

“GENETIC CHARACTERIZATION OF ONION (*Allium cepa* L.) GENOTYPES”

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“GENETIC CHARACTERIZATION OF ONION (*Allium cepa* L.) GENOTYPES”

By

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B. Sc. (Hons.) Hort.

**THIS IS SUBMITTED TO SRI KONDA LAXMAN TELANGANA STATE
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JULY, 2021

CERTIFICATE

Ms. MAREDDY PRASHANTHI has satisfactorily prosecuted the course of research and that the thesis entitled “**GENETIC CHARACTERIZATION OF ONION (*Allium cepa* L.) GENOTYPES**” submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination.

I certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any university.

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Chairman

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CERTIFICATE

This is to certify that the thesis entitled “**GENETIC CHARACTERIZATION OF ONION (*Allium cepa* L.) GENOTYPES**” submitted in partial fulfilment of the requirements for the degree of Master of Science in Horticulture (Vegetable Science) of Sri Konda Laxman Telangana State Horticultural University, Rajendranagar, Hyderabad, is a record of the bonafide research work carried out by **Ms. MAREDDY PRASHANTHI** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance received during the course of the investigations have been duly acknowledged by the author of the thesis.

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I, **Ms. MAREDDY PRASHANTHI**, hereby declare that the thesis entitled **“GENETIC CHARACTERIZATION OF ONION (*Allium cepa* L.) GENOTYPES”** submitted to Sri Konda Laxman Telangana State Horticultural University, Rajendranagar, for the Degree of Master of Science in Horticulture (Vegetable Science) is the result of original research work done by me. I declare that no material contained in the thesis has been published earlier in any manner.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	: Per cent
s^2g	: Genotypic variance
s^2P	: Phenotypic variance
ANOVA	: Analysis of variance
CD	: Critical difference
cm^2	: Square centimeter
m^2	: Square meter
COH	: College of Horticulture
Contd.	: Continued
CV	: Coefficient of Variation
D^2	: Genetic distance
d.f.	: Degrees of freedom
Ha	: Hectare
$t\ ha^{-1}$	: tonnes per hectare
MOP	: Muriate of Potash
SSP	: Single Super Phosphate

<i>et al</i>	: and others
etc.	: and so on; and other people / things
Fig	: Figure
/	: Per
G	: Gram
GA	: Genetic Advance
GCV	: Genotypic Co-efficient of Variation
h^2_b	: Heritability in broad sense
<i>i.e.</i> ,	: That is
Kg	: Kilogram
Mg	: Milligram
ml	: Milliliter
Kj	: Kilojoule
MSS	: Mean Sum of Squares
M	: Meters
Q	: Quintal
Oz	: Ounce
DAT	: Days after transplanting
FAO	: Food and Agriculture Organization
Σ	: Summation

ICAR	: Indian Council of Agricultural Research
NHB	: National Horticulture Board
FYM	: Farm Yard Manure
No.	: Number
HPO ₃	: Metaphosphoric acid
P	: Phenotypic Correlation
PCV	: Phenotypic Coefficient of Variation
<i>Per se</i>	: As such with mean
RBD	: Randomized Block Design
RH	: Relative humidity
R _p	: Phenotypic correlation coefficient
R _g	: Genotypic correlation coefficient
SE (m) _±	: Standard error of mean
SKLTSHU	: Sri Konda Laxman Telangana State Horticultural University
T	: Tonne
TSS	: Total Soluble Solids
<i>Viz.,</i>	: Namely
Wt.	: Weight
SE	: Standard error
μmol	: Micromole

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ABSTRACT

The present investigation entitled “Genetic characterization of onion (*Allium cepa* L.) genotypes” was carried out at College of Horticulture, SKLTSHU, Rajendranagar, Hyderabad, season of the year, during *rabi*, 2021, to estimate the genetic divergence, genetic variability, correlation and path analysis for yield and yield components of onion genotypes.

Forty onion genotypes were sown in a Randomized Block Design with three replications to estimate the genetic divergence, genetic variability, correlation and path analysis for yield and yield components of onion genotypes.

The data on analysis of variance (ANOVA) for yield and yield contributing characters observed revealed that there was significant difference among genotypes for all the ten characters studied. Among them, wide range of variability was observed for average bulb weight (769.40 g) followed by yield per hectare (164.45 t) and days taken to maturity (145.05 days) indicating the scope for selection of initial breeding material for further improvement.

The results pertaining to mean performance of forty genotypes for ten characters indicated that the genotype 1770 was the superior for yield and yield contributing characters *i.e.*, yield per hectare (57.59 t), average bulb weight (129.60 g), equatorial bulb diameter (7.20 cm) and polar bulb diameter (6.63 cm), the genotype Bhima Raj was significantly best for plant height (62.39 cm). While Bhima Shwetha recorded less number of days taken to maturity (95.33 days) and maximum for ascorbic acid content (12.52 mg 100⁻¹ g) as compared to

other genotypes. The genotype 1745 registered higher neck thickness (2.01 cm) and more number of leaves per plant (12.80). Highest total soluble solids (TSS) was found in W-246 cp (14.60 °Brix).

Mahalanobis D^2 statistical analysis classified forty genotypes into twelve clusters and showed that total soluble solids (28.33 %) contributed maximum towards divergence, followed by neck thickness (24.36 %), ascorbic acid (21.15 %), average bulb weight (14.10 %), yield per hectare (4.87 %), days taken to maturity (4.10 %), number of leaves per plant (1.92 %), plant height (0.64 %) and equatorial bulb diameter (0.51 %).

The inter cluster D^2 value revealed that the highest inter cluster generalized distance (150.67) was between cluster VIII and VII, while the lowest (13.56) was between cluster III and II. The genotypes of clusters who were expressing high genetic divergence could be effectively utilized in heterosis breeding programme.

High heritability coupled with maximum genetic advance as per cent of mean indicates operation of additive gene action which was observed in characters *viz.*, neck thickness, average bulb weight and yield per hectare.

The data on correlation studies, indicating that bulb yield exhibited, significantly positive association with number of leaves per plant, neck thickness, equatorial bulb diameter, polar bulb diameter, ascorbic acid content and average bulb weight expressing the importance of these traits in selection for yield.

The path coefficient analysis revealed that improvement of yield by improving the characters *i.e.*, plant height, TSS, polar bulb diameter, and average bulb weight and the genotypes which exhibited better performance for these characters can be used in further improvement of onion.

By considering the mean performance of the forty genotypes, five superior genotypes *viz.*, 1770, 1774, Bhima Shwetha, W-125 and 1772 with high yield and quality components may be utilized as parents in further improvement studies through various breeding strategies and after multilocation, multiseasonal studies may be released.

CHAPTER I

INTRODUCTION

Chapter I

INTRODUCTION

Onion is one of the important spice and vegetable crop grown in tropical, sub-tropical and temperate regions of the world (Katyal., 1985). It is a highly cross-pollinated crop, biennial for seed production and annual for bulb production. It is cultivated year round, but maximum area is cultivated during *Rabi* season in our country.

Onion (*Allium cepa* L, $2n = 2x = 16$) is a bulb crop belonging to the family Alliaceae with diploid chromosome number and it is locally known as Pyaj. The Central Asia is the primary center of its origin and the Mediterranean region is the secondary center for large type of onion (McCollum., 1976).

In India onion occupies an area of 1263'000 ha and production are around 23485'000 MT (NHB Database, 2018-19). India ranks second in area and production in the world. Maharashtra, Madhya Pradesh, Karnataka, Gujarat, Bihar, Andhra Pradesh, Rajasthan, Haryana and Tamil Nadu are the major onion growing states in India.

It displays great morphological diversity in bulb and leaf size, colour and shape, flower colour, fertility and bulbil (top set) development (Pooler and Simon., 1993). Two types of onion are commercially grown in India. The first type is common onion (*Allium cepa* L), whose bulbs are large, normally single, and its plants are propagated through seeds. The second type is multiplier onion (*Allium cepa* var. *aggregatum* Don.) which produces small sized bulbs, many in number to form an aggregated cluster.

The yellow colour of the outer skin of onion bulbs is due to quercetin. Considerable differences exist between onion varieties in phytochemical content, particularly for polyphenols. Yellow onions have the highest total flavonoid content, and it is 11 times higher than in white onions. Red onions have considerable content of anthocyanin pigments, with at least 25 different compounds identified, representing 10 per cent of total flavonoid content.

Anti-fungal factor in onion is phenolics compound known as 'catechol'. Tear inducing action in onion by lachrymatory factor *i.e.*, 1-Propenyl sulfonic acid (Block *et al.*, 1992). Onion is strongly flavoured due to the presence of sulphur containing the compound in very small quantity (about 0.005%) in the form of volatile oil Allyl Propyl Disulphide, responsible for distinctive smell and pungency acts as gastric stimulant and promotes digestion.

Onion is an indispensable item in every kitchen as vegetable and condiment, used to flavour many of the food stuffs. In addition, onion is used as a salad, pickle and also dehydration in the form of onion flakes and powder which are in great demand in the world market. It is valued for its distinct pungent flavour. It is consumed round the year by all the sections of people through-out the world due to healing properties with respect to cardiac diseases, rheumatism, cancer, digestive disorders, blood sugar and prolong cough.

The Phyto-chemicals in onions that scavenge free radicals may also reduce your risk of developing gastric ulcers (according to the National Onion Association). The chromium in onions assists in regulating blood sugar. The sulphur in onions helps lower blood sugar by triggering increased insulin production. Most onion cultivars are about 89 per cent water, 9 per cent carbohydrates (including 4 % sugar and 2 % dietary fibre), 1 per cent protein, and negligible fat (Nadkarni., 1993). Onions contain low amounts of essential nutrients and have an energy value of 166 kJ (40 Calories) in a 100 g (3.5 oz) amount. It contributes savoury flavour to dishes without contributing significant caloric content.

Onion belongs to the genus *Allium* which possesses enormous wealth of genetic diversity. Extent of genetic diversity determines the success level of crop improvement programme. Maximum diversity can be noticed among different cultivars available in India and outside with respect to shape, size, yield, quality and other traits. Collection and maintenance of the genetic diversity in onion is important to avoid genetic erosion. Besides the identification of species, the characterization and evaluation of genotypes are of fundamental importance. Among the various methods identified/developed to study the genetic divergence

in the genotypes, the Mahalanobis D^2 (Mahalanobis., 1936) is reliable and most frequently used.

To initiate any breeding work, it is necessary to assess the genetic variability present in the available genotypes for yield and its components. Parameter of genotypic and phenotypic coefficient of variations is useful in detecting the amount of variability present in the germplasm. Heritability and genetic advance help in determining the influence of environment in expression of the characters and the extent to which improvement is possible after selection. Hence, the genotypes would be characterized to assess the variability and identification of promising genotypes which can be used in further breeding programme.

Yield is a complex trait, governed by a large number of component traits. It depends on a number of agronomic traits and is influenced by many factors which could be genetic or environmental (Uddin *et al.*, 1985). It is imperative to know the interrelationship between yield and its component traits to arrive at an optimal selection index for improvement of yield.

Wright (1921) was first to propose the correlation and path analysis to organize the relationship between the predictor and response variables. Correlation simply measures the association between yield and other traits, whereas path coefficient analysis permits the separation of correlation into direct effects and indirect effects (effects exerted through other variables). This technique, which aims to improve a dependent character like yield when the independent characters have a significant relation in desirable direction and positive direct or indirect effect through other component traits on the dependent characters, became routine in plant breeding programme only after its use by Dewey and Lu (1959).

