local Selection (16.0), Chakar Local

Selection (14.93), Yamuna Safed-2 (12.40), Yamuna Safed-1 (12.07) and Pungh Local Selection (12.0) were found statistically superior than standard check variety, GHC-1 (9.65), while genotypes, Kasharala Local Selection (11.20) followed by Jhungi Local Selection (11.20), Yamuna Safed-8 (11.07), Yamuna Safed-3 (11.0), Chambi Local Selection (10.80) and Agrifound White (10.67) were statistically at par with GHC-1 (9.65). The mean number of cloves per bulb was 11.09. Significant variation for number of cloves per bulb was reported by Tsega et al. (2011), Singh et al. (2012 a), Yadav et al. (2012), Panse et al. (2013), Vatsyayan et al. (2013), Pervin et al. (2014) and Kumar et al. (2017 a).

4.2.10 Clove weight (g)

The range of clove weight varied from 1.01 to 5.37 g amongst the genotypes evaluated. Maximum clove weight was recorded in Kanaid Local Selection (5.37 g) followed by Agrifound Parvati-2 (3.13 g), Chambi Local Selection (3.12 g), Yamuna Safed-9 (3.09 g) and GHC-1 (3.06 g), while minimum clove weight was recorded in Yamuna Safed-4 (1.01 g). The genotype, Kanaid Local Selection (5.37 g) was found significantly superior as compared to check variety, GHC-1 (3.06 g). The genotypes, Agrifound Parvati-2 (3.13 g), Chambi Local Selection (3.12 g), Yamuna Safed-9 (3.09 g) and Biara Local Selection (2.99 g) were recorded statistically at par with check variety, GHC-1 (3.06 g). The mean clove weight of genotypes was 2.25. The variability for clove weight in garlic has also been reported earlier by Tsega et al. (2011), Singh et al. (2012 a), Panse et al. (2013) and Sandhu et al. (2015)

4.2.11 Clove length (cm)

Among the genotypes, clove length ranged between 2.93 to 5.56 cm. Maximum clove length was recorded in Kanaid Local Selection (5.56 cm) followed by Leda Local Selection (4.85 cm), Jhungi Local Selection (4.20 cm), Yamuna Safed-9 (4.10 cm) and Agrifound Parvati (3.99 cm), while minimum clove length was recorded in Kangra Local Selection (2.93 cm). The genotypes, Kanaid Local Selection (5.56 cm), Leda Local Selection (4.85 cm) and Jhungi Local Selection (4.20 cm) were found significantly superior to standard check variety, GHC-1 (3.83 cm). The clove length of check variety, GHC-1 (3.83 cm) was found statistically at par with Agrifound Parvati (3.99 cm), Chambi Local Selection (3.83 cm), Ner Chowk Local

Selection (3.81 cm), Chakar Local Selection (3.69 cm), Badraina Local Selection (3.68 cm), Agrifound Parvati-2 (3.64 cm), Agrifound White (3.62 cm) and Bijni Local Selection (3.59 cm). The mean clove length of genotypes was 3.70 cm. The results are in close conformity with the findings of Vatsyayan et al. (2013) and Kumar et al. (2017 a), who reported the mean clove length of 3.61 cm, 2.80 cm and 2.45 cm, respectively in garlic.

4.2.12 Clove polar diameter (mm)

Among the genotypes, clove polar diameter ranged between 18.45 to 46.75 mm. Maximum clove polar diameter was recorded in Kanaid Local Selection (46.75 mm) followed by Bijni Local Selection (37.03 mm), Yamuna Safed-9 (32.27 mm), Jhungi Local Selection (31.73 mm), Agrifound White (31.44 mm) and GHC-1 (30.65 mm), while minimum clove polar diameter was recorded in Kangra Local Selection (18.45 mm). The genotypes, Kanaid Local Selection (46.75 mm) and Bijni Local Selection (37.03 mm) were found statistically superior to standard check variety, GHC-1 (30.65 mm), while the genotypes, Yamuna Safed-9 (32.27 mm), Jhungi Local Selection (31.73 mm), Agrifound White (31.44 mm) and Biara Local Selection (28.94 mm) were found statistically at par with GHC-1 (30.65 mm). The mean clove polar diameter of genotypes was 27.13 mm. The variability for clove polar diameter in garlic has also been reported by Tsega et al. (2011), Singh et al. (2012 a), Panse et al. (2013) and Sandhu et al. (2015)

4.2.13 Clove equatorial diameter (mm)

The clove equatorial diameter ranged between 9.66 to 29.93 mm in the experimental material evaluated. Maximum clove equatorial diameter was recorded in Kanaid Local Selection (29.93 mm) followed by Kasharala Local Selection (19.66 mm), GHC-1 (19.14 mm), Pungh Local Selection (18.84 mm), Yamuna Safed-9 (18.59 mm) and Biara Local Selection (18.45 mm). Minimum clove equatorial diameter was recorded in Yamuna Safed-2 (9.66 mm) which was statistically at par with Yamuna Safed-8 (10.40 mm) and Ner Chowk Local Selection (10.42 mm), while genotypes, Kasharala Local Selection (19.66 mm), Pungh Local Selection (18.84 mm), Yamuna Safed-9 (18.59 mm) and Biara Local Selection (18.45 mm) were statistically at par with standard check variety, GHC-1 (19.14 mm). The mean clove equatorial diameter of genotypes was 14.71 mm. The findings of Vatsyayan et al. (2013) and Kumar et al. (2017 a) are in close conformity with the results of present study who reported mean clove equatorial diameter of 19.3 mm, 11.2 mm and 11.6 mm, respectively in garlic.

4.2.14 Bulb yield per plant (g)

Among the genotypes, bulb yield per plant ranged between 15.67 to 38.07 g. Maximum bulb yield per plant was recorded in Kanaid Local Selection (38.07 g) followed by Chambi Local Selection (33.33 g), Agrifound Parvati-2 (30.60 g), Bijni Local Selection (30.46 g), GHC-1 (29.57 g) and Biara Local Selection (26.20 g), while minimum bulb yield per plant was recorded in Agrifound White (15.67 g). The genotypes, Kanaid Local Selection (38.07 g) and Chambi Local Selection (33.33 g) were found significantly superior than standard check variety, GHC-1 (29.57 g). The genotypes, Agrifound Parvati-2 (30.60 g), Bijni Local Selection (30.46 g) were found statistically at par with standard check variety, GHC-1 (29.57 g). The mean bulb yield per plant of genotypes was 23.16 g. More number of leaves resulted in more production of chlorophyll that ultimately led to more amount of photosynthates and hence more bulb weight. The results of the present investigation are in confirmation with the findings of Gupta et al. (2007), Tsega et al. (2011), Yadav et al. (2012), Sandhu et al. (2015) and Khar et al. (2015).

4.2.15 Bulb yield per plot (kg)

The range of bulb yield per plot existed between 0.38 to 0.91 kg with genotypes evaluated. Maximum bulb yield per plot was recorded in Kanaid Local Selection (0.91 kg) followed by Chambi Local Selection (0.80 kg), Agrifound Parvati-2 (0.73 kg), Bijni Local Selection (0.73 kg), GHC-1 (0.71 kg) and Biara Local Selection (0.63 kg). Minimum bulb yield per plot was recorded in Agrifound White (0.38 kg). The genotypes, Kanaid Local Selection (0.91 kg) and Chambi Local Selection (0.80 kg) were found significantly superior to standard check variety, GHC-1 (0.71 kg). The genotypes, Bijni Local Selection (0.73 kg) and Agrifound Parvati-2 (0.73 kg) were statistically at par with standard check variety, GHC-1 (0.71 kg). The mean bulb yield per plot was 0.55 kg. The results are in conformity with the findings of earlier researchers Gupta et al. (2007), Tsega et al. (2011), Sandhu et al. (2015) and Khar et al. (2015).

4.2.16 TSS (^{0}b)

Among the genotypes, total soluble solids (TSS) ranged between 34.0 to 46.42 ^{0}b. Maximum TSS was recorded in Kasharala Local Selection (46.42 ^{0}b) which was statistically at par with Agrifound White (44.77 ^{0}b), Ner Chowk Local Selection (44.63 ^{0}b) and Yamuna Safed-9 (44.44 ^{0}b) but significantly superior to standard check variety, GHC-1 (39.92 ^{0}b). However, minimum TSS was recorded in Kanaid Local Selection (34.0 ^{0}b). The other genotypes viz., Pungh Local Selection (42.91 ^{0}b), Badraina Local Selection (42.60 ^{0}b), Yamuna Safed-1 (42.35 ^{0}b) and Yamuna Safed-2 (42.33 ^{0}b) were found statistically at par with check variety, GHC-1 (39.92 ^{0}b). The mean performance of genotypes for TSS was 40.80 ^{0}b. Variation for total soluble solids has also been reported by Vatsyayan et al. (2013), Kumar et al. (2017 a) and Bhatt et al. (2017).

4.2.17 Bulbils per plant

Maximum bulbils per plant were recorded in Yamuna Safed-9 (4.18) followed by Agrifound White (4.07), Agrifound Parvati-2 (3.97), Agrifound Parvati (3.83) and Chambi Local Selection (3.83). Minimum bulbils per plant were recorded in Yamuna Safed-1 (2.83). The mean bulbils per plant of genotypes was 2.69. The bulbils were found absent in genotypes GHC-1, Leda Local Selection, Bijni Local Selection, Kanaid Local Selection, Mahadev Local Selection and Chakar Local Selection. The findings of Vatsyayan et al. (2013) and Kumar et al. (2017 a) are in close conformity with the results of present investigation.

4.2.2 Qualitative characters of garlic genotypes

4.2.2.1 Bulb skin colour

Bulb skin colour of different garlic genotypes were categorized as purplish-2, purplish white-6, whitish purple-12 and creamish white-4 and light pink-1.

4.2.2.2 Clove skin colour

Out of 25 genotypes, clove skin colour of different garlic genotypes was categorized as: purplish-6, purplish white-7, creamish white-4, whitish purple-3, two genotypes each of light pink, light brown and single genotype was reddish brown.

Table 4.3 Qualitative characters for different genotypes of garlic

Genotypes	Bulb skin colour	Clove skin colour	Foliage colour	Leaf waxiness	Plant bolting/ Non bolting	Growth habit
Yamuna Safed-1	Whitish purple	Whitish purple	Light green	Present	Present	Erect
Yamuna Safed-2	Creamish white	Whitish purple	Light green	Absent	Present	Erect
Yamuna Safed-3	Whitish purple	Purplish white	Light green	Absent	Present	Erect
Yamuna Safed-4	Whitish purple	Purplish	Light green	Absent	Present	Erect
Yamuna Safed-5	Whitish purple	Purplish white	Light green	Absent	Absent	Semi spreading
Yamuna Safed-8	Light pink	Whitish purple	Light green	Absent	Present	Erect
Yamuna Safed-9	Purplish white	Purplish white	Dark green	Absent	Absent	Semi spreading
Agrifound Parvati	Whitish purple	Light pink	Dark green	Present	Present	Spreading
Agrifound Parvati-2	Whitish purple	Creamish white	Dark green	Present	Present	Semi spreading
Agrifound White	Creamish white	Creamish white	Dark green	Absent	Present	Semi spreading
GHC-1	Whitish purple	Reddish brown	Dark green	Present	Present	Spreading
Leda Local Selection	Whitish purple	Creamish white	Light green	Absent	Present	Erect
Bijni Local Selection	Whitish purple	Light pink	Light green	Absent	Present	Erect
Ner Chowk Local Selection	Purplish white	Purplish	Dark green	Absent	Absent	Semi spreading
Mahadev Local Selection	Creamish white	Purplish	Light green	Absent	Absent	Erect
Kangra Local Selection	Purplish	Purplish	Light green	Absent	Absent	Erect
Kanaid Local Selection	Whitish purple	Creamish white	Dark green	Present	Present	Spreading
Gheru Local Selection	Creamish white	Purplish white	Dark green	Present	Absent	Spreading
Chambi Local Selection	Whitish purple	Light brown	Dark green	Present	Absent	Spreading
Biara Local Selection	Purplish white	Purplish white	Dark green	Absent	Absent	Semi spreading
Kasharala Local Selection	Purplish white	Purplish	Light green	Absent	Absent	Semi spreading
Jhungi Local Selection	Whitish purple	Light brown	Dark green	Present	Absent	Spreading
Chakar Local Selection	Purplish white	Purplish white	Light green	Absent	Absent	Erect
Pungh Local Selection	Purplish white	Purplish	Dark green	Present	Absent	Erect
Badraina Local Selection	Purplish	Purplish white	Light green	Present	Absent	Erect

4.2.2.3 Foliage colour

Among the twenty five genotypes, 12 genotypes were with dark green foliage and remaining were light green in colour.

4.2.2.4 Leaf waxiness

All the genotypes were observed for presence or absence of leaf waxiness in which 10 genotypes possessed leaf waxiness, while leaf waxiness was absent in remaining 15 genotypes.

4.2.2.5 Bolting / Non bolting

Out of 25 genotypes of garlic, 12 exhibited the presence of bolting, while bolting was absent in rest 13 garlic genotypes.

4.2.2.6 Growth habit

Among the genotypes, 12 had shown erect, 7 were semi-spreading and remaining 6 were with spreading type of plant growth habit.

4.2.3 Promising genotypes identified on the basis of mean performance for bulb yield and related traits

Overall, two genotypes viz., Kanaid Local Selection (38.07 g) and Chambi Local Selection (33.33 g) were found superior than standard check variety, GHC-1 (29.57 g) for bulb yield per plant (Table 4.4 and Plate 1); four genotypes for TSS viz., Kasharala Local Selection (46.42 ^{0}b), Agrifound White (44.77 ^{0}b), Ner Chowk Local Selection (44.63 ^{0}b) and Yamuna Safed-9 (44.44 ^{0}b); two genotypes viz., Kanaid Local Selection (0.91 kg), and Chambi Local Selection (0.80 kg) for bulb yield per plot; one genotype namely, Kanaid Local Selection (29.93 mm) for clove equatorial diameter; two genotypes viz., Kanaid Local Selection (46.75 mm) and Bijni Local Selection (37.03 mm) for clove polar diameter; three genotypes viz., Kanaid Local Selection (5.56 cm), Leda Local Selection (4.85 cm) and Jhungi Local Selection (4.20 cm) for clove length; one genotype viz., Kanaid Local Selection (5.37 g) for clove weight; seven genotypes viz., Yamuna Safed-5 (20.85), Yamuna Safed-4 (17.60), Bijni Local Selection (16.0), Chakar Local Selection (14.93), Yamuna Safed-2

Table 4.4 Promising genotypes identified on the basis of mean performance for bulb yield and related traits over standard check (GHC-1) in garlic

Pseudo stem length (cm)	Pseudo stem diameter (cm)	Bulb polar diameter (mm)	Bulb equatorial diameter (mm)	Cloves per bulb	Clove weight (g)	Clove length (cm)	Clove polar diameter (mm)	Clove equatorial diameter (mm)	Bulb yield per plant (g)	Bulb yield per plot (kg)	TSS (^{0}b)
Yamuna Safed-9	Kanaid Local selection	Kanaid Local Selection	Kanaid Local Selection	Yamuna Safed-5	Kanaid Local Selection	Kanaid Local Selection	Kanaid Local Selection	Kanaid Local Selection	Kanaid Local Selection	Kanaid Local Selection	Kasharala Local Selection
Badraina Local Selection	Pungh Local Selection		Chambi Local Selection	Yamuna Safed-4		Leda Local Selection	Bijni Local Selection		Chambi Local Selection	Chambi Local Selection	Agrifound White
Bijni Local Selection				Bijni Local Selection		Jhungi Local Selection					Ner Chowk Local Selection
Pungh Local Selection				Chakar Local Selection							Yamuna Safed-9
Yamuna Safed-1				Yamuna Safed-2							
				Yamuna Safed-1							
				Pungh Local Selection							

Plate 1 Promising genotypes identified on the basis of mean performance for bulb yield and related traits

(12.40), Yamuna Safed-1 (12.07) and Pungh Local Selection (12.0) for number of cloves per bulb; two genotypes viz., Kanaid Local Selection (50.86 mm) and Chambi Local Selection (45.93 mm) for bulb equatorial diameter; one genotype viz., Kanaid Local Selection (41.04 mm) for bulb polar diameter; two genotypes viz., Kanaid Local Selection (2.32 cm) and Pungh Local Selection (1.57 cm) for pseudo stem diameter; five genotypes viz., Yamuna Safed-9 (28.69 cm), Badraina Local Selection (28.24 cm), Bijni Local Selection (27.67 cm), Pungh Local Selection (26.39 cm) and Yamuna Safed-1 (26.26 cm) were found superior for pseudo stem length. However, none of the genotypes could surpass standard check variety, GHC-1 for plant height, leaves per plant, leaf length, leaf width at middle portion and number of bulbils per plant.

4.3 Parameters of variability

The knowledge of phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) is helpful in predicting the amount of variation present in the given genetic stock which in turn helps in formulating an efficient breeding programme. The estimates of PCV were higher than corresponding GCV for all the traits studied which indicated that the apparent variation was not due to genotypes alone but also due to the influence of environment. Therefore, caution has to be exercised in making selection for these traits on the basis of phenotype alone as environmental variation is unpredictable in nature. The estimates of mean, range and parameters of variability viz., phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) along with heritability in broad sense (h^2_{bs}) and genetic advance (GA) expressed as percentage of mean (Genetic gain) for different traits are presented in the Table 4.5 and described here after:

4.3.1 Phenotypic coefficient of variation (PCV)

An assessment of variability parameters revealed that there was lot of variation among the genotypes. In general, the magnitude of phenotypic coefficients of variation (PCV) was higher than their respective genotypic coefficients of variation (GCV), indicating considerable influence of environment on the performance of genotypes.

Table 4.5 Estimates of phenotypic, genotypic coefficients of variation, heritability and genetic gain for different traits in garlic

Trait	Mean ± SE (m)	Range	PCV (%)	GCV (%)	Heritability (h^2bs)	Genetic gain
Plant height	50.55 ± 1.08	33.49-71.30	17.50	17.10	95.51	34.43
Leaves per plant	8.15 ± 0.44	7.00-9.87	11.67	7.05	36.43	8.76
Leaf length	31.81 ± 0.81	18.27-46.37	20.74	20.27	95.49	40.80
Leaf width at middle portion	1.26 ± 0.09	0.76-2.70	39.10	36.86	88.88	71.58
Pseudo stem length	21.40 ± 0.68	12.71-28.69	22.41	21.71	93.91	43.35
Pseudo stem diameter	1.17 ± 0.08	0.63-2.32	30.02	27.45	83.6	51.69
Bulb polar diameter	32.32 ± 0.90	25.47-41.04	13.32	12.42	86.95	23.86
Bulb equatorial diameter	35.45 ± 0.78	25.01-50.86	18.88	18.49	95.87	37.30
Cloves per bulb	11.09 ± 0.67	6.53-20.85	30.82	28.98	88.46	56.16
Clove weight	2.25 ± 0.13	1.01-5.37	41.02	39.73	93.80	79.27
Clove length	3.70 ± 0.11	2.93-5.56	15.33	14.50	89.48	28.26
Clove polar diameter	27.13 ± 0.83	18.45-46.75	22.44	21.80	94.41	43.64
Clove equatorial diameter	14.71 ± 0.72	9.66-29.93	31.62	30.48	92.87	60.50
Bulb yield per plant	23.16 ± 1.01	15.67-38.07	25.87	24.74	91.43	48.73
Bulb yield per plot	0.55 ± 0.02	0.38-0.91	25.90	24.74	91.23	48.68
TSS	40.80 ± 1.12	34.00-46.42	8.19	6.68	66.48	11.21
Bulbils per plant	2.69 ± 0.11	0.00-4.18	42.22	41.72	97.67	84.38

The phenotypic coefficients of variation ranged from 8.19 % for TSS to 42.22 % for bulbils per plant. The highest phenotypic coefficients of variation was observed for bulbils per plant (42.22 %) followed by clove weight (41.02 %), leaf width at middle portion (39.10 %), clove equatorial diameter (31.62 %), cloves per bulb (30.82 %) and pseudo stem diameter (30.02 %), while bulb yield per plot (25.90 %), bulb yield per plant (25.87 %), clove polar diameter (22.44 %), pseudo stem length (22.41 %) and leaf length (20.74 %) exhibited moderate phenotypic coefficients of variation.

The remaining characters viz., bulb equatorial diameter (18.88 %), plant height (17.50 %), clove length (15.33 %), bulb polar diameter (13.32 %), leaves per plant (11.67 %) and TSS (8.19 %) showed low phenotypic coefficient of variation. The results are in line with the finding of Shigwedha (2009), Tsega et al. (2011), Vatsyayan et al. (2013), Khar et al. (2015), Kumar et al. (2017 b) and Bhatt et al. (2017) who recorded high estimates of phenotypic and genotypic coefficients of variation for bulb yield per plot. Similarly, higher magnitude of phenotypic and genotypic coefficients of variation were also observed by Singh et al. (2012 b) for clove weight. Results of the present study are analogous with the findings of Shigwedha (2009) who recorded high phenotypic and genotypic coefficients of variation for different characters in garlic.

4.3.2 Genotypic coefficient of variation (GCV)

The genotypic coefficients of variation varied from 6.68 % for TSS to 41.72 % for bulbils per plant. The highest genotypic coefficients of variation were observed for bulbils per plant (41.72 %) followed by clove weight (39.73 %), leaf width at middle portion (36.86 %), clove equatorial diameter (30.48 %), while cloves per bulb (28.98 %), bulb yield per plant, bulb yield per plot (24.74 %), clove polar diameter (21.80 %), pseudo stem length (21.71 %) and leaf length (20.27 %) exhibited moderate genotypic coefficients of variation. The remaining traits such as bulb equatorial diameter (18.49 %), plant height (17.10 %), clove length (14.50 %), bulb polar diameter (12.42 %), leaves per plant (7.05 %) and TSS (6.68 %) displayed low genotypic coefficients of variation. The findings of the present investigation are in accordance with the results obtained by Shridhar (2002), Agarwal and Tiwari (2004), Singh and Chand (2004), Jabeen et al. (2010), Tsega et al. (2010), Singh et al. (2012 b) and Panse et al. (2013).