Genetic divergence analysis estimates the extent of diversity present among the genotypes and these could help the plant breeder in selecting the diverse parents for purposeful hybridization. It is an efficient tool for an effective choice of parents for hybridization programme.

Keeping in view of the above information, the research work entitled "Genetic characterization of onion (*Allium cepa* L.) genotypes" was designed with the following objectives:

1. To study the genetic variability, heritability and genetic advance for different quantitative characters in onion genotypes.
2. To study inter-relationship among different yield and yield component characters of onion.
3. To estimate the direct and indirect effects of yield and yield component characters in onion.
4. To study the genetic divergence among genotypes of onion.

CHAPTER II

REVIEW OF LITERATURE

Chapter II

REVIEW OF LITERATURE

Genetic diversity in a crop species is of paramount importance for making rapid improvement in yield and other characteristics. It is also beneficial to the plant breeder as well as for overall development of agricultural industry. Various studies on onion genotypes confirmed significant differences between yield and other characteristics. The present investigation was undertaken to assess the magnitude of genetic variability, heritability and genetic divergence of important economic characters, interrelationship among themselves and their direct and indirect effect on yield in onion (*Allium cepa* L.) genotypes.

The review of literature on “Genetic characterization of onion (*Allium cepa* L.) genotypes” are presented under the following headings.

- 2.1 Variability
- 2.2 Heritability and genetic advance
- 2.3 Correlation coefficient analysis
- 2.4 Path coefficient analysis
- 2.5 Genetic diversity

2.1 Variability

Considerable differences exist in the size, shape, TSS and other characters of the onion bulbs. This variability is fortunate for the onion breeder as well as for onion industry, the existing variability can be tailored to obtain number of cultivars that can be fashioned for a wide range of uses in addition to adapting to a specific growing condition. The genetic and environmental component of variations were described long back in early part of 20th century by Johannsen (1909), he attributed the variation in a segregating population to both heritable and non-heritable factors and the variation in a pure line to only environmental factors.

Charles and Smith (1939) partitioned the genetic variance from total variance in non - segregating populations. The genetic component of variation is

important as only as this particular component is transmitted to the next generations. Partitioning the overall variability into heritable and non - heritable factors will help in developing suitable breeding programmes.

Bajaj *et al.* (1990) performed the varietal variation in some important chemical constituents of onion and revealed that the dry matter content ranged from 9.28 (VI-67) to 12.9 (Punjab 48) and total soluble solids varied from 10.00 (257-9-1) to 12.10 (Pusa Red) with Punjab-48 second highest at 11.83, thus showing that there was not much wide variation in T.S.S content.

Shintre (1994) executed an experiment on the variability of onions and reported that the observed coefficient of variation of the phenotype was greater than the coefficient of variation of the genotype. Yield was the highest phenotypic coefficient of variation, followed by sprout, rot loss, bulb weight, and total loss, while the lowest phenotypic coefficient of variation were root diameter, polar diameter, thickness of the neck, dry matter, reducing sugar and diameter of the equatorial bulb

Magar (1995) studies conducted on variability in onion and noticed that variation were observed in the characters like number of leaves, plant height, yield per hectare, bulb diameter, neck thickness and storage character.

Sharma *et al.* (1997) described chemical evaluation of some varieties of onion and reported that dry matter content varied from 10.9 (B-11-2) to 14.10 (B-13-1-1) per cent and also expressed that T.S.S varied from 9.73 (B-12-2) to 13.13 (B-14-2).

Mohanty (2001a) conducted an experiment on genetic variability in onion and found that the phenotypic coefficient of variation (PCV) was high for neck thickness (24.06 %), while the bulb weight (15.71 %), plant height (14.96 %) and bulb diameter (10.66) were medium, and the bulb yield (5.99) was low and it also showed that high genotypic coefficient of variation (GCV) was marked by neck thickness (24.14 %), while the number of leaves per plant (19.00 %) and bulb weight (14.12 %) were moderate.

Mohanty (2002) concluded variability in onion and found that the phenotypic coefficient of variation (PCV) was higher for neck thickness (27.51 %) and number of leaves per plant (22.97 %), while it was moderate for plant height (14.13 %) and weight of bulb (13.21%). High genotypic coefficient of variation (GVC) was marked for neck thickness (24.94%), while it was moderate for number of leaves per plant (18.64) and weight of bulb (11.56 %) which reflect greater genetic variability among the accessions and responsiveness of the attributes for making further selection.

Mohanty and Prusti (2002) evaluated variability of *kharif* onion and noticed that they noted high phenotypic coefficient of variation and genotypic coefficient of variation were noticed for bulb yield (22.24 and 21.01 % respectively), neck thickness (20.20 and 17.04 % respectively) and weight of bulb (20.01 and 18.57 % respectively), while they were moderate for plant height (13.85 and 11.72 % respectively) and number leaves per plant (13.68 and 11.54 % respectively).

Mohanty (2004) observed the genetic variability in onion and mentioned that the phenotypic coefficient of variation (PCV) was high for neck thickness (24.18 %) and number of leaves per plant (21.78 %), while it was moderate for plant height (13.34 %) and weight of bulb (12.17 %). High genotypic coefficient of variation (GCV) was marked for neck thickness (21.42 %), while it was moderate for number of leaves per plant (17.54) and weight of bulb.

Trivedi *et al.* (2006a) suggested variability in onion genotypes and stated that the phenotypic coefficient of variation was highest for percentage of bolters, while the lowest for T.S.S. The genotypic coefficient of variation was lowest for dry matter of leaves and percentage of B grade bulb, while the highest for percentage of bolters followed by percentage of doubles.

Trivedi *et al.* (2006b) found genetic variability in 20 onion genotypes and found that the phenotypic coefficient of variation was higher than genotypic coefficient of variation for characters percentage of total loss, rotting loss, bulb weight, dry matter of bulb, reducing sugars and marketable yield indicated that these attributes had reacted with the environment present in the storage structure.

Golani *et al.* (2006) documented 32 genotypes of onion and reported that substantial differences within phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were marked for bulb weight (16.19 and 6.35 % respectively), bulb yield (15.38 and 5.99 % respectively) and T.S.S (9.92 and 4.62 % respectively), which explained greater genotypic as well as phenotypic variability among the accessions and responsiveness of these three characters for making further improvement by selection.

Gurjar and Singhania (2006) examined 30 varieties and revealed that the low estimates of coefficient of variation indicated less variability, while the characters having high estimate of coefficient of variation exhibited greater genetic variability among the accession for these attributes for making effective selection.

Ananthan and Balkrishnamoorthy (2007a) evinced variability in onion and showed that in storage loss, higher estimates of genotypic and phenotypic coefficient of variation were recorded for bulb weight, reducing sugars, non-reducing sugars, total sugars and sulphur content.

Ananthan and Balkrishnamoorthy (2007b) observed the variability of onions and cited that the genotypic and phenotypic coefficient of variation (GCV and PCV) of bulb weight, economic dry matter, yield, chlorophyll (a and b) and sulphur content were high, while it was moderate for all the characters except number of leaves per plant.

Haydar *et al.* (2007) demonstrated variability of 10 genotypes of onion and observed that the highest genotypic and phenotypic coefficient of variation was recorded in fresh weight of bulb and days to harvest, followed by bulb yield which also indicated that there was scope for selection.

Hossain *et al.* (2008) mentioned variability in seven varieties in onion and revealed that higher genotypic coefficients of variation were recorded in number of seeds per scape, final plant height, final scape height, fresh weight of bulb and bulb length.

Hosamani *et al.* (2010) reported 21 diverse onion genotypes and found that the range of variation was maximum for yield tonnes per ha (8.52 to 32.42), followed by average bulb weight (26.67 to 84.00 g), dry matter content (15.93 to 24.80 %) and bulb neck thickness (0.47 to 1.37 cm). The genotypic and phenotypic coefficients of variation were high for yield per ha and average bulb weight (g).

Singh *et al.* (2010) executed an experiment on variability of 16 diverse onion genotypes and noticed that phenotypic and genotypic coefficients of variation were high for marketable yield (14.57 to 12.69 %) and gross yield (11.42 to 9.78 %). However, moderate to low phenotypic and genotypic coefficients of variation were observed for plant height, bulb size, index, neck thickness, bulb diameter, weight of 20 bulbs and days for harvesting.

Degewione *et al.* (2011) analyzed moderate heritability estimates for plant height (49.14 %) and low GCV and PCV, indicating less scope of selection as they are under the influence of environment in shallot.

Navaldehy *et al.* (2011) noticed that the genotype cv. Pusa Madhavi, AOSDRB-0919 and AOSDRB-0913 performed better in terms of yield and yield attributing characters and therefore, these lines may be used for breeding programme. The highest phenotypic and genotypic coefficient of variations were recorded on yield per plot (16.96-15.81%), yield per ha (14.86-14.07 %), bulb size (12.34-11.65 %), plant height (12.00-11.57 %) bulb weight (14.27-11.57 %).

Ibrahim *et al.* (2013) studied high GCV for soluble solid content (276.11) and bulb yield (250.10) which is an indication that greater genetic variability exists in these traits.

Porta *et al.* (2014) performed Fifty-one S_1 lines and the original population using an incomplete random block design. The original population and S_1 lines were highly diverse for quantitative and qualitative traits. S_1 lines were significantly different, with transgressive segregation for number and maximum leaf length, bulbing index, bulb weight, diameter, and dry matter

content. Variances within S₁ lines were greater than among S₁ lines for all traits. Bulb colour and number of skins responded to selection.

Bhatt (2015) carried out studies in twelve genotypes of garlic and reported presence of considerable variability for all the twelve characters. High GCV and PCV were observed for volume of bulb and weight of 10 uniform cloves. High estimates of heritability along with high genetic advance as per cent of mean was observed for volume of bulb and bulb yield.

Sachin *et al.* (2015) proclaimed the genetic variability, correlation and path analysis in 44 onion genotypes for growth, yield, quality and nutrient composition related traits. The range of variation was maximum for bulb yield per plot (2.09 to 7.15 kg) followed by average bulb weight (29.86 to 35.18 g) and TSS (8 to 22.6 Brix). Heritability in broad sense ranged from 27.90 (days to 50 % neck fall) to 99.18 (TSS). The genetic advance as percentage of mean varied from 3.44 (days to 50% neck fall) to 109.62 (magnesium mg per 100 g).

Jat and Vikram (2016) concluded that the highest phenotypic and genotypic coefficient of variation were recorded on dry weight of bulb (25.04-20.18 %), bulb yield per plot and yield per ha (23.31-17.74 %) and bulb diameter (22.12- 17.12 %).

Richapyasi and Akhilesh (2016) scrutinized 33 genotypes of *kharif* onion to discern the yield characters and component traits in relation to genetic variability. The estimates of means due to genotypes were highly significant for all the characters, indicating the presence of genetic diversity in the existing material. The variation was highest for marketable bulb yield followed by average weight of marketable bulb. Genotype BSKO-1256 performed best in terms of yield and gave marketable yield of 296.90 q per ha followed by ASKO-1231 having 291.90 q per ha.