4.3.3 Heritability in broad sense (h^2_{bs})

When a major portion of variability is due to heritable variation it could be measured in terms of degree in which it is transmitted to the progeny, the term referred to as heritability. Burton and De Vane (1953) has suggested that genetic coefficients of variability together with the heritability estimates would provide more reliable estimates of expected genetic gain through selection. Heritability in broad sense is of tremendous significance to the breeders as its magnitude indicates reliability with which a genotype can be recognized by its phenotypic expression (Lush, 1940). The information on heritability estimates is useful in studying the inheritance of quantitative traits as well as for planning breeding programmes with desired degree of expected genetic progress.

The heritability estimates were high for bulbils per plant (97.67 %), bulb equatorial diameter (95.87 %), plant height (95.51 %), leaf length (95.49 %), clove polar diameter (94.41 %), pseudo stem length (93.91 %), clove weight (93.80 %), clove equatorial diameter (92.87 %), bulb yield per plant (91.43 %), bulb yield per plot (91.23 %), clove length (89.48 %), leaf width at middle portion (88.88 %), cloves per bulb (88.46 %), bulb polar diameter (86.95 %) and pseudo stem diameter (83.6 %). However, moderate heritability estimates were recorded for TSS (66.48 %). Low heritability estimates were observed for leaves per plant (36.43 %). The results are in close proximity with the findings of Kohli and Prabal (2000), Shridhar (2002) and Singh and Chand (2004) who observed low to high heritability estimates for bulb yield and yield contributing traits in garlic.

4.3.4 Genetic advance as percentage of mean (Genetic gain)

For an effective selection programme, knowledge of the estimates of heritability alone is not sufficient and genetic advance, if studied along with heritability is more useful (Johnson et al. 1955). Thus, the genetic gain has an added edge over heritability as a guiding factor to breeders in various selection programmes. Genetic advance may or may not be in proportion to genetic variability and heritability estimates, because both heritability and high genetic variability are important to obtain higher genetic gain.

Based on the estimates of heritability (broad sense), expected genetic advance was computed on the hypothetical selection at 5 per cent best individual ($k = 2.06$). Due to masking influence of environment upon character concerned, values of genetic advance exhibited high fluctuations. Therefore, to attain relative comparison of the characters in relation to environment, genetic advance as percentage of mean was calculated to predict the genetic gain.

The highest estimates of genetic advance as percentage of mean were recorded for bulbils per plant (84.38 %), clove weight (79.27 %), leaf width at middle portion (71.58 %), clove equatorial diameter (60.50 %), cloves per bulb (56.16 %) and pseudo stem diameter (51.69 %), while bulb yield per plant (48.73 %), bulb yield per plot (48.68 %), clove polar diameter (43.64 %), pseudo stem length (43.35 %), leaf length (40.80 %), bulb equatorial diameter (37.30 %), plant height (34.43 %) and clove length (28.26 %) exhibited moderate values for genetic advance. However, the traits like bulb polar diameter (23.86 %), TSS (11.21 %) and leaves per plant (8.76 %) had the lowest estimates of genetic advance as percentage of mean (genetic gain)

For predicting reliable estimates of additive and non-additive effects, heritability should be considered in conjunction with genetic advance. The high heritability coupled high genetic advance as percentage of mean was observed for bulbils per plant, clove weight, leaf width at middle portion, clove equatorial diameter, cloves per bulb and pseudo stem diameter. This indicated the presence of additive gene effects in the inheritance of these traits.

High heritability with moderate genetic advance was observed for bulb yield per plant, bulb yield per plot, clove polar diameter, pseudo stem length, leaf length, bulb equatorial diameter, plant height and clove length. High heritability coupled with low genetic gain was observed for bulb polar diameter. However, TSS displayed moderate heritability estimates with low genetic gain.

Low heritability coupled with low genetic gain was observed for leaves per plant indicated non-additive gene action and lateral selection in such a situation would be more effective in its improvement. The results of present investigation indicated presence of additive gene action in the inheritance of most of the traits studied, offering ample scope for improvement of these traits through selection. The results of the present study are in accordance with the findings of Gupta et al. (2007), Singh et al. (2012 b), Dhall and Brar (2013), Vatsyayan et al. (2013), Pervin et al. (2014) and Sandhu et al. (2015) who observed high heritability estimates coupled with low to high genetic gain for bulb yield and yield related traits in garlic.

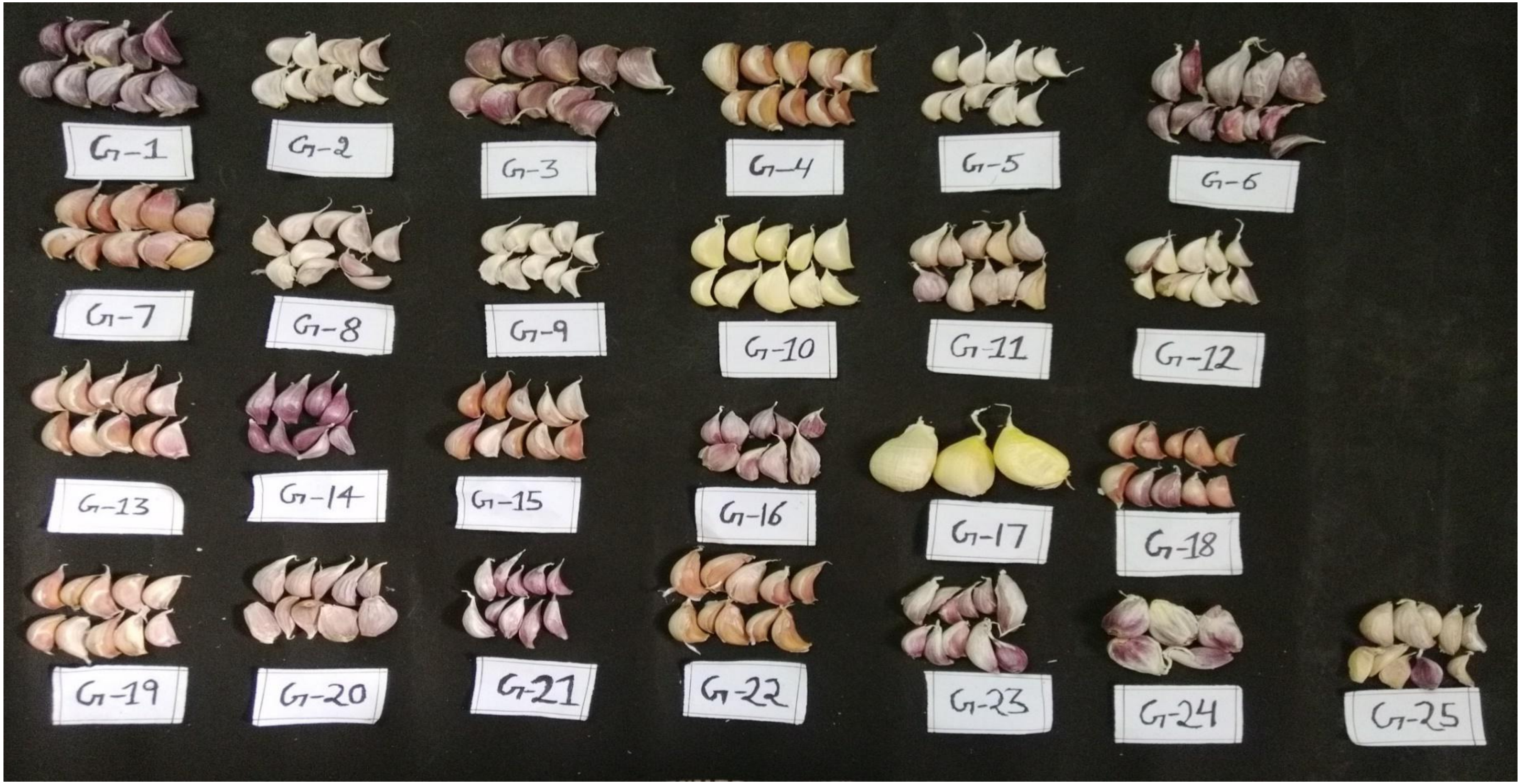


Plate 2 Variation in garlic genotypes for clove size and skin colour

4.4 Correlation coefficient analysis

Correlation coefficient is 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 a complex character controlled by several yield contributing components and is highly influenced by environmental factors, consequently selection based on yield alone will not be much effective. Hence, knowledge of association of characters with yield is important for making selection in the breeding programme.

In the present study, the estimates of phenotypic and genotypic correlation coefficients were observed for different characters and same have been presented in Table 4.6. The estimates of genotypic correlations, in general, were higher than their respective phenotypic correlations for all the traits, indicating inherent relationship. Genotypic correlation provides measure of genetic association between traits and is more reliable than phenotypic correlation and these along with observed correlations help to identify the traits to be considered in breeding programmes.

4.4.1 Bulb yield per plant

Bulb yield per plant had positive and significant correlation with bulb equatorial diameter, clove weight, clove equatorial diameter, pseudo stem diameter, clove polar diameter, bulb polar diameter, clove length, leaf length, leaf width at middle portion, plant height and leaves per plant, whereas negative and significant correlation with TSS and bulbils per plant.

4.4.2 Plant height (cm)

Plant height had positive and significant association with bulb equatorial diameter, bulb polar diameter, leaf length, pseudo stem length, pseudo stem diameter, clove equatorial diameter, leaf width at middle portion, clove polar diameter, leaves per plant, clove weight, clove length, whereas it had negative and significant correlation with bulbils per plant.

Table 4.6 Estimates of Phenotypic (P) and genotypic (G) coefficients of correlation among different characters in garlic

Character		LPP	LL (cm)	LWMP (cm)	PSL (cm)	PSD(cm)	BPD (mm)	BED (mm)	CPB	CW (g)	CL (cm)	CPD (mm)	CED (mm)	TSS	BPP	BYPP
PH	P	0.32*	0.64*	0.35*	0.45*	0.43*	0.65*	0.69*	0.15	0.31*	0.30*	0.35*	0.42*	-0.21	-0.30*	0.558*
	G	0.50	0.67	0.35	0.47	0.46	0.69	0.71	0.15	0.34	0.34	0.37	0.44	-0.29	-0.30	0.589
LPP	P		0.43*	0.32*	0.02	0.34*	0.47*	0.51*	-0.06	0.37*	0.36*	0.40*	0.32*	-0.34*	-0.35*	0.542*
	G		0.73	0.51	0.01	0.57	0.72	0.82	-0.19	0.72	0.56	0.65	0.56	-0.45	-0.55	0.926
LL (cm)	P			0.55*	0.34*	0.35*	0.54*	0.62*	-0.19	0.42*	0.46*	0.45*	0.38*	-0.30*	-0.16	0.572*
	G			0.59	0.36	0.37	0.60	0.64	-0.03	0.47	0.48	0.45	0.40	-0.33	-0.17	0.607
LWMP (cm)	P				0.12	0.70*	0.49*	0.51*	-0.26	0.61*	0.56*	0.58*	0.58*	-0.44*	-0.38*	0.570*
	G				0.12	0.76	0.50	0.56	-0.35	0.70	0.65	0.62	0.61	-0.59	-0.40	0.585
PSL (cm)	P					0.03	0.23	0.17	0.29	-0.19	-0.12	0.14	-0.02	0.37*	0.11	-0.026
	G					0.05	0.24	0.17	0.30	-0.18	-0.11	0.14	-0.02	0.48	0.12	0.01
PSD(cm)	P						0.60*	0.73*	-0.26	0.68*	0.56*	0.60*	0.73*	-0.42*	-0.32*	0.650*
	G						0.67	0.80	-0.32	0.79	0.65	0.66	0.81	-0.58	-0.36	0.755
BPD (mm)	P							0.74*	-0.15	0.53*	0.57*	0.60*	0.60*	-0.20	-0.42*	0.612*
	G							0.80	-0.16	0.62	0.65	0.65	0.65	-0.30	-0.45	0.657
BED (mm)	P								-0.13	0.70*	0.66*	0.59*	0.66*	-0.44*	-0.34*	0.848*
	G								-0.16	0.73	0.70	0.60	0.70	-0.53	-0.34	0.902
CPB	P									-0.64*	-0.36*	-0.13	-0.40*	0.17	0.00	-0.054
	G									-0.66	-0.40	-0.17	-0.47	0.21	0.00	-0.133
CW (g)	P										0.72*	0.60*	0.81*	-0.43*	-0.27	0.735*
	G										0.80	0.66	0.89	-0.56	-0.29	0.790
CL (cm)	P											0.72*	0.63*	-0.46*	-0.44*	0.606*
	G											0.77	0.66	-0.55	-0.46	0.663
CPD (mm)	P												0.66*	-0.19	-0.47*	0.622*
	G												0.69	-0.26	-0.48	0.664
CED (mm)	P													-0.21	-0.22	0.693*
	G													-0.28	-0.22	0.741
TSS	P														0.36*	-0.403*
	G														0.41	-0.555
BPP	P															-0.399*
	G															-0.401

*Significant at 5% level of significance

PH- Plant height, LPP- Leaves per plant, LL-Leaf length, LWMP- Leaf width at middle portion, PSL- Pseudo stem length, PSD- Pseudo stem diameter, BPP- Bulb polar diameter, BED- Bulb equatorial diameter, CPB- Cloves per bulb, CW- Clove weight, CL- Clove length, CPD- Clove polar diameter, CEC- Clove equatorial diameter, TSS- Total soluble solids, BPP- Bulbils per plant, BYPP- Bulb yield per plant.

4.4.3 Leaves per plant

Leaves per plant exhibited positive and significant association with bulb equatorial diameter, bulb polar diameter, leaf length, clove polar diameter, clove weight, clove length, pseudo stem diameter, leaf width at middle portion and clove equatorial diameter, while negative and significant association with bulbils per plant and TSS.

4.4.4 Leaf length (cm)

Leaf length displayed significant positive association with bulb equatorial diameter, leaf width at middle portion, bulb polar diameter, clove length, clove polar diameter, clove weight, clove equatorial diameter, pseudo stem diameter and pseudo stem length, while significant negative association with TSS.

4.2.5 Leaf width at middle portion (cm)

Leaf width at middle portion expressed positive and significant association with pseudo stem diameter, clove weight, clove polar diameter, clove equatorial diameter, clove length, bulb equatorial diameter and bulb polar diameter, while it expressed negative and significant association with TSS and bulbils per plant.

4.2.6 Pseudo stem length (cm)

Pseudo stem length had positive and significant association with TSS.

4.2.7 Pseudo stem diameter (cm)

Pseudo stem diameter depicted significant positive association with bulb equatorial diameter, clove equatorial diameter, clove weight, bulb polar diameter, clove polar diameter and clove length, while significant and negative association was recorded with TSS and bulbils per plant.

4.2.8 Bulb polar diameter (mm)

Bulb polar diameter exhibited positive and significant association with bulb equatorial diameter, clove equatorial diameter, clove polar diameter, clove length and clove weight, while negative and significant association was recorded with bulbils per plant.

4.2.9 Bulb equatorial diameter (mm)

Bulb equatorial diameter had positive and significant association with clove weight, clove length, clove equatorial diameter and clove polar diameter, while negative and significant association was recorded with TSS and bulbils per plant.

4.2.10 Cloves per bulb

Cloves per bulb displayed negative and significant association with clove weight, clove equatorial diameter and clove length only.

4.2.11 Clove weight (g)

Clove weight had positive and significant association with clove equatorial diameter, clove length, clove polar diameter, while it had negative and significant association with TSS.

4.2.12 Clove length (cm)

Clove length had positive and significant association with clove polar diameter and clove equatorial diameter, while negative and significant association was recorded with TSS and bulbils per plant.

4.2.13 Clove polar diameter (mm)

Clove polar diameter had positive and significant association with clove equatorial diameter, whereas negative and significant association was recorded with bulbils per plant.

4.2.14 TSS (^{0}b)

TSS had positive and significant association with bulbils per plant only.

The results of the present investigation confirmed the findings of earlier researchers viz., Agarwal and Tiwari (2009), Singh et al. (2013 a), Panse et al. (2013) and Ijaz et al. (2015), who observed significant positive association of plant height, bulb length, bulb equatorial diameter, clove weight, days to maturity and neck thickness with bulb yield in garlic.

4.5 Path coefficient analysis

Path coefficient analysis depicts the effects of different independent characters individually and in combination with other characters on the expression of yield. It is an important tool for partitioning the correlation coefficients into direct and indirect effects of independent variables on a dependant variable. It provides an effective means for critical examination of specific force action to produce a given correlation and measure the relative importance of each factor.

Correlation coefficients are quite helpful in determining the components of a complex trait like yield but an exact picture of the relative importance of direct and indirect influence of each component trait is not provided by such studies as these estimates provide nature and magnitude but not its cause. Path coefficient (Wright, 1921; Dewey and Lu, 1959) under such circumstances plays an important role in partitioning the correlations into direct and indirect effects of a specific causal factor and in determining the degree of relationship between dependent trait and its component factors and also permits critical examination of specific factors that provide a given correlation. Therefore, in order to find out the direct and indirect contribution of different traits towards bulb yield per plant, the path coefficient analysis was done.

When a dependent character is to be improved, which is governed by many independent characters through direct or indirect effects of other characters, then sometimes even character showing significant correlation with the yield may not be considered for improvement as its correlation with yield may be due to the indirect effects of this trait through other characters. Under such circumstances, it is always appropriate to split the correlation values into direct and indirect effects through path coefficient analysis. Path coefficient analysis provides better means for selection by resolving the correlation coefficients of yield and its components into direct and indirect effects. In the present study, bulb yield per plant was taken as dependant variable and rest of the traits were considered as independent variables and their direct and indirect effects both at phenotypic and genotypic levels are presented in Table 4.7.

4.5.1 Estimates of direct and indirect effects at phenotypic and genotypic level

At phenotypic level, the direct positive effects of different traits on bulb yield per plant could be arranged in the following descending order: clove weight, bulb equatorial diameter, cloves per bulb, leaf width at middle portion, TSS, leaves per plant, clove equatorial diameter, leaf length and clove polar diameter. However, pseudo stem diameter, clove length, bulb polar diameter, pseudo stem length, bulbils per plant and plant height had negative direct effects on bulb yield per plant. At genotypic level, the estimates of direct effects revealed that clove weight, bulb equatorial diameter, cloves per bulb, clove polar diameter, leaf length, pseudo stem length and clove equatorial diameter had positive direct effects on bulb yield per plant. The traits like, clove length, bulb polar diameter, bulbils per plant, pseudo stem diameter, plant height and leaf width at middle portion had negative direct effects on bulb yield per plant.

The plant height exhibited positive indirect effects via bulb equatorial diameter, clove weight, cloves per bulb, leaf width at middle portion, leaves per plant, clove equatorial diameter, bulbils per plant and leaf length, whereas negative indirect effects via bulb polar diameter, pseudo stem diameter, pseudo stem length, clove length and TSS. However, at genotypic level, it showed positive indirect contribution through bulb equatorial diameter, clove weight, cloves per bulb, leaf length and bulbils per plant, while negative indirect effects via bulb polar diameter, clove length, pseudo stem diameter and leaf width at middle portion.

At phenotypic level, number of leaves per plant had positive indirect effects via bulb equatorial diameter, clove weight, leaf width at middle portion, clove equatorial diameter, bulbils per plant, leaf length and clove polar diameter, while negative indirect effects via bulb polar diameter, pseudo stem diameter, clove length, TSS, cloves per bulb, plant height and clove polar diameter. At genotypic level, it revealed positive indirect effects via clove weight, bulb equatorial diameter, bulbils per plant, clove polar diameter and leaf length, while negative indirect effects via bulb polar diameter, clove length, cloves per bulb, pseudo stem diameter and plant height.

The trait, leaf length depicted positive indirect effects via bulb equatorial diameter, clove weight, leaf width at middle portion, leaves per plant, clove equatorial diameter, bulbils per plant and clove polar diameter, while negative indirect effects via bulb polar diameter, clove length, pseudo stem diameter, pseudo stem length, TSS, plant height and cloves per bulb at phenotypic level. However, leaf length had positive indirect effects via clove weight, bulb equatorial diameter, clove polar diameter, leaves per plant and bulbils per plant, while negative indirect effects via bulb polar diameter, clove length, plant height, leaf width at middle portion and pseudo stem diameter at genotypic level.

At phenotypic level, leaf width at middle portion expressed positive indirect effects via clove weight, bulb equatorial diameter, clove equatorial diameter, leaves per plant and bulbils per plant, while negative indirect effects via cloves per bulb, pseudo stem diameter, clove length, bulb polar diameter, TSS, pseudo stem length and plant height. At genotypic level, the character expressed positive indirect effects via clove weight, bulb equatorial diameter, clove polar diameter, bulbils per plant and leaf length, while negative indirect effects via clove length, cloves per bulb, pseudo stem diameter and plant height.

The trait, pseudo stem length had positive indirect effects with cloves per bulb, bulb equatorial diameter, TSS, leaf width at middle portion, leaf length, leaves per plant and clove polar diameter, while negative indirect effects via clove weight, bulb polar diameter, clove length, plant height, bulbils per plant, pseudo stem diameter and clove equatorial diameter at phenotypic level. The trait, pseudo stem length had positive indirect effects via cloves per bulb, bulb equatorial diameter, clove length, leaf length and clove polar diameter, while negative indirect effects via clove weight, bulb polar diameter, plant height, TSS and bulbils per plant at genotypic level.