Santra *et al.* (2017) mentioned ten genotypes and indicated significant differences among genotypes for all traits. Pooled mean performances showed that Agrifound Dark Red had highest plant height (51.42 cm), average bulb weight (75.06 g), total bulb yield (306.42 q ha⁻¹) and marketable bulb yield

(295.09 q ha⁻¹). High GCV was recorded for Plant height, number of leaves, polar diameter, equatorial diameter, neck thickness, average marketable bulb weight, marketable yield, days to maturity, total soluble solids, pyruvic acid and phenol content in bulbs.

Aditika *et al.* (2017) revealed the genetic variability among 21 genotypes. High degree of variation was observed for all the characters studied. The difference between phenotypic (PCV) and genotypic (GCV) coefficient of variation was found to be narrow for most of the traits except bulb weight and neck thickness. The GCV ranged from 4.82 (bulb diameter) to 14.60 per cent (bulb weight) while PCV ranged from 5.72 (number of marketable bulbs per plot) to 17.29 per cent (bulb weight) for the various characters studied.

Hussen and Albaiaty (2019) studied the genotype and phenotypic variation of onion bulb composition, which included eight onion genotypes, and the results showed that there are significant differences among all the traits, namely the number of leaves per plant, biological yield, Bulb length, diameter and weight, T.S.S. and total yield per plant. The Bevas sspy genotype has the highest number of leaves per plant, biological yield, bulb diameter and total yield. GCV and PCV are higher in leaf number per plant, bulb length and total yield.

Pujar *et al.* (2019) 40 onion genotypes were investigated to determine genetic variability, which indicates that the environment has very little influence on the expression of these traits, as evidenced by the small gap between genotype and phenotype coefficient of variation. For all the traits studied, the genotype and phenotypic coefficients of variation were medium to high, except for 50% days of flowering and TSS.

Meena *et al.* (2020) investigated the genetic variability, heritability and genetic advance of garlic in Central Uttar Pradesh during *rabi* season. All the treatments were randomly distributed among the plots and replicated thrice. The estimates of phenotypic coefficient of variation (PCV) were higher than the

genotypic coefficient of variation (GCV) for all the characters. These characters would be effective in selection for garlic improvement.

2.2 Heritability and genetic advance

The ratio of genotypic variance to the total variance (phenotypic variance) is known as heritability. Lush (1949) termed thus estimated heritability as broad sense heritability. The estimates of heritability serve as a useful guide to the breeder. The breeder will be able to realize the proportion of variation that is due to genotypic effect in case of broad sense heritability. If heritability of a character is very high, selections for this character would be fairly successful as there would be close correspondence between genotype and phenotype due to a relatively smaller contribution of environment to the phenotype. But for a character of low heritability, selection may be considerably difficult or virtually impractical due to the masking effect of environment on the genotypic effect (Singh., 1990).

Genetic advance is the measure of improvement that can be achieved by practicing selection in population. Since, the estimates of heritability give no indication of the amount of progress expected from the selection they are most meaningful when accompanied by estimates of genetic advance. High genetic advance coupled with high heritability is an indication of more additive gene action (Panse., 1957).

Johnson *et al.* (1955) revealed that the heritability estimates along with expect genetic advance is more useful than the heritability alone for improving a particular trait.

Magdum (1981) compared 35 onion cultivars and reported that the characters like yield, bulb weight, total loss and sprouting percentage recorded fairly higher values with respect to genetic advance.

Patil (1983) scrutinized variability in onion and found that very high estimates of heritability were observed for non reducing sugar before (91.12) and

after storage (99.78) and maximum genetic advance (29.87 %) was observed for bulb weight.

Patil (1984) carried out studies on heritability in onion and reported that the highest values were observed for the characters *viz.*, sprouting loss (98.07 %), rotting loss (97.74 %), total loss (96.5 %) and physiological loss in weight (95.80 %), while the lowest values were observed for polar and equatorial diameter of bulb, neck thickness and root plate diameter. Moreover, the highest genetic advance was observed for bulb weight (29.56 %).

Shaha (1985) performed genetic divergence and variability in onion and noticed higher heritability was observed for sprouting (99.32 %), total loss (98.96 %), bolting (97.55 %), physiological loss in weight (96.21 %) and rotting loss (94.34 %), while root plate diameter showed lowest heritability. The highest genetic advance was registered for bulb weight, total loss, sprouting and bolting characters.

Patil *et al.* (1986) studied the bulb characters such as diameter of bulb and neck thickness showed minimum heritability with lower genetic advance and the characters like per cent bolting, twins, number of leaves, height of plant, bulb weight showed maximum heritability with high value of genetic advance. They also cited that the biochemical characters like dry matter, reducing, non-reducing, total sugars and T.S.S. indicated high heritability with low genetic advance.

Shintre (1994) noticed heritability in onion and found that the highest heritability was observed for dry matter (97.4 %), followed by T.S.S and non-reducing and reducing sugars, while it was lowest for rotting loss, equatorial bulb diameter, yield, bolting and number of leaves per plant. The highest genetic advance was observed for yield, followed by bulb weight, total loss, bolting and PLW loss, while lower genetic advance was observed for root plate diameter, equatorial bulb diameter, neck thickness, polar diameter of bulb and reducing sugars.

Magar (1995) analyzed variability in onion and revealed that the highest genetic advance was observed for yield, followed by average weight of bulb,

alcohol insoluble solids and percentage of non-marketable bulb, while lower genetic advance was observed for protein, neck thickness of bulb, polar diameter, reducing sugars and equatorial diameter of bulb.

Ram *et al.* (2000) executed an experiment on genetic variability in onion and noticed that high heritability (>85) was recorded for bulb diameters number of leaves per plant, yield per plot and bulb weight.

Patil *et al.* (2000) reported that the highest heritability with maximum genetic advance was observed for natural top fall, premature bolting, bulb weight and marketable yield indicating additive gene action and also observed that neck thickness, polar diameter and bulb shape showed non-additive gene action because of high heritability with low genetic advance.

Ghetia and Singh (2000) compared 26 genotypes of onion and observed that high heritability was observed for bulb weight, whereas rest of characters showed moderate coefficient of variation except days to maturity of bulbs as it was low in plant height and dry matter of bulb and they also reported high genetic advance for bulb weight, moderate for bulb yield, equatorial diameter of bulb and number of leaves per plant, while low genetic advance was observed for dry matter of bulb, plant height, neck thickness and polar diameter of bulb.

Mohanty (2001a) observed heritability and genetic advance in onion and revealed that high heritability was observed for neck thickness (81.7 %), bulb weight (80.8 %) and diameter of bulb (55.1 %). The high genetic advance was registered for neck thickness (45.12 %) and number of leaves per plant (44.27 %), while moderate for weight of bulb (39.63 %).

Mohanty and Prusti (2002) evinced that heritability (broad sense) ranged from 55.2 per cent for diameter of bulb to 89.2 per cent for bulb yield and also observed high genetic advance for number of leaves per plant (71.08 %), while it was moderate for weight of bulb (39.63 %).

Mohanty (2002) examined heritability and genetic advance in onion and revealed that heritability ranged from 36.0 to 82.0 per cent. High values of

heritability was obtained for neck thickness (82.2 %) and weight of bulb (76.6 %), while it was moderate for plant height (46.1 %), number of leaves per plant (44.3 %), diameter of the bulb (42.4 %) and bulb yield (36.0 %) which clarified that they were least affected by environmental modification and selection based on phenotype performance would be available.

Mohanty (2004) evaluated 12 varieties of onion and reported that the heritability (broad sense) ranged from 32.6 to 76.5 per cent. High value of heritability was obtained for neck thickness (78.5 %), whereas weight of bulb (69.1 %) and yield (59.0 %) recorded moderate values. He found that the genetic advance varied from 7.26 to 38.55 per cent. The highest genetic gain was realized for neck thickness (38.55 %), followed by number of leaves per plant (35.71 %) and weight of bulb (26.63 %).

Trivedi *et al.* (2006a) suggested estimates of heritability and genetic advance of yield and its components in onion and revealed that high heritability percentage was observed in polar diameter, followed by T.S.S., whereas total yield, neck thickness and percentage of 'A' grade bulb showed moderate heritability. The highest genetic advance was observed for bulb weight followed by A grade bulb percentage, number of leaves per plant, while per cent dry matter of leaves was recorded with lowest genetic advance.

Trivedi *et al.* (2006b) evaluated 22 genotypes of onion and found that heritability in broad sense ranged from 1.5 per cent (dry matter of bulb) to 98.27 per cent (sprouting loss). High heritability coupled with high genetic advance was recorded for sprouting loss (98.27 and 19.23 %, respectively), followed by rotting loss (93.83 and 20.84 %, respectively) and total loss (56.15 and 10.65 %, respectively). High heritability with low genetic advance was recorded for total sugars, non-reducing sugars, marketable yield, polar bulb diameter, T.S.S and physiological loss in weight.

Golani *et al.* (2006) compared 32 genotypes of onion and revealed that heritability in broad sense ranged from 2.40 per cent for bulb girth to 25.10 per

cent for plant height. The genetic advance ranged from 0.28 per cent for bulb girth to 5.14 per cent for 10 bulb weights.

Gurjar and Singhanian (2006) described that the high heritability was observed for plant height, neck thickness and equatorial bulb diameter, while moderate heritability for days to maturity and dry matter content. Expected genetic gain for bulb yield, moderate for neck thickness, bulb weight and dry matter content, while low genetic advance was observed for plant height, days to maturity, number of leaves per plant, equatorial and polar bulb diameter and T.S.S.

Ananthan and Balakrishnamoorthy (2007 a) reported that in onion, higher heritability coupled with high genetic advance was registered for sprouting loss, bulb weight, total loss, reducing sugars and sulphur content. They also observed that all biochemical constituents estimated showed very high values of heritability.

Ananthan and Balakrishnamoorthy (2007 b) investigated 62 genotypes of onion and cited that high values of heritability associated with moderate to high genetic gain were manifested by bulb weight, economic dry matter, chlorophyll a and sulphur content. The genetic gain ranged from 13.44 to 110.83 per cent. Highest estimate of genetic gain was observed for bulb weight.

Hossain *et al.* (2008) studied seven varieties of onion and noticed that characters like number of seed per scape, final plant height, final scape height, fresh weight of bulb and bulb length exhibited high heritability along with high genetic advance as percentage of mean.

Hosamani *et al.* (2010) performed twenty one diverse onion genotypes and found that the heritability in broad sense ranged from 37.33 (number of leaves per plant) to 80.30 per cent (dry matter content). However, higher heritability estimates were obtained for the dry matter content (80.30 %), yield per ha (79.63 %), total soluble solids (74.24 %) and average bulb weight (64.64 %). The genetic advance varied from 10.36 to 47.88 per cent for plant height and average bulb weight respectively.

Singh *et al.* (2010) inspected 16 genotypes of red onion and revealed that the high heritability was obtained for days to harvesting (82.06 %), gross yield (73.26 %), weight of 20 bulbs (66.71 %), plant height (45.81 %) and bulb diameter (33.56 %). The genetic advance was high for marketable yield (22.80 %) and gross yield (17.26 %). However, the plant height, bulb size index, bulb diameter and bulb weight showed low genetic advance.