Table 4.7 Estimates of direct and indirect effects of different characters on bulb yield of garlic

Character		PH	LPP	LL (cm)	LWMP (cm)	PSL (cm)	PSD (cm)	BPD (mm)	BED (mm)	CPB	CW (g)	CL (cm)	CPD (mm)	CED (mm)	TSS (^{0}B)	BPP	BYPP
PH	P	**-0.023**	0.038	0.014	0.050	-0.055	-0.063	-0.084	0.377	0.074	0.240	-0.043	0.004	0.033	-0.024	0.020	0.558*
	G	**-0.109**	0.019	0.057	-0.036	0.020	-0.061	-0.180	0.467	0.064	0.326	-0.102	0.046	0.017	0.012	0.049	0.589
LPP	P	-0.007	**0.118**	0.009	0.046	-0.002	-0.050	-0.060	0.283	-0.030	0.272	-0.050	0.004	0.026	-0.041	0.024	0.542*
	G	-0.054	**0.038**	0.063	-0.052	0.001	-0.075	-0.188	0.538	-0.079	0.689	-0.165	0.082	0.021	0.018	0.089	0.926
LL	P	-0.015	0.051	**0.021**	0.079	-0.042	-0.051	-0.071	0.340	-0.010	0.323	-0.064	0.005	0.030	-0.035	0.011	0.572*
	G	-0.073	0.028	**0.086**	-0.060	0.015	-0.049	-0.156	0.417	-0.013	0.441	-0.141	0.057	0.015	0.013	0.027	0.607
LWMP	P	-0.008	0.038	0.012	**0.144**	-0.015	-0.103	-0.063	0.283	-0.130	0.465	-0.079	0.006	0.046	-0.052	0.026	0.570*
	G	-0.038	0.019	0.050	**-0.103**	0.005	-0.100	-0.131	0.364	-0.145	0.664	-0.191	0.079	0.023	0.024	0.065	0.585
PSL	P	-0.010	0.002	0.007	0.018	**-0.122**	-0.005	-0.030	0.091	0.144	-0.139	-0.017	0.002	-0.002	0.043	-0.008	-0.026
	G	-0.051	0.001	0.031	-0.013	**0.042**	-0.006	-0.064	0.110	0.128	-0.179	0.033	0.018	-0.001	-0.020	-0.019	0.01
PSD	P	-0.010	0.040	0.007	0.101	-0.004	**-0.146**	-0.079	0.402	-0.129	0.510	-0.079	0.007	0.058	-0.050	0.022	0.650*
	G	-0.050	0.022	0.032	-0.078	0.002	**-0.132**	-0.181	0.521	-0.134	0.749	-0.191	0.083	0.030	0.023	0.059	0.755
BPD	P	-0.015	0.055	0.012	0.070	-0.029	-0.089	**-0.129**	0.409	-0.058	0.405	-0.079	0.007	0.048	-0.024	0.029	0.612*
	G	-0.075	0.028	0.051	-0.052	0.010	-0.092	**-0.260**	0.523	-0.068	0.593	-0.194	0.083	0.024	0.013	0.073	0.657
BED	P	-0.016	0.061	0.013	0.074	-0.020	-0.107	-0.096	**0.547**	-0.068	0.525	-0.093	0.006	0.052	-0.053	0.023	0.848*
	G	-0.078	0.032	0.055	-0.057	0.007	-0.106	-0.209	**0.651**	-0.066	0.700	-0.208	0.077	0.026	0.022	0.056	0.902
CPB	P	-0.003	-0.007	0.000	-0.037	-0.035	0.038	0.015	-0.074	**0.501**	-0.488	0.050	-0.001	-0.033	0.020	0.000	-0.054
	G	-0.017	-0.007	-0.003	0.036	0.013	0.043	0.042	-0.103	**0.418**	-0.627	0.121	-0.021	-0.018	-0.009	-0.001	-0.133
CW (g)	P	-0.007	0.043	0.009	0.089	0.023	-0.099	-0.070	0.381	-0.325	**0.753**	-0.101	0.007	0.064	-0.051	0.019	0.735*
	G	-0.037	0.028	0.040	-0.072	-0.008	-0.104	-0.162	0.478	-0.275	**0.952**	-0.235	0.083	0.033	0.023	0.046	0.790
CL	P	-0.007	0.042	0.010	0.081	0.015	-0.082	-0.073	0.361	-0.177	0.543	**-0.140**	0.008	0.050	-0.055	0.030	0.606*
	G	-0.038	0.021	0.041	-0.066	-0.005	-0.086	-0.170	0.458	-0.170	0.755	**-0.296**	0.098	0.025	0.022	0.074	0.663
CPD	P	-0.008	0.048	0.010	0.083	-0.017	-0.088	-0.078	0.320	-0.067	0.450	-0.102	**0.011**	0.051	-0.023	0.032	0.622*
	G	-0.040	0.025	0.039	-0.064	0.006	-0.087	-0.171	0.394	-0.071	0.621	-0.229	**0.126**	0.026	0.011	0.078	0.664
CED	P	-0.010	0.039	0.008	0.083	0.003	-0.107	-0.078	0.360	-0.204	0.612	-0.089	0.007	**0.079**	-0.025	0.015	0.693*
	G	-0.048	0.021	0.034	-0.063	-0.001	-0.108	-0.170	0.458	-0.196	0.839	-0.196	0.087	**0.037**	0.011	0.036	0.741
TSS	P	0.005	-0.041	-0.006	-0.063	-0.045	0.061	0.026	-0.242	0.085	-0.324	0.065	-0.002	-0.017	**0.119**	-0.024	-0.403*
	G	0.031	-0.017	-0.028	0.060	0.020	0.076	0.080	-0.346	0.088	-0.530	0.163	-0.033	-0.011	**-0.041**	-0.067	-0.555
BPP	P	-0.007	-0.041	-0.004	-0.055	-0.014	0.048	0.055	-0.187	0.001	-0.208	0.062	-0.005	-0.018	0.042	**-0.068**	-0.399*
	G	0.033	-0.021	-0.015	0.041	0.005	0.048	0.118	-0.226	0.002	-0.275	0.136	-0.061	-0.008	-0.017	**-0.161**	-0.401

Residual effects (P) = 0.086; (G) = 0.022 *Significant at 5% level of significance

PH- Plant height, LPP- Leaves per plant, LL-Leaf length, LWMP- Leaf width at middle portion, PSL- Pseudo stem length, PSD- Pseudo stem diameter, BPP- Bulb polar diameter, BED- Bulb equatorial diameter, CPB- Cloves per bulb, CW- Clove weight, CL- Clove length, CPD- Clove polar diameter, CEC- Clove equatorial diameter, TSS- Total soluble solids, BPP- Bulbils per plant, BYPP- Bulb yield per plant.

At phenotypic level, pseudo stem diameter had positive indirect effects through clove weight, bulb equatorial diameter, leaf width at middle portion, clove equatorial diameter, leaves per plant, bulbils per plant, leaf length and clove polar diameter, while negative indirect effects through cloves per bulb, bulb polar diameter, clove length, TSS, plant height and pseudo stem length. At genotypic level, pseudo stem diameter had positive indirect effects through clove weight, bulb equatorial diameter, clove polar diameter, bulbils per plant and leaf length, while negative indirect effects through clove length, bulb polar diameter, cloves per bulb, leaf width at middle portion and plant height.

Bulb polar diameter displayed positive indirect effects through bulb equatorial diameter, clove weight, leaf width at middle portion, leaves per plant, clove equatorial diameter, bulbils per plant and leaf length, while negative indirect effects through pseudo stem diameter, clove length, cloves per bulb, pseudo stem length, TSS and plant height at phenotypic level. Bulb polar diameter had positive indirect effects at genotypic level through clove weight, bulb equatorial diameter, clove polar diameter, bulbils per plant and leaf length, while negative indirect effects through clove length, pseudo stem diameter, plant height, cloves per bulb and leaf width at middle portion.

At phenotypic level, bulb equatorial diameter had positive indirect effects via clove weight, leaf width at middle portion, leaves per plant, clove equatorial diameter, bulbils per plant and leaf length, while negative indirect effects via pseudo stem diameter, bulb polar diameter, clove length, cloves per bulb, TSS, pseudo stem length and plant height. At genotypic level, bulb equatorial diameter had positive indirect effects via clove weight, clove polar diameter, bulbils per plant, leaf length and leaves per plant, while negative indirect effects via bulb polar diameter, clove length, pseudo stem diameter, plant height and cloves per bulb.

Cloves per bulb exhibited positive indirect effects via clove length, pseudo stem diameter, TSS and bulb polar diameter, while negative via clove weight, bulb equatorial diameter, leaf width at middle portion, pseudo stem length, clove equatorial diameter, leaves per plant and plant height at phenotypic level. The trait had positive indirect effects through clove length, pseudo stem diameter, bulb polar diameter, leaf width at middle portion and pseudo stem length, while negative through clove weight, bulb equatorial diameter, clove polar diameter, clove equatorial diameter and plant height at genotypic level.

At phenotypic level, clove weight displayed positive indirect effects through bulb equatorial diameter, leaf width at middle portion, clove equatorial diameter, leaves per plant, pseudo stem length and bulbils per plant, while negative indirect effects through cloves per bulb, clove length, pseudo stem diameter, bulb polar diameter, TSS and plant height. At genotypic level, clove weight had positive indirect effects via bulb equatorial diameter, clove polar diameter, bulbils per plant, leaf length and clove equatorial diameter, while negative indirect effects via cloves per bulb, clove length, bulb polar diameter, pseudo stem diameter, leaf width at middle portion.

The trait, clove length had positive indirect effects at phenotypic level through clove weight, bulb equatorial diameter, leaf width at middle portion, clove equatorial diameter, leaves per plant, bulbils per plant, pseudo stem length, leaf length and clove polar diameter, while negative indirect effects through cloves per bulb, pseudo stem diameter, bulb polar diameter, TSS and plant height. At genotypic level, clove length had positive indirect effects via clove weight, bulb equatorial diameter, clove polar diameter, bulbils per plant, and leaf length, while negative through cloves per bulb, bulb polar diameter, pseudo stem diameter, leaf width at middle portion and plant height.

Clove polar diameter depicted positive indirect effects at phenotypic level through clove weight, bulb equatorial diameter, leaf width at middle portion, clove equatorial diameter, leaves per plant, bulbils per plant and leaf length, while negative indirect effect through clove length, pseudo stem diameter, bulb polar diameter, cloves per bulb, TSS, pseudo stem length and plant height, whereas at genotypic level, it had positive indirect effects via clove weight, bulb equatorial diameter, bulbils per plant, leaf length and clove equatorial diameter, while negative through clove length, bulb polar diameter, pseudo stem diameter, cloves per bulb and leaf width at middle portion.

At phenotypic level, clove equatorial diameter had positive indirect effects via clove weight, bulb equatorial diameter, leaf width at middle portion, leaves per plant, bulbils per plant, leaf length, clove polar diameter and pseudo stem length, while negative through cloves per bulb, pseudo stem diameter, clove length, bulb polar diameter, TSS and plant height. At genotypic level, clove equatorial diameter had positive indirect effects through clove weight, bulb equatorial diameter, clove polar diameter, bulbils per plant and leaves per plant, while negative through clove length, cloves per bulb, bulb polar diameter pseudo stem diameter and leaf width at middle portion.

Total soluble solids displayed positive indirect effects via cloves per bulb, clove length, pseudo stem diameter and plant height, while negative via clove weight, bulb equatorial diameter, leaf width at middle portion, pseudo stem length, leaves per plant, bulbils per plant, clove equatorial diameter, leaf length and clove polar diameter. At genotypic level, TSS had positive indirect effects via clove length, cloves per bulb, bulb polar diameter, pseudo stem diameter and leaf width at middle portion, while negative indirect effects through clove weight, bulb equatorial diameter, bulbils per plant, clove polar diameter and leaf length.