Navaldehy *et al.* (2011) reported that in onion, high heritability and genetic advance for yield per plot (36.9 and 0.60 %), yield per ha (89.6 and 7.30 %), plant height (93.0 and 11.38 %), bulb size (59.2 and 6.16 %) and bulb weight (65.7 and 18.80 %), suggesting the major role of genetic constitution in the expression of the characters.

Ibrahim *et al.* (2013) observed high heritability estimate for soluble solid content (SSC) and bulb yield (BY) and suggested that these traits could be controlled by additive genetic effect and can therefore be used for improvement through phenotypic selection.

Porta *et al.* (2014) evaluated Fifty-one S₁ lines and reported that the heritability for dry matter and soluble solids were 52.6 % and 36.1 %, respectively and both traits were highly correlated. The development of S₁ lines allowed the expression of genetic variation and the identification of better genotypes for agronomic traits of interest.

Jat and Vikram (2016) revealed that fresh bulb weight (71.7044.35%) and dry bulb weight (65.0039.45%) recorded high heritability and genetic progress in onion.

Hussen and Albaitay (2019) investigated the eight onion genotypes and found that wide heritability for number of leaves per plant, biological yield and total yield exceeded 25 per cent, and the genetic progress had the same result for the above traits of the onion learned.

Pujar *et al.* (2019) studied 40 onion genotypes to determine genetic variability. Moderate to high heritability was observed for all the characters and

high genetic advance as per cent mean indicating that simple selection is sufficient to bring genetic improvement to these traits.

Karak and Hazra (2020) concluded that high GCV coupled with high broad sense heritability and high genetic advance was registered for seed yield per square meter and moderate GCV coupled with high heritability and moderate to high genetic advance was recorded for leaves per plant, scapes per plant and seeds per umbel suggesting early generation selection for improving these characters. Low GCV coupled with heritability and moderate genetic advance was recorded for length of scape and 1000 seed weight.

Meena *et al.* (2020) reported that most of the traits under study exhibited high estimates of heritability *viz.*, plant height, bulb weight, dry weight of bulb, fresh weight of bulb and weight of 10 uniform cloves. The number of cloves had positive and desirable association with bulb yield and selection of these traits would be effective for yield improvement in garlic.

2.3 Correlation coefficient analysis

The yield is a complex character in an inheritance and it depends on many other attributes of plants. Correlation studies help in understanding the association between such traits and for making efficient selection. The chief genetic cause of correlation is pleiotropy and linkage (Falconer, 1960), so it becomes difficult to get the actual idea about positive or negative effect of segregating genes.

Robinson *et al.* (1951) concluded that the correlation values are of potential importance since selection is usually concerned with changing two or more traits simultaneously, Leaner (1958) found them useful for the construction of selection indices and predicating correlated response. Dewey and Lu (1959) used this correlation coefficient first time in plant for plant analysis by following Wright (1921).

Sandhu *et al.* (1975) compared the storage quality of red and white onion varieties and revealed that sprouting was more in red varieties (85.7 %) than

white varieties showing its negative association with T.S.S but was not correlated with loss in the total weight loss in marketable weight and of percentage of rotten bulbs and they also showed that T.S.S. had no relationship with loss in total weight, loss in marketable weight and the percentage of rotten bulbs.

Suthanthirapandian and Muthukrishnan (1980) investigated on correlation in onion and observed that among the yield components, number of bulbs, weight of bulb, T.S.S, shape index and bulb density exhibited significant positive association with yield. Interestingly each component was also highly and positively inter-correlated among themselves. The T.S.S. was also found to be positively associated with yield as well as its components like number of bulbs and shape index.

Magdum (1981) studied the correlation in onion and noticed that the bulb weight had significant positive correlation with bulb diameter (both equatorial and polar) yield and T.S.S. He also reported that the equatorial bulb diameter was positively correlated with yield, T.S.S and negatively correlated with per cent shrinkage and total per cent loss.

Suthanthirapandian and Muthukrishnan (1982) performed correlation in onion and revealed that the number of leaves and weight of bulb exhibited significant positive association with yield as well as between themselves.

Patil (1983) cited that the bulb weight had positive correlation with neck thickness, bulb diameter (both polar and equatorial) and per cent rotting. The equatorial bulb diameter was positively correlated with polar diameter, total loss, physiological loss in weight, sprouting and rotting.

Patil (1984) observed that the bulb weight had positive correlation for bulb diameter, neck thickness, diameter of root plate, yield per hectare, per cent of twins and per cent of sprouting.

Patel *et al.* (1985) evaluated interrelationship between bulb yield and important plant characters of onion and reported that the interrelationship among plant height, number of leaves per plant, diameter and weight of bulb were

positive and significant at phenotypic and genotypic level, while neck thickness showed significantly negative correlation with plant height, number of leaves per plant, diameter and weight of bulb at both the levels.

Shaha (1985) studied divergence and variability in onion and revealed that the bulb weight showed positive correlation with bulb diameter (both equatorial and polar) and neck thickness, while it was negative correlation with percentage of bolting and percentage of dry matter and also reported that neck thickness was positively correlated with bulb weight, bulb diameter (polar and equatorial), per cent total loss, sprouting and physiological loss in weight loss.

Patil *et al.* (1987) conducted correlation studies, morphological and storage characters of some onion varieties and noticed that plant height, number of leaves per plant, polar diameter, equatorial diameter, T.S.S., marketable yield, total yield, minimum doubles and bolters except neck thickness, should be minimum as they are positively correlated with storability.

Pal *et al.* (1988) documented correlation in onion and mentioned that there was a positive and highly significant phenotypic correlation between yield and bulb weight, bulb diameter (both horizontal and vertical) and plant height.

Pal and Singh (1988) examined the biochemical characters and found that dry matter was positively correlated with total soluble solids, total sugars and non-reducing sugars, while negatively correlated with storage loss, dry ration and reducing sugars.

Shintre (1994) observed variability in onion and revealed that yield was positively correlated with plant height, number of leaves per plant and bulb diameter.

Magar (1995) evinced correlation in onion and cited that equatorial diameter of bulb was positively correlated with percentage of twin and yield per hectare. The per cent of unmarketable bulb was negatively correlated with percentage of marketable bulb and yield per hectare. He also opined that the percentage of marketable bulb was positively correlated with yield per ha.

Ravankar *et al.* (1998) demonstrated genetic correlation in onion and observed that high and positive genotypic as well as phenotypic correlation were recorded for yield per hectare with polar and equatorial diameter and the ten number of bulb weight. They also noticed that yield per hectare had showed negative correlation with number of leaves per plant, T.S.S and per cent dry weight.

Ram *et al.* (2000) evaluated genetic variability in onion and reported that yield per plot was significantly and positively correlated with plant height, number of leaves per plant, neck thickness, bulb weight, bulb diameter but negatively correlated with dry matter and T.S.S.

Ghetia and Singh (2000) studied correlation in onion and reported that bulb yield per plot was found to be highly significant and positively correlated with plant height, number of leaves per plant, bulb weight, polar and equatorial diameter of bulb. The bulb yields also negatively correlated with neck thickness, dry matter of bulb and leaves.

Rajalingam and Haripriya (2000) executed an experiment on correlation in onion and observed that the yield components like plant height, leaf length, number of leaves per plant, weight of bulb, bulb diameter and bulb length had exhibited significant positive association with yield.

Saranganath *et al.* (2000) analyzed correlation in the eight onion genotypes and reported that the bulb yield had significant positive correlation with plant height, number of leaves per plant, bulb length and bulb diameter.

Mohanty (2001a) studied correlation in onion and revealed that the phenotypic and genotypic association of bulb yield had significantly positive correlation with plant height, number of leaves per plant, diameter of bulb and weight of bulb but significantly negative correlation with neck thickness.

Mohanty and Prusti (2002) proclaimed that yield showed positive and significant association with plant height, number of leaves per plant, weight of

bulb at phenotypic and genotypic level. The diameter of bulb exhibited significantly positive correlation with yield at genotypic level only.

Mohanty (2002) scrutinized correlation in onion and found that bulb yield was significantly and positively correlated with plant height, number of leaves per plant, diameter and weight of bulb but significantly negative correlated with neck thickness.

Rahman *et al.* (2002) perceived correlation in onion and reported that total bulb yield (kg ha^{-1}) had significant positive correlation with plant height, leaf number per plant, bulb diameter and bulb yield per plant but had significant negative association with plant spacing.

Mohanty (2004) studied correlation in onion and mentioned that the phenotypic and genotypic association of bulb yield was significantly positive with plant height, number of leaves per plant, diameter and weight of bulb but significantly negative with neck thickness.

Trivedi *et al.* (2006a) conducted an experiment on correlation between yield and its components in onion and revealed that yield is a poly genetically controlled character was significantly and positively associated with plant height, dry matter of leaves, equatorial diameter, bulb weight, per cent A grade bulb and marketable yield. Further, it was positively correlated with polar diameter, B grade bulb and significantly and negatively correlated with T.S.S., per cent of C grade bulb and bolter plant height was positively correlated with equatorial diameter T.S.S., A grade bulb, bolters and marketable yield.

Trivedi *et al.* (2006b) investigated correlation in storage life of onion and observed that yield was positively and significantly associated with bulb weight and equatorial bulb diameter. Total loss was positively and significantly associated with loss due to rotting and polar bulb diameter and negatively associated with T.S.S., reducing, non-reducing and total sugars.

Golani *et al.* (2006) documented correlation of yield components in onion and revealed that the bulb yield showed significant and positive association with

number of leaves per plant, bulb length, bulb girth and 10 bulbs weight at both genotypic and phenotypic levels. However, bulb yield was significantly and negatively correlated with T.S.S. at both the levels.

Gurjar and Singhanian (2006) found correlation in onion and cited that the bulb yield was significantly and positively associated with plant height, number of leaves per plant, bulb neck thickness and bulb diameter (polar and equatorial), while bulb yield had negative correlation with T.S.S. and dry matter. Neck thickness had significantly positive correlation with all the characters except T.S.S. and dry matter content.

Foroudi (2006) carried out studies in quantitative and qualitative characters in onion and revealed that a highly significant positive correlation was found between T.S.S. and dry matter of bulbs. During storage, a significant negative correlation was observed between bulb firmness, sprouting and rotting.

Ananthan and Balakrishnamoorthy (2007 b) executed correlation in onion for economic dry matter yield and found that economic dry matter yield was positively and significantly associated with plant height, number of leaves per plant, bulb weight, total soluble solids, bulb weight, pyruvic acid and sulphur content.

Haydar *et al.* (2007) demonstrated the correlation in ten varieties of onion and indicated that the bulb yield had highly positive and significant correlation with bulb length and bulb diameter. However, bulb diameter also had positive and significant association with plant height and weight of bulb.

Yaso (2007) performed correlation in onion genotypes and revealed that bulb weight had positive correlation with plant height, number of leaves per plant and time of maturity in both the seasons. He also opined that plant height had positive correlation with number of leaves per plant, time of maturity and total soluble solids (T.S.S.).

Hossain *et al.* (2008) described interrelationship between yield and yield contributing characters in onion and reported that bulb length, bulb diameter and

scape diameter was positively and significantly correlated with fresh weight of bulb.

Hosamani *et al.* (2010) investigated the twenty one diverse onion genotypes and noticed that bulb yield was significantly positive with bulb diameter, bulb neck thickness and average bulb weight.

Singh *et al.* (2010) evinced correlation in the 16 diverse genotypes of red onion and indicated that the gross yield had strong positive correlation between bulb diameters, bulb size index and bulb weight at both genotypic and phenotypic levels. However, the bulb diameter had negative correlation with number of leaves per plant and neck thickness at genotypic level.

Abdissa *et al.* (2011) reported that bulb weight was positively and strongly correlated with bulb length and diameter.

Navaldehy *et al.* (2011) observed that yield per hectare had positive and highly significant correlation with yield per plot, TSS and bulb size both at phenotypic and genotypic levels, respectively.

Saini and Maurya (2014) observed that bulb yield had significant and positive correlation with plant height volume of bulb, bulb weight, equatorial bulb diameter, neck thickness, dry matter content and nitrogen content in leaves and had significant negative correlation with number of doubles bulb.

Chattoo *et al.* (2015) reported that the total bulb yield was found to be positively correlated with average bulb weight, days to harvest, per cent splitted bulb, equatorial diameter, dry matter, polar diameter, total soluble solids, plant height, collar thickness and per cent double genotypes.

Sharma *et al.* (2015) studied correlation in 28 genotypes of *kharif* onion (*Allium cepa* L.) along with a check *i.e.*, Agri Found Dark Red and found that out of 11 characters, total yield showed positive and significant association with plant height, number of leaves per plant, collar height, collar girth, leaf length, equatorial diameter of bulb, average weight of bulb and marketable bulb yield,

indicating that an intense selection for these characters improve bulb yield in onion.

Bhatt (2015) evaluated 12 genotypes of garlic and indicated that bulb yield had highly significant positive correlation with number of cloves per bulb, ascorbic acid and weight of 10 uniform cloves at both the levels.

Kamal (2015) carried out an experiment on five genotypes of garlic. Result revealed that total yield was positively and significantly correlated with plant height, head weight, head diameter, head length, clove weight, clove diameter and TSS. Plant height and head diameter were positively and significantly correlated with all traits except number of cloves per head.

Raghuwanshi *et al.* (2016) association study resulted plant height at 30 DAT showed significant and positive correlation with plant height at 60 DAT, number of leaves plant⁻¹ at 60 DAT and number of leaves plant⁻¹ at 30 DAT. They also reported that plant height at 60 DAT showed highly significant and positive correlation with number of leaves plant⁻¹ at 60 DAT, number of leaves plant⁻¹ at 30 DAT, plant height at 90 DAT, neck thickness, number of leaves plant⁻¹ at 90 DAT and equatorial diameter.

Agrawal and Tiwari (2016) evaluated 21 genotypes of garlic for two years at Pant Nagar. Results revealed that bulb yield both at genotypic and phenotypic levels showed significant and positive correlation with bulb weight, clove weight, bulb diameter, clove length, leaf area index and neck diameter during both the years. Genotypic correlations were higher than their corresponding phenotypic values for most of the character combinations establishing predominant role of heritable traits. Positive direct effect of bulb weight, clove length and leaf area index during both the years indicated good scope for improvement in bulb selecting the genotypes bearing bigger and heavier bulbs and cloves along with broad leaves.

Hussen and Albaitay (2019) reported that total yield showed significant negative phenotypic and genotypic correlation coefficient with all traits *i.e.*, number of leaves per plant, bulb length, bulb diameter, bulb weight and T.S.S.

Segundo *et al.* (2020) observed that the phenotypic and genotypic correlations reveal low associations between the traits assessed in all experiments. The phenotypic and genotypic correlations among plant cycle, plant architecture, average bulb mass, bulb firmness and bulb postharvest vary from low to high, depending on the origin of the population of the genotype evaluated.

2.4 Path coefficient analysis

To find out a clear picture of the inter relationship between yield and yield components, direct and indirect effects should be determined by using path analysis at genotypic level.

The concept of path coefficient was originally developed by Wright (1921). But the technique was first used in plant breeding by Dewey and Lu in 1959. A path coefficient is simply a standardized partial regression co-efficient and as such measures the direct influence of one variable upon another and permits the separation of the correlation co-efficient into components of direct and indirect effects.

Suthanthirapandian and Muthukrishnan (1982) in onion revealed that very high direct effects of days to maturity on yield. Number of leaves influenced the yield both by its direct effect and high indirect effect mainly through weight of plant. They also observed that, number of leaves per plant, days to maturity, shape index had positive direct effects on yield while plant height had negative direct effects in onion.

Rajalingam and Haripriya (2000) examined that plant height, leaf breadth, weight of plant, bulb length, shape index. days to maturity and harvest index had direct positive effect on yield while leaf length, number of leaves, number of bulbs, bulb diameter, and volume of bulb had negative direct effects.

Singh and Tiwari (2001) evaluated that the genotypic path coefficients were higher than the corresponding phenotypic values indicating a masking effect of the environment and among the yield components, bulb diameter and bulb weighthad the maximum contribution towards onion bulb yield.

Mohanty (2001b) concluded that number of leaves per plant had high positive direct effect on yield. Other characters also exerted high positive indirect effect through this trait on yield suggesting to give emphasis on such trait independently or in combination with thin neck trait, while imposing selection for amenability in bulb yield of onion and plant height displayed a negative direct effect on yield.

Mohanty (2004) noticed that in onion weight and diameter of bulb had positive direct effect on yield and positive indirect effect through each other on yield.

Gurjar and Singhanian (2006) observed that the plant height, number of leaves per plant, bulb neck thickness, bulb weight and equatorial and polar bulb diameter had high positive direct effect with each other on yield of onion.

Golani *et al.* (2006) suggested that the *viz.*, traits number of leaves per plant and bulb girth exerted maximum positive and direct effect on yield thus emphasizing on such traits during selection for amenability in bulb yield of onion.

Haydar *et al.* (2007) revealed that plant height, bulb length and bulb diameter were the major components of bulb yield in onion.

Yaso (2007) executed an experiment on path coefficient analysis and showed that the plant height had high positive direct effect on bulb weight and leaf number exhibited positive and direct effect on bulb weight in onion.

Aliyu *et al.* (2007) revealed that bulb diameter, plant height and number of leaves per plant were the principal components of yield.

Hosamani *et al.* (2010) found bulb neck thickness, bulb yield, bulb length, TSS and plant height as good contributors to bulb yield.

Degewione *et al.* (2011) studied the genotypic path coefficient analysis and found that bulb dry weight exerted maximum positive direct effect on bulb yield

and also exhibited positive association with bulb yield per plant, suggesting their possible utilization to improve bulb yield per plant.

Awale *et al.* (2011) genotypic path-coefficient analysis demonstrated that bulb dry weight exerted maximum positive direct effect on bulb yield and also exhibited positive association with bulb yield per plant, suggesting their possible utilization to improve bulb yield per plant.

Dewangan and Sahu (2012) by path coefficient analysis noticed that number of leaves per plant, plant height, leaf thickness, TSS, polar and equatorial diameter of bulb, average bulb weight and marketable bulb yield exhibited positive direct effect on total bulb yield.

Saini and Maurya (2014) reported that phosphorous in leaves, followed by bulb and neck thickness had highest positive direct effect on bulb yield.

Chattoo *et al.* (2015) described that average bulb weight had maximum positive direct effect on total bulb yield, followed by days to harvest, per cent splitted bulb, equatorial diameter, dry matter, polar diameter, TSS, plant height, collar thickness and per cent double genotypes, indicating true and perfect relationship.

Sharma *et al.* (2015) performed path co-efficient analysis for bulb yield and reported that it was expressed positive and significant association with plant height, number of leaves per plant, collar height, collar girth, leaf length, equatorial diameter of bulb, average weight of bulb and marketable bulb yield, indicating that an intense selection for these characters improve bulb yield in onion.

Solanki *et al.* (2015) conducted path coefficient analysis in 31 genotypes of onion and concluded that polar diameter had the highest positive direct effect, followed by plant height at 60 DAT, TSS, plant height at 90 DAT, number of leaves plant⁻¹ at 90 DAT and polar equatorial diameter were the most important traits contributing towards bulb yield plant⁻¹. Direct selection of equatorial diameter, neck thickness, days to maturity, the number of leaves plant⁻¹ at 30 and

60 DAT and plant height at 30 DAT should be avoided instead of indirect selection.

Pyasi and Tiwari (2016) suggested that characters like plant height, collar thickness, polar diameter, equatorial diameter, fresh weight of bulb and TSS had positive direct effect on average weight of marketable bulb yield and hence purposeful selection based on these traits would help in improvement of *kharif* onion genotypes.

Raghuwanshi *et al.* (2016) by path coefficient analysis mentioned that polar diameter had the highest positive direct effect, followed by plant height at 60 DAT, TSS, plant height at 90 DAT, number of leaves plant⁻¹ at 90 DAT and polar equatorial diameter were the most important traits contributing towards bulb yield plant⁻¹. Direct selection of equatorial diameter, neck thickness, days to maturity, number of leaves plant⁻¹ at 30 and 60 DAT and height at 30 DAT should be avoided instead of indirect selection.

Jat and Vikram (2016) revealed that the genotype cvs. Pusa Madhavi (38.48 t ha⁻¹), Bhima Sakti (30.93 t ha⁻¹) and Bhima Kiran (30.16 t ha⁻¹) performed better in terms of yield and yield attributing characters and therefore, these lines may be used for breeding programme. Dry weight of bulb had positive and highly significant correlation with yield per hectare and bulb yield per plot both at phenotypic and genotypic levels, respectively.

Segundo *et al.* (2020) concluded that cycle and bulb postharvest demonstrated little direct and indirect effects on average bulb mass in 53 advanced lines and showed the impracticability of indirect selection for onion average bulb mass.

2.5 Genetic diversity

Genetic diversity is the genetic differences as observed between the individuals or genetic stocks with respect to individual traits or an array of traits. It is the result of inherent genetic variation present in the germplasm. The knowledge of nature and degree of genetic divergence is useful in selecting the

desirable parents for breeding programme. Genetic divergence has been successfully utilized by different workers in various crops. Mahalanobis (1936) described D^2 statistics as a tool for quantitative estimate of genetic divergence among the population. Rao (1948) suggested more flexible method, which would replace the measurements on large number of characters, all of which contribute in some degree towards discrimination by relatively few measurements.

Mahalanobis *et al.* (1949) applied D^2 statistics in a detailed statistical study of anthropometric data of Uttar Pradesh, India.

Moll *et al.* (1962) reported no relationship between geographical distribution and genetic diversity and its reflection in expression of heterosis.

Murthy and Arunachalam (1966) revealed that geographical distribution and genetic diversity could not be directly related to any of the crops and also showed that genetic diversity among genotypes of common geographical origin could be due to homogeneity, genetic architecture, past history of selection, developmental traits and degree of general combining ability.

Patil (1983) studied variability in onion and revealed that the thirty seven populations were grouped into eighteen clusters on the basis of D^2 values. The D^2 statistic showed that there was adequate diversity between strains with D^2 values ranged from 187.48 to 5681.74.

Patil (1984) mentioned variability and correlation in onion and showed that 45 varieties were grouped into twelve clusters on the basis of D^2 values. The D^2 values ranged from 36.87 to 3557.37.

Patil and Kale (1985) conducted genetic divergence in onion with respect to storage quality and indicated that clustering with pattern proved that genetic divergence was not associated with geographic origin as the distribution of accessions into various clusters was fairly at random.