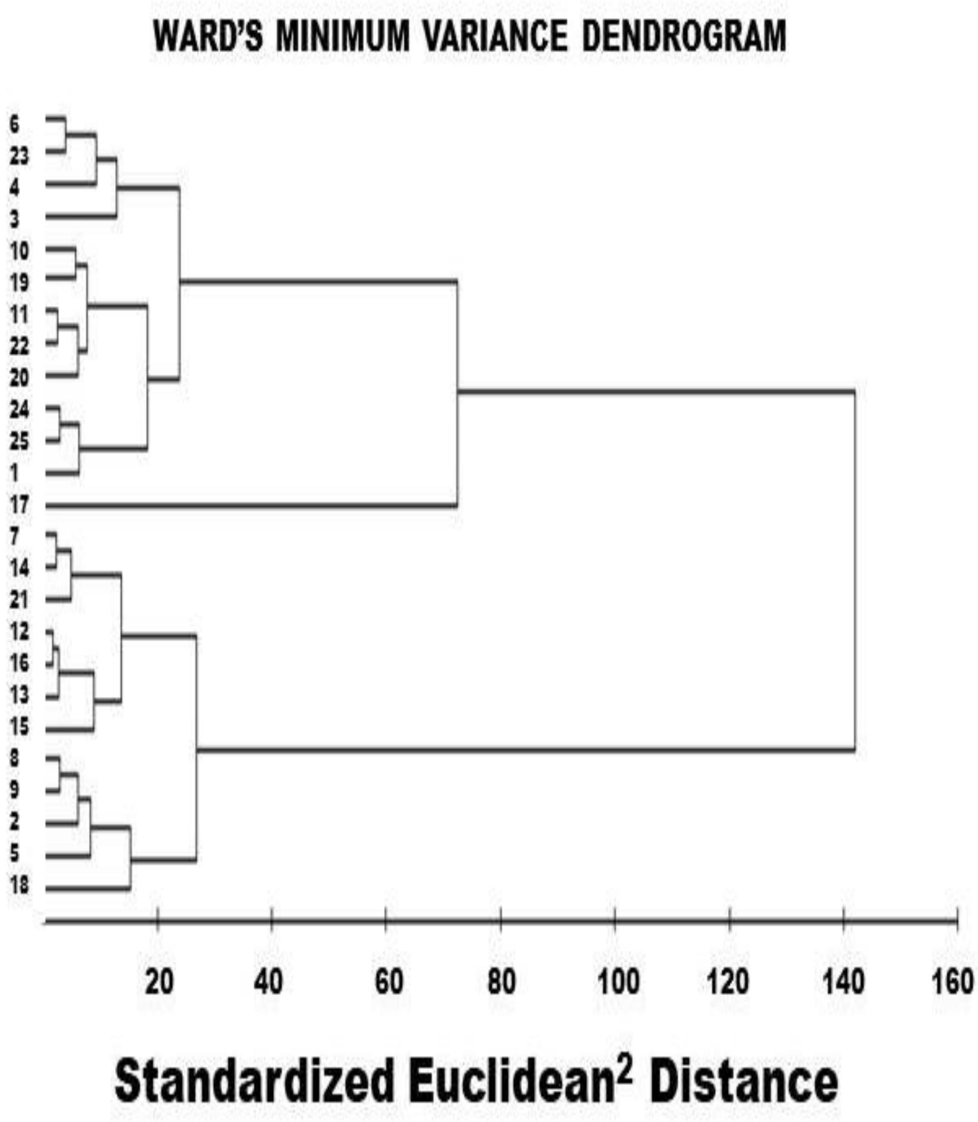
At phenotypic level, bulbils per plant exhibited positive indirect effects through clove length, bulb polar diameter, pseudo stem diameter, TSS and cloves per bulb, while negative indirect effects through clove weight, bulb equatorial diameter, leaf width at middle portion, leaves per plant, clove equatorial diameter, plant height and clove polar diameter. At genotypic level, it expressed positive indirect effects via clove length, bulb polar diameter, pseudo stem diameter, leaf width at middle portion and plant height, while negative indirect effects through clove weight, bulb equatorial diameter, clove polar diameter, leaves per plant and TSS.

The results of the present study are in agreement with those of Agarwal and Tiwari (2009), Meena (2010), Tsega et al. (2010), Sonkiya et al. (2012), Singh et al. (2012 b), Singh et al. (2013 b), Pervin et al. (2014), Kumar et al. (2015), Sharma et al. (2016 b) and Bhatt et al. (2017) who observed direct positive effects of plant height, clove weight, bulb polar and equatorial diameters, clove length, leaves per plant on bulb yield per plant both at genotypic and phenotypic levels. However, the traits viz., leaves per plant, leaf width at middle portion, pseudo stem height, TSS, leaf length, average weight of cloves, bulb polar diameter had negative direct effects on bulb yield per plant as reported by Prajapati et al. (2016), Chotaliya and Kulkarni (2017), Bhatt et al. (2017). Based on the present investigation, the traits viz., clove weight, bulb equatorial diameter, cloves per bulb, leaves per plant, clove equatorial diameter, leaf length and clove polar diameter turned out to be the major components of bulb yield and selection for these traits will be more rewarding in bringing substantial yield improvement in garlic.

4.6 Genetic divergence studies using D^2- statistic

The selection of suitable diverse parents for hybridization programme is an important feature of any crop improvement strategy for getting desired recombinants. Genetic diversity present in the available germplasm offers ample opportunities for any crop improvement programme. For selecting the parents for hybridization which are required to be divergent enough for the character(s) of interest, estimation of the genetic distance is most important. The genetic divergence can be estimated by using an effective statistical tool, Mahalanobis D^2 statistics, which gives clear idea about the diverse nature of the population. It is a powerful tool for estimating genetic diversity among different genotypes and to identify the parents for hybridization to obtain desirable recombinants. The assessment of genetic diversity helps in reducing the number of breeding lines from large germplasm and the progenies derived from diverse parents are expected to show a broad spectrum of genetic variability and provide better scope to isolate superior recombinants.

In the present investigation, 25 genotypes of garlic were grouped into six clusters (Fig. 4.2, Table 4.8). Cluster V, II, VI, I and III contained 7, 5, 5, 4 and 3 genotypes, respectively and the remaining cluster viz., cluster IV was solitary, containing a single genotype. The results of the present investigation are in conformity with the findings of Sabir et al. (2017) who conducted diversity studies involving 27 garlic genotypes and categorized the genotypes into 6 clusters each comprising of 8, 6, 6, 4, 2 and 1 genotypes.



1. Yamuna Safed-9
2. Yamuna Safed-4
3. GHC-1
4. Leda Local Selection
5. Yamuna Safed-5
6. Bijni Local Selection
7. Agrifound White
8. Yamuna Safed-3
9. Yamuna Safed-1
10. Agrifound Parvati-2
11. Agrifound Parvati
12. Yamuna Safed-2
13. Yamuna Safed-8
14. Ner Chowk Local Selection
15. Mahadev Local Selection
16. Kangra Local Selection
17. Kanaid Local Selection
18. Gheru Local Selection
19. Chambi Local Selection
20. Biara Local Selection
21. Kasharala Local Selection
22. Jhungi Local Selection
23. Chakar Local Selection
24. Pungh Local Selection
25. Badraina Local Selection

Fig. 4.2 Dendrogram of 25 genotypes generated using Ward's Minimum variance

Table 4.8 Grouping of garlic genotypes into different clusters on the basis of Mahalanobis D^2 cluster analysis

Cluster No	No of genotypes	Genotypes
I	4	Bijni Local Selection, Chakar Local selection, Leda Local Selection and GHC-1
II	5	Agrifound Parvati-2, Chambi Local Selection, Agrifound Parvati, Jhungi Local Selection and Biara Local Selection
III	3	Pungh Local Selection, Badraina Local Selection and Yamuna Safed-9
IV	1	Kanaid Local Selection
V	7	Agrifound White, Ner Chowk Local Selection, Kasharala Local Selection, Yamuna Safed-2, Kangra Local Selection, Yamuna Safed-8 and Mahadev Local Selection
VI	5	Yamuna Safed-3, Yamuna Safed-1, Yamuna Safed-4, Yamuna Safed-5 and Gheru Local Selection

4.6.2 Average intra and inter cluster distances among 25 garlic genotypes

In the present studies, the highest intra-cluster distance (Table 4.9) was observed in cluster I (17.55) followed by cluster VI (16.32), cluster V (11.49), cluster II (10.95) and cluster III (9.24) The highest intra-cluster distances observed in the studies revealed that genotypes within the same cluster were quite diverse, hence selection of parents within cluster would be more effective.

The highest inter cluster distance was observed between cluster IV and cluster V (166.66) followed by cluster IV and cluster VI (154.0), cluster III and cluster IV (101.40), cluster I and cluster IV (82.99), cluster II and cluster IV (80.82), cluster I and cluster V (45.96), cluster II and cluster V (34.33), cluster I and cluster VI (33.87), cluster III and V (31.69), cluster II and VI (29.48), cluster I and cluster III (23.52), cluster III and cluster VI (21.80), cluster V and cluster VI (20.70), cluster I and cluster II (20.61) and cluster II and cluster III (17.22).

The results of the present study are in line with the findings of Islam et al. (2017) and Sabir et al. (2017) who observed that the genotypes were categorized into 4 and 6 clusters, respectively with variable inter and intra-cluster distances. The inter cluster distances were observed to be higher than intra-cluster distances, suggesting presence of high genetic diversity between the lines of any two clusters than the lines present within the cluster. Hence, crossing between genotypes belonging to these clusters may result in generating variability, which could be exploited in garlic improvement. The grouping pattern of the genotypes suggested no parallelisms between genetic divergence and geographical distribution of genotypes. Shashidhar and Dharmatti (2005), Singh et al. (2012 b), Mohammadi et al. (2014) and Sandhu et al. (2014) reported that genetic diversity was independent of geographical region.

Table 4.9 Average intra and inter cluster distances among garlic genotypes

	Cluster I	**Cluster II**	**Cluster III**	**Cluster IV**	**Cluster V**	**Cluster VI**
Cluster I	**17.55 (4.19)**	20.61 (4.54)	23.52 (4.85)	82.99 (9.11)	45.96 (6.78)	33.87 (5.82)
Cluster II		**10.95 (3.31)**	17.22 (4.15)	80.82 (8.99)	34.33 (5.86)	29.48 (5.43)
Cluster III			**9.24 (3.04)**	101.40 (10.07)	31.69 (5.63)	21.80 (4.67)
Cluster IV				**0.00 (0)**	166.66 (12.91)	154.00 (12.41)
Cluster V					**11.49 (3.39)**	20.70 (4.55)
Cluster VI						**16.32 (4.04)**