Shaha (1985) evaluated 42 onion cultivars obtained from different geographic regions for their morphological, biochemical variability and genetic diversity in bulb characters. The D^2 statistics showed that there was adequate

diversity among the cultivars with D^2 values ranged from 46.23 to 6773.56. On the basis of these values, 42 onion cultivars were grouped under 14 clusters. Clustering pattern of the cultivars does not necessarily follow the geographical distribution.

Shintre (1994) suggested variability in onion and observed that thirty cultivars were grouped into thirteen clusters on the basis of D^2 values. The D^2 values ranged from 6.51 to 1330.76.

Magar (1995) evaluated 26 white onion cultivars and reported that these cultivars were grouped into twelve and eleven clusters on the basis of D^2 values based on morphological and biochemical characters, respectively.

Mohanty (2001b) found analysis of genetic divergence in *kharif* onion and mentioned that distribution of accessions into various clusters showed no uniformity and those belonging to the same place, were distributed among various clusters, thus ruling out the association between geographical distribution of genotypes and genetic divergence.

Mohanty and Prusti (2002) scrutinized Mahalanobis generalized distance analysis in *Kharif* onion and noticed that considerable variability among the accessions for the aggregate effect of all the characters. The population was grouped into three clusters, which include two monogenic groups. Genetic divergences not parallel to geographic distribution. Weight of bulb and neck thickness contributed predominately towards total divergence.

Gurjar *et al.* (2003) demonstrated divergence analysis in local cultivars of onion and observed that the clusters separated by largest statistical distance (D^2) showed the maximum divergence such as cluster II and V in experiment I and cluster VII and XIII in experiment II and exhibited that it would be desirable to make crosses among the genotypes belonging to different clusters separated by high genetically distances to evolve desirable high yielding lines such crosses were expected to throw superior segregates.

Khar *et al.* (2006) executed an experiment on genetic diversity analysis in elite lines of late *Kharif* onion and revealed that geographical distribution did not play an important role in grouping the genotypes. They also found that marketable yield, T.S.S. and total yield contributed maximum towards total divergence.

Dhotre *et al.* (2010) conducted a genetic diversity study on 14 genotypes and divided them into five groups, among which the V group was significantly different from the other groups. The first group includes four genotypes, and the second group has up to seven genotypes. The shortest distance between clusters is observed between IV and II; groups IV and I showed the largest distance between groups. Among the 17 quantitative traits, the only traits that contributed to diversity were fresh bulb weight, equatorial diameter, bulb yield, and total storage loss. They also observed that the pattern of genetic diversity has nothing to do with its geographic distribution.

Rashid *et al.* (2012) studied thirty genotypes, collected from India, Burma, and Bangladesh. Altogether five clusters were formed. The pattern of distribution of genotypes into five clusters was random, demonstrating that the geographical isolation might not be the only factor causing genetic diversity. Leaf length and sulfur content contributed predominantly towards genetic divergence. Cluster III recorded the highest means for number of leaves per plant, leaf length, bulb length, plant height, and bulb yield. The results obtained from D² analysis was confirmed by canonical analysis. The genotype G12 showed highest mean performance for moisture content (88.49 %), G13 for leaf length (39.06 cm), G15 for neck diameter at vegetative stage (11.21 mm), bulb length (49.09 mm), plant height (64.82 cm) and as well as bulb yield (13.17 t ha⁻¹), G19 for per cent sulfur content (0.84) and G26 for number of leaves per plant (12), respectively.

Wamser *et al.* (2012) concluded the length of the pseudo stem, number of leaves per pseudo stem, stem diameter, bulb diameter, height of the bulb, bulb weight, height:diameter ratio; total production of bulbs, bulb shape, flowering percentage and percentage of rotten bulbs. A matrix of dissimilarity was prepared by using Mahalanobis distance method. The morphological and agronomic traits

used were sufficient to characterize the genotypes, indicating that breeding programmes have a wide genetic base for the development of new cultivars.

Singh *et al.* (2013) described 38 long day onion accessions. All accessions were grouped into six different clusters. The highest inter cluster distance was observed between IV and V and lowest between II and VI. Based on cluster means the important cluster was I for plant height and per cent marketable bulbs cluster IV for mean yield, total yield and equatorial diameter and cluster III for the number of leaves, collar thickness and average bulb weight. Accordingly, parents could be selected for hybridization. Principal component analysis, first two principal component accessions accounted for 59.29 per cent of the variance among 38 accessions. The greater part of the variance was accounted for other traits such as plant height, collar thickness, percent marketable bulb yield, polar diameter of the bulb and neck thickness. The high diversity found in the accessions showed its great potential for improving qualitative as well as quantitative traits in long day onion.

Kale *et al.* (2014) evaluated forty four onion genotypes during *Rabi* season for nineteen characters. The results revealed that considerable variability among the D² genotypes. Based on values, the genotypes were grouped into eleven clusters. There were twenty four genotypes in cluster I, five genotypes in cluster VII, four genotypes in cluster IX, three genotypes in cluster VIII, two genotypes in cluster VI and the cluster II, III, IV, V, X and XI contained solitary genotype. The maximum inter cluster D² value of 30.67 was observed between cluster VI and IX, followed by the cluster IX and X. Cluster VII showed maximum intra cluster diversity ($D^2=10.51$), followed by cluster IX ($D^2=10.17$). Total soluble solids contributed maximum towards total divergence, followed by leaf area, dry matter, magnesium, calcium, vitamin C, bulb splitting per cent, pyruvic acid and bulb yield.

Akter *et al.* (2015) documented genetic divergence of ten genotypes analyzing 16 characters with the help of multivariate analysis. They clustered the genotypes in three clusters. Cluster III, Cluster I and II had five, three and two

genotypes, respectively. The inter cluster distance was lesser than the inter cluster distances. The maximum inter cluster distance (6.336) was observed between cluster II and III while the distance was least between cluster I and II (3.876). The genotypes within each cluster shared close similarity. They recommended genotypes Indian big (G1) and Patnai pink (G5) from the cluster II and genotypes Taherpuri, Indian medium (G1), Big single bulb (G7), Big double bulb (G8). Small single bulb (G9) and Small double bulb (G10) from the cluster III as potential parents for future genetic improvement work.

Islam *et al.* (2017) found variations for bulb yield, morphological traits and quality parameters among onion genotypes grown in *kharif* season. There was 2.08 and 1.44-fold difference between lowest and highest yielding genotypes for yield and TSS, respectively. Agrifound Dark Red was found superior for yield and total phenols content. Antioxidant activity, as measured by CUPRAC and FRAP had 1.73 and 3.09 fold difference between highest and lowest performers and ranged between 1.70-2.95 μmol and 0.30-0.93 $\mu\text{mol Trolox g}^{-1}$ FW, respectively. Bulb yield had positive association with total phenols content, but negative association with TSS values. No single variety per selection was found consistently superior for all the traits.

Ratan *et al.* (2017) screened twenty nine onion genotypes including one check variety (Arka Pragati) at IIHR, Bengaluru, Karnataka during *kharif* season for yield and quality parameter. They identified a high yielding germplasm PBR- 14-26 (47.44 t ha⁻¹) which mature on days after planting. It also had high number of rings per bulb. Highest ten bulb weight was observed in PBR-14-60 (844.00 g) with a considerably higher yield 41.47 t ha⁻¹. They also identified an early maturing genotype PBR-14-59 which matures on 82 days after planting. Highest TSS and dry weight was observed in PBR-14-59 (13.17 %) and PBR-14-60 (15.60 % of fresh wt.), respectively. Plant height was maximum in PBR-14-37 (81.58 cm), followed by PBR-14-18. Maximum polar diameter and equatorial diameter were reported in PBR-14-64 and PBR-14-46, respectively.

Santra *et al.* (2017) performed genetic variability in *kharif* onion and reported high GCV for plant height, number of leaves per plant, polar diameter, equatorial

diameter, neck thickness, average marketable bulb weight, marketable yield, days to maturity, total soluble solids, pyruvic acid and phenol content in bulbs. Plant height (0.802), number of leaves (0.630), polar diameter (0.572), equatorial diameter (0.919) and average bulb weight (0.974) exhibited significant and positive correlation with total bulb yield.

Perez *et al.* (2018) executed quality traits variation in open pollinated onion collection from Western Europe and identified superior genotypes for pyruvic acid, fructan and dry matter content. They also confirmed significant link between individual quality components in onion bulbs.

Dangi *et al.* (2018 a) observed variability for quantitative and qualitative traits in onion genotypes. The correlation between total soluble solids and dry matter ($r = 0.45$); pyruvic acid and dry matter ($r = 0.35$) were positive and significant, while the association between TSS and TPC ($r = -0.32$) was negative and significant.

Dangi *et al.* (2018 b) investigated genetic diversity of 58 onion genotypes using 13 traits and clustered the genotypes into four groups. Cluster I comprised of accessions with highest yield, yield related traits and high pungency. Cluster II composed of accessions with highest TSS and dry matter content. Cluster III comprised of accessions having highest polar diameter and total phenols. Cluster IV comprised of accessions having low yielding potential. Five principal components (PC1 to PC5) accounted for 78.5 per cent total variation. In the first principal component, plant height, leaf length and pseudo stem diameter were the most contributing traits, whereas dry matter, total soluble solids (TSS) and pyruvic acid were the principal traits of the second principal component.

Islam *et al.* (2019) described variability for morphological and biochemical parameters in onion. They reported wide variation for the quality traits like TSS, pungency, total phenols, antioxidant activity and these traits were independent of the skin colour group.

Jeevitha *et al.* (2020) using Mahalanobis D^2 statistics to study the genetic diversity of 56 onion genotypes, it was found that GKD3, Bhima Shakti, GKD42,

Arka Kalyan, Bhima Super, RGP1, GKD75, these genotypes exist in clusters II, III, IV, V And VI and lines L883, Pune Red, L863, DOGR344, L355, Bhima Kiran, PRO7, RGP2, RGP3 exist in cluster I expressed moderate diversity. Therefore, they can be used as lines in hybridization procedures to improve growth, performance, and storage traits.

CHAPTER III

MATERIAL AND METHODS

Chapter III

MATERIAL AND METHODS

The present investigation entitled “**Genetic Characterization of Onion (*Allium cepa* L.) Genotypes**” was carried out at the PG Research Block of the College of Horticulture, Rajendranagar, Sri Konda Laxman Telangana State Horticultural University during the *rabi*, season of the year 2020-2021. The details of material and methods used to carry out the experiment and statistical procedures are described in this chapter.

3.1 Geographical and weather conditions of the experimental site

The experimental site is located at College of Horticulture, Rajendranagar, Hyderabad. The experimental site falls under semi-arid tropical climate with an average rainfall of 615.6 mm located at an altitude of 542.3 m above mean sea level at latitude of 17.90° North and longitude of 78.23° East. The mean monthly meteorological data *i.e.*, rainfall, mean minimum and maximum temperature, relative humidity recorded during the period of experimentation is presented in Appendix - I.

3.2 Seed material

The seed material for the present investigation consisted of forty onion genotypes, which were procured from ICAR- Directorate of Onion and Garlic Research Station, Rajgurunagar, Pune. The list of genotypes is given in Table 3.2.

3.3 Study of genetic diversity of onion

3.3.1 Nursery

The seeds of forty genotypes were raised in pro-tray in the green house of College of Horticulture, Rajendranagar during third week of November, 2020 and water was sprinkled regularly. The seeds germinated within 10 to 14 days after sowing and the seedlings were transplanted to the main field in second week of January, 2021.

3.3.2 Layout details

The experiment with forty genotypes of onion was laid out in a Randomized Block Design (RBD) with three replications.

Name of the crop	:	Onion (<i>Allium cepa</i> L.)
Design	:	Randomized Block Design (RBD)
Genotypes	:	40
Replications	:	03
Season	:	Rabi, 2020
Location	:	COH, Rajendranagar, PG research block, Hyderabad
Plot size	:	3.0 m x 1.5 m
Spacing	:	15 cm x 10 cm

3.3.3 Main field

The land was thoroughly ploughed to a depth of 15-20 cm and brought in to a fine tilth. Finally, it was levelled and divided into plots as per the layout.

Well decomposed farm yard manure at 25 t ha⁻¹ was incorporated in to the soil uniformly during the final ploughing as a basal application. Nitrogen, phosphorus and potash were applied at 100, 50 and 50 kg ha⁻¹. Nitrogen was applied in the form of urea (46.2 % N), phosphorus in the form of single super phosphate (16 % P₂O₅) and potash in the form of murate of potash (60.1 % K₂O). Entire dose of phosphorus, potash and half dose of nitrogen is applied as basal dose and the remaining half dose of nitrogen is applied in two splits viz, 25th day and 50th day after transplanting.



Plate 1. Overall view of experimental field



Fig 3.1. Plan and layout view of the experimental site

3.3.4 Transplanting

Healthy and uniform seedlings were selected for this purpose. Seedlings were transplanted in the plots at a spacing of 10 cm x 15 cm, accommodating 40 plants in each plot. Immediately after transplanting irrigation was given.

3.3.5 Interculture and after care

Gap filling was done within a week after transplanting. Irrigation was given uniformly at 6-8 days intervals depending on requirement during crop period. Weeding was done at 20 days interval from transplanting stage to maturity stage. Timely plant protection measures were followed. The recommended cultural operations were carried out timely or as and when required for better crop growth.

3.3.6 Harvesting

Generally, for harvesting of onion bulbs, the optimum time is when the leaves turned yellow, becoming dry at the top and more than 50 per cent neck fall was observed. In the present investigation also harvesting was done as per the maturity indices. Harvested bulbs were field cured for about four days and then tops were cut and leaving 2.5-3.0 cm neck length, then bulbs were kept for shade curing for three weeks.

3.4 Observations recorded

Five plants were selected at random from each genotype in each replication. Randomly selected plants were tagged for observations. All the observations were recorded from the five randomly selected plants.

3.4.1 Growth and bulb parameters

3.4.1.1 Plant height (cm)

It was measured from the base to the tip of the plants was expressed in centimeters at the time of final harvest with the help of measuring scale.

3.4.1.2 Number of leaves per plant

The number of leaves both green and dried leaves were counted at the time of final harvest and mean expressed in number.

3.4.1.3 Days to maturity (days)

It was counted from the transplanting to the day when more than half of the population in each plot reached neck fall or leaf yellowing stage and expressed in days.

3.4.1.4 Neck thickness (cm)

Neck thickness was measured at the time of harvest by vernier calliper and expressed in centimeter.

3.4.1.5 Equatorial bulb diameter (cm)

It is the maximum distance between opposite sides at right angles (to the polar diameter) and was measured by vernier calliper in centimeter from the same five randomly selected bulbs, which were used for recording polar diameter and mean equatorial diameter was worked out.

3.4.1.6 Polar bulb diameter (cm)

It was measured by vernier calliper in centimeter from the junction of the root plate to the top of the bulb from the same bulbs, which were used for recording neck thickness and the mean polar diameter was worked out.

3.4.1.7 Average bulb weight (g)

Five randomly selected bulbs were with the help of electronic balance and mean values were worked out and expressed in grams.



Plate 2. Measurement of bulb diameter with vernier caliper

3.4.1.8 Yield (t ha⁻¹)

The total bulb yield was calculated after harvest of the crop. The bulbs were weighed after separating from the top. The total yield per plot was calculated and after multiplication with hectare factor, the yield per hectare was calculated.

3.4.2 Morphological characters

3.4.2.1 Bulb colour

Bulb colour was assigned based on visual observation.

3.4.2.2 Bulb shape

Bulb shape was assigned based on visual observation.

3.4.3 Bulb quality parameters

3.4.3.1 Total soluble solids (°Brix)

It was measured by using a hand refractometer on which a drop of juice extracted from the bulbs is placed and observations were recorded and expressed in (°Brix).

3.4.3.2 Ascorbic acid content (mg 100⁻¹g)

Preparation of sample and titration

Ten grams of pulp was grounded and blended with three per cent metaphosphoric acid (HPO₃) and volume made up to 100 ml with three per cent HPO₃. The contents after shaking well were filtered through Whatman No.1 filter paper. Ten ml of the filtrate was titrated against 2, 6- Dichlorophenol-Indophenol dye until the light pink colour persisted for at least 15 seconds. The ascorbic acid content was estimated using the given formula and expressed as mg 100⁻¹g (Ranganna. 1986).

Ascorbic acid= $\frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up} \times 100}{\text{Aliquot of extract taken for estimation} \times \text{Volume of sample taken}}$

(mg 100⁻¹g)

Table 3.2. List of genotypes used for evaluation along with their sources

S.No.	Genotypes	Color	Source of collection
1	1773	Red	ICAR - Directorate of Onion and Garlic Research, Rajgurunagar, Pune
2	Bhima Shubra	White	- do -
3	1774	Red	- do -
4	W-125	White	- do -
5	1742	Red	- do -
6	1771	Red	- do -
7	1784	Red	- do -
8	W-203	White	- do -
9	1768	Red	- do -
10	1772	Red	- do -
11	1769	Red	- do -
12	W-182	White	- do -
13	Bhima Shakti	Red	- do -
14	W-464	White	- do -
15	1745	Red	- do -
16	W-177	White	- do -
17	W-253 cp	White	- do -
18	1770	Red	- do -
19	Bhima Kiran	Red	- do -
20	W-390	White	- do -
21	Bhima Shwetha	White	- do -
22	W-398	White	- do -
23	W-405	White	- do -
24	1785	Red	- do -
25	Bhima Raj	Red	- do -
26	Bhima Safed	White	- do -
27	W-210	Red	- do -
28	Bhima Red	Red	- do -
29	W-226 cp	White	- do -
30	W-444	White	- do -
31	Bhima Super	Red	- do -
32	W-045	White	- do -
33	1744	Red	- do -
34	W-364	Red	- do -
35	W-405 cp	White	- do -
36	W-498	White	- do -
37	W-500	White	- do -
38	W-1786	White	- do -
39	W-507	Red	- do -
40	W-246 cp	White	- do -

3.5 Statistical analysis

The mean values of observations were computed for each of the ten characters for each of the genotype in each replication, were subjected to statistical analysis.

3.5.1 Analysis of variance (ANOVA)

The data available on individual characters were subjected to the method of analysis of variance commonly applicable to the randomized block design. The analysis of variance was carried out according to Panse and Sukhatme (1985) in the following form.

Table 3.2 Analysis of variance

Sources of variation	Degrees of freedom	Mean sum of squares	Expected mean sum of squares
Replication	r-1	RMS	$\sigma^2e + g\sigma^2r$
Genotypes	g-1	GMS	$\sigma^2e + r\sigma^2r$
Error	(r-1) (g-1)	EMS	σ^2e
Total	(rg-1)		

Where,

r = number of replications

g = number of genotypes

The genotype mean square (GMS) was tested against error mean square (EMS) by 'F' test at $n_1 = (g-1)$ and $n_2 = (r-1) (g-1)$ degrees of freedom.

3.5.2 Estimation of mean and range

The mean value for each character was worked out by using the following formula

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i$$

where,

ΣX_i = sum of the character

n = number of observations

The lowest and highest values from mean of each character were recorded as range, whereas the arithmetic average of all the observation as mean of the character.

3.5.3 Estimation of standard error of mean, standard error of difference and critical difference

- i. The S.E. of mean difference was calculated as

$$\text{S.E. of mean} = \sqrt{\sigma^2 e} \sqrt{r}$$

- ii. The standard error of difference between two means was calculated as

$$\text{S. E. of difference [SE(d)]} = \text{S.E. (m)} \times \sqrt{2}$$

- iii. The critical difference between any two means was calculated as

$$\text{C. D.} = \text{S. E. (d)} \times 't' \text{ at error d.f.}$$

3.5.4 Estimation of components of variation

The phenotypic and genotypic variances were calculated by utilizing the respective mean square values from the variance table (Johnson *et al.*, 1955 a).

- i. Environmental variance = $\sigma^2 e$ = EMS

- ii. Genotypic variance = $\sigma^2 g$ = (GMS - EMS)/ r

- iii. Phenotypic variance = $\sigma^2 p$ = $\sigma^2 g$ + $\sigma^2 e$

Where,

GMS = genotypic mean sum of squares

EMS = error mean sum of squares

r = number of replications

3.5.5 Estimation of coefficients of variation

The genotypic and phenotypic coefficients of variation were calculated by the formula suggested by Burton (1952).

- i. Genotypic coefficient of variation (GCV)

$$\text{GCV (\%)} = \sqrt{\sigma^2 g / \bar{X}} \times 100$$

Where,

$$\sigma^2g = \frac{\text{Mean sum of square due to genotypes} - \text{Mean sum of square due to Error}}{r}$$

Here,

$\sigma^2g = V_g$ = genotypic variance

$\bar{X}$ = general mean of the character

r = number of replications

ii. Phenotypic coefficient of variation (PCV)

$$\text{PCV (\%)} = \sqrt{\sigma^2p/\bar{X}} \times 100$$

Where,

σ^2p = Genotypic variance + mean sum of square due to error

Here,

$\sigma^2p = V_p$ = phenotypic variance

3.5.6 Estimation of heritability (broad sense)

Heritability in broad sense was estimated for various characters as per the formula suggested by Hanson *et al.* (1956).

$$h^2 \text{ (b. s.)} = (\sigma^2g/\sigma^2p) \times 100$$

where,

h^2 = heritability percentage in broad sense

σ^2g = genotypic variance

σ^2p = phenotypic variance

The heritability values were categorized as given by Lush (1940)

Heritability in percent	Category
<30	Low
31-61	Medium
>61	High

3.5.7 Estimation of genetic advance (G.A.)

The extent of genetic advance expected through selection for each character was calculated as per the formula suggested by Johnson *et al.* (1955 b).

$$G.A. = (\sigma^2_g / \sigma^2_p) \times \sigma_p \times K$$

OR

$$G.A. = h^2 \times \sigma_p \times K$$

Where,

h^2 = heritability percentage in broad sense

σ^2_g = genotypic variance

σ^2_p = phenotypic variance

K = Selection differential (2.06 at 5 % selection intensity, Lush, 1949)

σ_p = phenotypic standard deviation

3.5.7.1 Genetic advance as per cent of mean

$$G.A. = (G.A. / \bar{X}) \times 100$$

Where,

G.A. = genetic advance

$\bar{X}$ = mean of the character

The range of genetic advance as per cent of mean is classified as suggested by Johnson *et al.* (1955 a)

Low	:	Less than 10%
Moderate	:	10-20 %
High	:	More than 20 %

3.5.8 Estimation of correlation coefficients

Genotypic and phenotypic correlation coefficient for yield and other traits were computed using the method given by Johnson *et al.* (1955b).