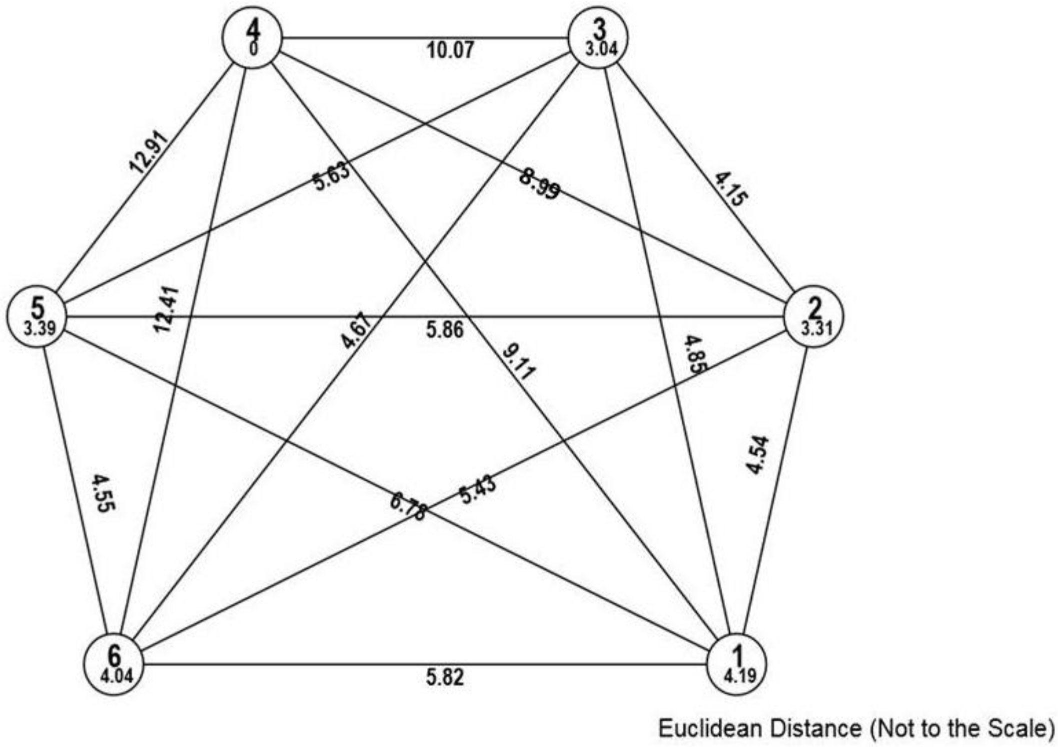


Fig. 4.3 Cluster diagram depicting inter and intra-cluster distances (Mahalanobis Euclidean Distance)

4.6.3 Cluster means

The cluster means of garlic genotypes falling under different clusters are presented in Table 4.10. Cluster I was found best for the traits, plant height and leaves per plant; cluster II for leaf length and bulbils per plant; cluster III for pseudo stem length and TSS; cluster IV for bulb yield per plant, bulb yield per plot, clove weight, clove length, clove polar diameter, clove equatorial diameter, bulb polar diameter, bulb equatorial diameter and leaf width at middle portion; cluster V for pseudo stem diameter and cluster VI for cloves per bulb.

Table 4.10 Cluster means of six clusters for different traits in garlic

Cluster No.	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V	Cluster VI
Plant height (cm)	58.71	51.12	57.28	57.85	40.38	52.17
Leaves per plant	8.97	8.69	8.01	8.93	7.65	7.56
Leaf length (cm)	35.81	35.99	34.01	35.10	24.69	32.42
Leaf width at middle portion (cm)	1.46	1.29	1.21	2.70	0.90	1.29
Pseudo stem length (cm)	23.55	18.77	27.77	16.54	17.41	25.00
Pseudo stem diameter (cm)	1.23	1.30	1.37	2.31	0.89	1.03
Bulb polar diameter (mm)	35.60	33.67	35.11	41.04	28.24	30.64
Bulb equatorial diameter (mm)	39.76	40.95	38.03	50.86	27.89	32.47
Cloves per bulb	12.73	10.0	9.08	6.53	10.31	14.03
Clove weight (g)	2.26	2.84	2.57	5.36	1.78	1.50
Clove length (cm)	3.99	3.84	3.74	5.56	3.38	3.38
Clove polar diameter (mm)	31.19	27.13	28.48	46.75	23.80	23.77
Clove equatorial diameter (mm)	14.63	16.67	17.99	29.93	12.18	11.35
Bulb yield per plant (g)	27.36	28.08	22.65	38.07	18.08	19.30
Bulb yield per plot (kg)	0.65	0.67	0.54	0.91	0.43	0.46
TSS (^{0}b)	39.82	39.06	43.31	33.99	42.17	41.21
Bulbils per plant	0.00	3.63	3.72	0.0	3.00	3.38

4.6.4 Contribution of individual character towards divergence

The relative contribution of individual trait to the genetic divergence among garlic genotypes is presented in Table 4.11. The maximum contribution towards the genetic divergence was exhibited by bulbils per plant (40.33 %), leaf length (12.67

%), plant height (10.67 %), bulb yield per plant (6.67 %), pseudo stem length (6.33 %), clove polar diameter (6.0 %), cloves per bulb (4.0 %), clove equatorial diameter (3.33 %), bulb equatorial diameter (3.33%), leaf width at middle portion (2.67 %), clove weight (2.33 %) and clove length (1.33 %). No contribution towards genetic divergence was exhibited by leaves per plant and pseudo stem diameter, while lowest contribution towards the genetic divergence was exhibited by bulb yield per plot (0.67 %), bulb polar diameter (0.67 %) and TSS (0.33%).

Table 4.11 Relative contribution (%) of individual trait to genetic divergence

Trait	**No. of times ranked first**	**Contribution (%)**
1. Plant height	32	10.67
2. Leaves per plant	0	0.00
3. Leaf length (cm)	38	12.67
4. Leaf width at middle portion	8	2.67
5. Pseudo stem length (cm)	19	6.33
6. Pseudo stem diameter (cm)	0	0.00
7. Bulb polar diameter (mm)	2	0.67
8. Bulb equatorial diameter	10	3.33
9. Cloves per bulb	12	4.00
10. Clove weight (g)	7	2.33
11. Clove length (cm)	4	1.33
12. Clove polar diameter (mm)	18	6.00
13. Clove equatorial diameter (mm)	10	3.33
14. Bulb yield per plant (g)	18	6.67
15. Bulb yield per plot (kg)	2	0.67
16. TSS (^{0}b)	1	0.33
17. Bulbils per plant	121	40.33

4.7 Principal Component Analysis (PCA)

Principal component analysis (PCA) helps in identifying the most relevant characters that can be used as descriptors by explaining as much of total variation in the original set of variables as possible with a few components as possible and reducing the dimension of the problem. The characters contributing more to the divergence gave greater emphasis for deciding on the cluster for the purpose of further selection and the choice of parents for hybridization. Principal components were considered significant for eigen values greater than or equal to 1.0. As a result, a total of 92.93 per cent variation was explained by the first six significant principal components. The results are in agreement with the findings of Panthee et al. (2006) who reported that 86.0 % of the total genetic variation was described by first four principal components. The eigen values (Root), cumulative variation and proportion of accounted variance for each variable have been presented in Table 4.12.

Table 4.12 Eigen vectors of first six principal components for different traits

Variable	Eigen vector					
	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Eigen values (Root)	6.68	5.40	2.12	1.69	1.38	1.17
Variation (%)	**57.68**	**14.78**	**7.24**	**5.96**	**3.99**	**3.26**
Cumulative variation (%)	**57.68**	**72.46**	**79.70**	**85.67**	**89.66**	**92.93**
Plant height	0.54	0.54	-0.25	-0.33	-0.13	-0.34
Leaves per plant	0.03	-0.02	-0.01	0.02	0.03	-0.00
Leaf length (cm)	0.37	0.15	0.08	0.86	-0.13	-0.04
Leaf width at middle portion (cm)	0.21	-0.01	0.01	0.02	-0.01	-0.00
Pseudo stem length (cm)	0.11	0.45	0.54	-0.05	0.23	0.46
Pseudo stem diameter (cm)	0.01	-0.01	-0.00	-0.01	-0.00	0.00
Bulb polar diameter (mm)	0.25	-0.05	0.09	-0.16	-0.16	-0.06
Bulb equatorial diameter (mm)	0.44	-0.18	-0.21	-0.08	0.11	0.42
Cloves per bulb	-0.00	0.24	0.04	-0.05	0.72	-0.11
Clove weight (g)	0.04	-0.07	-0.01	0.00	-0.08	0.03
Clove length (cm)	0.02	-0.04	0.01	0.01	-0.01	-0.02
Clove polar diameter (mm)	0.29	-0.38	0.63	-0.06	0.17	-0.46
Clove equatorial diameter (mm)	0.23	-0.31	0.09	-0.22	-0.40	0.12
Bulb yield per plant (g)	0.36	-0.29	-0.16	0.00	0.41	0.33
Bulb yield per plot (kg)	0.00	-0.00	-0.00	0.00	0.01	0.00
TSS (^{0}b)	-0.08	0.15	0.36	-0.19	-0.10	0.27
Bulbils per plant	-0.04	0.05	0.01	0.05	-0.08	0.21

The first principal component (PC1) was the most important and explained 57.68 % of total variance which was mainly contributed by plant height (0.54), bulb equatorial diameter (0.44), leaf length (0.37), bulb yield per plant (0.36), clove polar diameter (0.29), bulb polar diameter (0.25), clove equatorial diameter (0.23) and pseudo stem length (0.11). The principal component (PC2) contributed 14.78 per cent to the total variance which was mainly contributed by plant height (0.54), pseudo stem length (0.45), cloves per bulb (0.24), TSS (0.15) and leaf length (0.15). The principal component (PC3) contributed 7.24 % to total variance through clove polar diameter (0.63), pseudo stem length (0.54) and TSS (0.36). The principal component (PC4) contributed 5.96 % to the total variance through leaf length (0.86). However, the remaining principal components (PC5 and PC6) contributed 3.99 and 3.26 per cent, respectively to the total variation through cloves per bulb, bulb yield per plant, pseudo stem length, clove polar diameter (PC5) and pseudo stem length, bulb equatorial diameter, bulb yield per plant, TSS and bulbils per plant (PC6). The results are in confirmation with the findings of Sharma et al. (2018) who reported that more than 75% of the total genetic variation in the experimental material evaluated was explained by first four principal components.

5. SUMMARY AND CONCLUSIONS

The present investigation entitled **"Genetic variability and inter relationships among bulb yield and associated traits in garlic (*Allium sativum* L.)"** was undertaken at the Research Farm of Department of Vegetable Science and Floriculture, College of Agriculture, CSKHPKV, Palampur during *Rabi*, 2017-18. The experimental material comprised of twenty five genotypes of garlic including GHC-1 as standard check, were evaluated in a randomized complete block design with three replications to assess genetic variability, association among various horticultural traits, direct and indirect effects on bulb yield and genetic diversity through multivariate analysis. The observations were recorded on ten competitive plants selected randomly in each entry over the replications for 17 quantitative traits viz., plant height (cm), leaves per plant, leaf length (cm), leaf width at middle portion (cm), pseudo stem length (cm), pseudo stem diameter (cm), bulb polar diameter (mm), bulb equatorial diameter (mm), cloves per bulb, clove weight (g), clove length (cm), clove polar diameter (mm), clove equatorial diameter (mm), bulb yield per plant (g), bulb yield per plot (kg), TSS (^{0}b) and bulbils per plant and six qualitative traits like bulb skin colour, clove skin colour, foliage colour, leaf waxiness, bolting/non bolting and plant growth habit. The data recorded for quantitative traits were subjected to statistical analysis as per the standard statistical procedures for estimation of various parameters of genetic variability, correlation, path coefficient and genetic diversity.

The analysis of variance revealed that mean squares due to genotypes were significant for all the traits studied which indicated the presence of sufficient genetic variability amongst genotypes for all the traits studied. Based on mean performance, Kanaid Local Selection and Chambi Local Selection were the top ranking genotypes for bulb yield per plant which significantly out yielded all the genotypes with a significant increase of 28.74 % and 12.71 %, respectively over standard check, GHC-1. The superior performance of these genotypes for bulb yield per plant was mainly attributed to their best performance for pseudo stem diameter, bulb polar diameter, bulb equatorial diameter, clove weight, clove length, clove polar diameter and clove equatorial diameter. Overall, two genotypes viz., Kanaid Local Selection and Chambi Local Selection for bulb yield per plant, bulb yield per plot and bulb equatorial diameter; four genotypes viz., Kasharala Local Selection, Agrifound White, Ner Chowk Local Selection and Yamuna Safed-9 for TSS; one genotype viz., Kanaid Local Selection for clove equatorial diameter, clove weight and bulb polar diameter; two genotypes viz., Kanaid Local Selection and Bijni Local Selection for clove polar diameter; three genotypes viz., Kanaid Local Selection, Leda Local Selection and Jhungi Local Selection for clove length; seven genotypes viz., Yamuna Safed-5, Yamuna Safed-4, Bijni Local Selection, Chakar Local Selection, Yamuna Safed-2, Yamuna Safed-1 and Pungh Local Selection for cloves per bulb; two genotypes viz., Kanaid Local Selection and Pungh Local Selection for pseudo stem diameter; five genotypes viz., Yamuna Safed-9, Badraina Local Selection, Bijni Local Selection, Pungh Local Selection and Yamuna Safed-1 for pseudo stem length were found superior than standard check, GHC-1. However, none of the genotypes could surpass standard check, GHC-1 for plant height, leaves per plant, leaf length, leaf width at middle portion and bulbils per plant.

High estimates of phenotypic and genotypic coefficients of variation were obtained for bulbils per plant, clove weight, leaf width at middle portion and clove equatorial diameter, indicated better scope for improvement through selection. In general, the magnitude of PCV was higher than their respective GCV for all the traits studied which reflected the considerable influence of environment on the manifestation of these traits.

The high heritability coupled with high genetic advance as percentage of mean was observed for bulbils per plant, clove weight, leaf width at middle portion, clove equatorial diameter, cloves per bulb and pseudo stem diameter. High heritability with moderate genetic gain was observed for bulb yield per plant, bulb yield per plot, clove polar diameter, pseudo stem length, leaf length, bulb equatorial diameter, plant height and clove length. This suggested the active involvement of additive gene action in the inheritance of these traits. However, low heritability coupled with low genetic gain was observed for leaves per plant, indicated non-additive gene action which revealed the importance of dominance and epistatic effects and delayed selection would be more effective.

The correlation studies revealed that in general, the genotypic correlations were higher in magnitude than phenotypic correlations, suggested the inherent relationship. Bulb yield per plant displayed significant positive correlation with bulb equatorial diameter, clove weight, clove equatorial diameter, pseudo stem diameter, clove polar diameter, bulb polar diameter, clove length, leaf length, leaf width at middle portion, plant height and leaves per plant, whereas negative and significant correlation with TSS and bulbils per plant, indicated that selection based on these traits would be more effective.

Path coefficients studies revealed that clove weight, bulb equatorial diameter, clove polar diameter, leaf length and clove equatorial diameter were the important traits for direct selection of bulb yield as these traits had high direct effects and significant positive correlation with bulb yield per plant. These traits can be considered as the best selection indices for increasing the bulb yield.

The genetic diversity studies using Mahalanobis D^2 statistic, grouped 25 genotypes into six clusters. Overall, cluster V was the largest containing seven genotypes followed by cluster II, cluster VI, cluster I and cluster III with 5, 5, 4 and 3 genotypes, respectively. However, cluster IV was solitary. The highest intra-cluster distance was observed in cluster I followed by cluster VI, cluster V, cluster II and cluster III. However, inter cluster distances were observed highest between cluster IV and cluster V followed by cluster IV and cluster VI, cluster III and cluster IV, cluster I and cluster IV, cluster II and cluster IV, cluster I and cluster V, cluster II and cluster V, cluster I and cluster VI, cluster III and cluster V, cluster II and cluster VI, cluster I and cluster III, cluster III and cluster VI, cluster V and cluster VI, cluster I and cluster II and cluster II and cluster III. The cluster I was found best for the traits, plant height and leaves per plant; cluster II for leaf length and bulbils per plant; cluster III for pseudo stem length and TSS; cluster IV for bulb yield per plant, bulb yield per plot, clove weight, clove length, clove polar diameter, clove equatorial diameter, bulb polar diameter, bulb equatorial diameter and leaf width at middle portion; cluster V for pseudo stem diameter and cluster VI for cloves per bulb. The highest inter cluster distances indicated the presence of high genetic diversity between the genotypes belonging to any two clusters than the genotypes within the cluster. The selection of genotypes based upon large cluster distances from all the clusters may lead to favorable broad spectrum genetic variability.

Ranking character wise D^2 values and adding the ranks for each character for all the genotypes identified the traits, which contributed towards the genetic divergence. The maximum contribution towards the genetic divergence was exhibited by bulbils per plant followed by leaf length, plant height, bulb yield per plant, pseudo stem length, clove polar diameter, cloves per bulb, clove equatorial diameter, bulb equatorial diameter, leaf width at middle portion, clove weight and clove length. The traits, bulb yield per plot, bulb polar diameter and TSS had the lowest relative contribution towards genetic divergence.

Based on principal component analysis, the traits, plant height (PC1 and PC2) followed by clove polar diameter (PC3), leaf length (PC4), cloves per bulb (PC5) and pseudo stem length (PC6) were observed as the maximum contributors towards genetic divergence.

Conclusion

- The analysis of variance revealed the presence of sufficient genetic diversity amongst genotypes for bulb yield and yield contributing traits. The genotypes, Kanaid Local Selection and Chambi Local Selection were found superior as these outyielded standard check, GHC-1 with a significant increase of 28.74 and 12.71 per cent, respectively.
- High estimates of phenotypic and genotypic coefficients of variation were obtained for bulbils per plant, clove weight, leaf width at middle portion and clove equatorial diameter. In general, the magnitude of PCV was higher than their respective GCV for all the traits studied which reflected the considerable influence of environment on the performance of the genotypes.
- The high heritability coupled high genetic advance as percentage of mean was expressed for bulbils per plant, clove weight, leaf width at middle portion, clove equatorial diameter, cloves per bulb and pseudo stem diameter, while low heritability coupled with low genetic gain was observed for leaves per plant.

- The correlation studies revealed that bulb yield per plant had significant positive correlation with bulb equatorial diameter, clove weight, clove equatorial diameter, pseudo stem diameter, clove polar diameter, bulb polar diameter, clove length, leaf length, leaf width at middle portion, plant height and leaves per plant.
- Path coefficients studies revealed that clove weight, bulb equatorial diameter, clove polar diameter, leaf length and clove equatorial diameter were the important bulb yield determinants as these displayed high direct effects and significant positive correlation with bulb yield per plant.
- The genetic diversity studies using Mahalanobis D2 statistic, categorized 25 genotypes into six different clusters. Overall, cluster V was the largest containing seven genotypes and cluster IV was solitary. The highest intra-cluster distance was observed in cluster I followed by cluster VI, whereas inter cluster distance was observed highest between cluster IV and cluster V.
- The maximum contribution towards the genetic divergence was exhibited by bulbils per plant followed by leaf length, plant height, bulb yield per plant, pseudo stem length, clove polar diameter, cloves per bulb, clove equatorial diameter, bulb equatorial diameter, leaf width at middle portion, clove weight and clove length.
- The principal component analysis revealed that 92.93 % variation was explained by first six significant principal components. The trait, plant height (PC1 and PC2), clove polar diameter (PC3), leaf length (PC4), cloves per bulb (PC5) and pseudo stem length (PC6) were observed as the maximum contributors towards genetic divergence.

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APPENDICES

APPENDIX-I

Mean weekly meteorological data during the crop season (*Rabi* 2017-18)

Standard meteorological week	Maximum Temp.(°C)	Minimum Temp.(°C)	Rainfall (mm)	Relative Humidity (%)	Sunshine (hrs)
40	26.93	15.49	2.63	69.79	8.9
41	27.83	14.20	0.00	62.45	9.9
42	27.43	13.00	0.00	51.79	10
43	25.21	11.57	0.00	50.64	9.4
44	22.79	10.56	0.00	62.50	7.9
45	23.67	10.20	0.00	63.64	8
46	20.96	9.03	0.11	62.86	4.6
47	19.79	5.73	0.00	52.21	7.3
48	19.67	5.96	0.00	57.43	8.9
49	20.07	6.60	0.00	59.07	7.4
50	16.36	8.20	13.51	75.71	3.9
51	21.64	7.27	0.00	48.64	8.9
52	18.36	5.86	0.00	52.64	6.7
1	15.96	3.14	0.00	59.43	8.1
2	17.43	3.69	0.00	52.86	7.7
3	19.64	4.99	0.00	46.64	8.9
4	16.36	3.06	1.34	63.22	7.4
5	20.14	6.29	0.00	48.79	9.2
6	15.71	4.29	14.86	61.22	7.6
7	17.67	5.46	6.11	63.43	5.9
8	21.14	9.14	0.66	54.36	7.1
9	22.00	10.21	0.66	64.86	5.9
10	23.00	9.00	0.00	46.00	9.3
11	23.93	10.50	1.09	42.50	9.1
12	23.21	10.24	2.91	47.14	7.2
13	27.00	12.57	0.00	43.72	9.7
14	27.00	15.00	2.00	56.00	6.8
15	24.17	12.71	3.60	55.57	6.1
16	26.43	14.36	2.43	42.64	7.8
17	29.00	17.00	2.00	43.50	8.7
18	28.29	17.64	6.54	54.355	8
19	26.86	15.64	6.7	60.57	6.3
20	29.89	16.96	0	39.5	6.6
21	32.89	19.43	0	24.07	8.1
22	32.65	19.07	1.71	47.14	7.8
23	30.64	20.64	2.57	67.21	5.29
24	30.28	20	4.74	63.5	6.14
25	29.5	19.14	4.46	52.93	6.14
26	28.29	19.86	19.88	78.36	4.21
27	26.21	19	23.07	86.495	3.79
28	28.18	20.29	42.46	89.57	3.43
29	28.21	20.14	24.86	89.57	4.43
30	26.29	19.71	37.74	91	1.86
31	27.28	19.71	13.8	87.28	4.29
32	24.39	19.86	22.11	94.93	0.50
33	26.57	19.78	39.83	91.92	2.36
34	26	19.57	44.4	89.49	2.29
35	26.93	19.79	25.23	88.71	5.14
36	26.5	19.5	11.2	81.66	2.5
37	26.21	17.36	15	86.50	3.07
38	25.87	15.93	20.74	81.74	7.50

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Examination passed	Year	School/Board/ University	Marks (%)	Division	Major Subjects
10^{th}	2010	CBSE	70.00	First	English, Hindi, Mathematics, Science and Social Science
10+2	2012	CBSE	71.00	First	English, Physics, Chemistry, Biology and Physical Education
B.Sc. (Horticulture)	2016	Dr. Y.S Parmar UHF, Nauni (Solan)	77.70	First	All horticulture and allied subjects
M.Sc. (Vegetable Science and Floriculture)	2019	CSKHPKV Palampur	74.8	First	Major: Vegetable Science Minor: Plant Breeding and Genetics