3.5.8.1 Genotypic correlation coefficient

$$r_{xy}(g) = \frac{\text{Cov}_{xy}(g)}{\sqrt{\sigma^2_{g_x} \times \sigma^2_{g_y}}}$$

where,

$r_{xy} (g)$ = Genotypic correlation coefficient between the traits 'x' and 'y'

$Cov_{xy} (g)$ = Genotypic covariance between the traits 'x' and 'y'

$\sigma^2 g_x$ = Genotypic variance of the trait 'x'

$\sigma^2 g_y$ = Genotypic variance of the trait 'y'

3.5.8.2 Phenotypic correlation coefficient

$$r_{xy} (p) = \frac{Cov_{xy} (p)}{\sqrt{\sigma^2 p_x \times \sigma^2 p_y}}$$

where,

$r_{xy} (p)$ = Phenotypic correlation coefficient between the traits 'x' and 'y'

$Cov_{xy} (p)$ = Phenotypic covariance between the traits 'x' and 'y'

$\sigma^2 p_x$ = Phenotypic variance of the trait 'x'

$\sigma^2 p_y$ = Phenotypic variance of the trait 'y'

The significance of the phenotypic and genotypic correlation coefficient was tested by referring the standard table given by Panse and Sukhatme (1985).

3.5.9 Path coefficient analysis

It is simply the standardized partial regression coefficient which split the correlation coefficient into the measures of direct and indirect effect of independent variable on the dependent variables. This technique was firstly used by Dewey and Lu (1959). Path analysis is worked out by using the estimates of correlation coefficient in all possible combinations among the dependent variables.

Path coefficient was estimated by solving the following simultaneous equations, including the basis relationship between correlation and path coefficient.

$$r_{ij} = p_{iy} + \sum_{j=1}^{l-1} p_{ij} r_{jl} \text{ for } i = 1, 2, 3, \dots, l-1$$

The above equation can be written in matrix form as follows;

$$[A]_{10 \times 1} = [B]_{12 \times 1} [C]_{12 \times 1}$$

where,

A = Column vector of correlation v_{ij}

B = Correlation matrix of r_{ij}

C = Column vector of direct p_{ij}

Residual factor was calculated as follows;

$$P_{xy} = \sqrt{1-R^2} \text{ where,}$$

$$R^2 = \sum r_{ij} p_{xy}$$

The r_{ijs} i.e. $r_{1.2}$ to $r_{8.9}$ denote correlation between all possible combinations of the independent characters and p_{ij} to p_{12y} denote direct effects of various characters on character y.

R_{ij} = Correlation coefficient between i^{th} and y characters.

P_{iy} = Direct effect of j^{th} character only.

The direct and indirect effects were ranked based on the scales of Lenka and Misra (1973) as given below

Negligible	: 0.00 to 0.09
Low	: 0.10 to 0.19
Moderate	: 0.20 to 0.29
High	: 0.30 to 0.99
Very high	: > 1.00

3.5.10 Genetic diversity

The generalized distance between two populations is defined by Mahalanobis (1936) as,

$$D^2 = \sum \sum \lambda_{ij} \cdot \delta_i \cdot \delta_j$$

where,

λ_{ij} = reciprocal matrix of the common dispersion matrix

δ_i = difference between the mean values of two populations for i^{th} character

δ_j = difference between the mean values of two
populations for j^{th} character

Estimation of D^2 values from the above formula is very complicated in the present study. Since, it requires the inversion of a seventeenth order determinant and then the evaluation of $17(17+1)/2$, term whose sum is D^2 . It was found convenient to work with a set of uncorrelated characters constructed from the original measurements. D^2 with such transformable variables reduced to the evaluation of simple sum of squares. Transformation was done by using pivotal condensation method (Singh and Chowdhary. 1977). The coefficient for the transformation was obtained by dividing the first row of the reduced matrix by the square root of the corresponding pivotal condensation elements.

3.5.10.1 Testing the significance of D^2 values

The D^2 value obtained for a pair of population is taken as the calculated value of χ^2 and was tested against the tabulated values of χ^2 for 'p' degrees of freedom where p is the number of characters considered (Singh and Chowdhary. 1977).

3.5.10.2 Determination of group constellations

Tocher's method as described by Rao (1952) was followed for cluster formation. No formal rules can be laid down for finding the clusters because a cluster is not a well defined term. The only criterion appeared to be that any two groups belonging to the same cluster should at least on the average show a smaller D^2 value than those belonging to two different clusters. This method was to start with two closely associated groups and find a third group which has the smallest D^2 value from the two. Similarly, fourth is chosen to have the smallest D^2 from the first three and so on. If at any stage the average D^2 of the group from those already listed appears to be high, then this group does not fit in the former groups and therefore, taken outside the former cluster. The group of the first cluster are then omitted and the rest are treated similarly. It was also helpful to calculate the change in average D^2 value within a cluster due to inclusion of an additional group. If the change was appreciable, then the newly added group had

to be considered as outside the cluster. The computational scheme was as given below.

Population added to a Cluster	D^2	Number of terms (n)	Increase in D^2 / increase in n	Average $D^2 = \Sigma D^2 / n$	Cluster
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3.5.10.3 Average intra and inter-cluster distance

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

where,

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

ii) Average inter-cluster D^2

$$D^2 = (\Sigma \text{ of distances between the population of cluster i and j}) / n_i \cdot n_j$$

where,

n_i = number of populations in the cluster i

n_j = number of populations in the cluster j

iii) Average intra and inter cluster distance

$$D = \sqrt{D^2}$$

3.5.10.4 Cluster means

Cluster means were calculated for individual character on the basis of mean performance of the genotypes included in that cluster.

3.5.10.5 Cluster diagram

With the help of D^2 values between the clusters, a diagram showing the relationship between different populations was drawn.

CHAPTER IV

RESULTS AND DISCUSSION

Chapter IV

RESULTS AND DISCUSSION

The present investigation entitled “Genetic characterization of onion (*Allium cepa* L.) genotypes” was carried out at the PG Research Block of the college of Horticulture, Rajendranagar, during *rabi* season of the year, 2020-2021. The research was conducted to study the extent of genetic variability, correlation co-efficient, path coefficient analysis and genetic divergence of different onion genotypes. The results obtained are discussed in this chapter, under the following headings.

- 4.1 Analysis of variance
- 4.2 Mean performance of genotypes
- 4.3 Variability, heritability and genetic advance
- 4.4 Correlation studies
- 4.5 Path coefficient analysis
- 4.6 Genetic divergence (D^2 statistic)

4.1 Analysis of variance

Analysis of variance showed significant differences among all 40 genotypes for ten characters studied at 5 per cent level of significance, indicating the presence of sufficient variability among genotypes. Thus indicating the scope for selection of promising genotypes from the present gene pool. These characters were plant height (cm), number of leaves per plant, days to maturity (days), neck thickness (cm), equatorial bulb diameter (cm), polar bulb diameter (cm), TSS (° Brix), ascorbic acid (mg 100⁻¹g), average bulb weight (g) and yield (t ha⁻¹) are given in Table 4.1.

Table 4.1. Randomized Block Design (RBD) ANOVA for ten bulb yield and yield attributes in onion

S.No.	Source of variation / Character	Mean sum of squares		
		Replications (df = 2)	Genotypes (df = 39)	Error (df = 78)
1	Plant height (cm)	7.04	41.18 **	24.35
2	Number of leaves per plant	0.10	2.48 **	0.32
3	Days to maturity (days)	18.31	145.05 **	12.10
4	Neck thickness (cm)	0.04	0.17 **	0.01
5	Equatorial bulb diameter (cm)	2.73	0.45 **	0.06
6	Polar bulb diameter (cm)	1.66	0.45 **	0.07
7	Ascorbic acid (mg 100 ⁻¹ g)	0.04	2.97 **	0.07
8	Total Soluble Solids (°Brix)	0.41	2.69 **	0.05
9	Average bulb weight (g)	1028.41	769.40 **	24.08
10	Yield (t ha ⁻¹)	160.52	164.45 **	4.12

****significant at 5 per cent level of significance**

4.2 Mean performance of genotypes

In any selection programme, the mean performance of the genotypes for individual character serves as an important criterion for discarding the undesirable types. This indicates that germplasm studies may act as a potential source and offer scope for selection of high yielding genotypes with desirable horticultural attributes. The mean performance of forty genotypes of onion with respect to various yield and yield attributes are described character wise below. The trait wise results of the mean performance are documented below in the Table 4.2.

4.2.1. Plant height (cm)

The highest plant height was recorded in genotype Bhima Raj (62.39 cm) followed by Bhima Kiran (59.68 cm) and Bhima Super (58.54 cm) and minimum was observed in W-1786 (38.32 cm). The general mean for the character is 55.13 cm within the range of 38.32 cm to 62.39 cm (Table 4.2).

4.2.2. Number of leaves per plant

Number of leaves per plant varied from 8.53 to 12.80 with a total mean of 10.58 (Table 4.2). Maximum number of leaves were observed in genotype 1745 (12.80), followed by W-125 (12.13) and 1785 (12.07) and minimum was observed in W-498 (8.53).

4.2.3. Days to maturity (days)

The trait days to maturity showed a range from 95.33 days to 122.67 days (Table 4.2). More number of days taken to harvest was recorded in genotype W-253cp (122.67 days) followed by W-203 (122.00 days) and 1771 (120.33 days) and least was observed in Bhima Shwetha (95.33 days). The average days to maturity is 110.91 days.

4.2.4. Neck thickness (cm)

The genotype 1745 (2.01 cm) recorded maximum neck thickness, followed by Bhima Shwetha (1.85 cm) and W-125 (1.84 cm) and minimum was observed in W-210 (0.96 cm). The general mean for the character is 1.38 cm within the range of 0.96 cm to 2.01 cm (Table 4.2).

4.2.5. Equatorial bulb diameter (cm)

The highest equatorial bulb diameter was observed in genotype 1770 (7.20 cm) followed by 1744 (6.71 cm) and W-125 (6.61 cm) and lowest was observed in W-405 (5.12 cm). The general mean for the character is 5.81 cm within the range of 5.12 cm to 7.20 cm (Table 4.2).

4.2.6. Polar bulb diameter (cm)

Maximum polar bulb diameter was registered in genotype 1770 (6.63 cm), followed by 1774 (6.01cm) and W-125 (5.88 cm) and minimum was observed in W-398 (4.73 cm). The general mean for the character is 5.13 cm within the range of 4.53 cm to 6.63 cm (Table 4.2).

4.2.7. Ascorbic acid (mg 100⁻¹g)

Higher ascorbic acid was recorded in genotype Bhima Shwetha (12.52 mg 100⁻¹g) followed by W-498 (11.98 mg 100⁻¹g) and W-177 (11.95 mg 100⁻¹g) and lower was recorded in 1769 (8.37 mg 100⁻¹g). The general mean for the character is 10.53 mg per 100g within the range of 8.37 mg 100⁻¹g to 12.52 mg 100⁻¹g of pulp (Table 4.2).

4.2.8. Total Soluble Solids (°Brix)

Maximum Total Soluble Solids was observed in genotype W-246cp (14.60°Brix), followed by 1773 (14.27°Brix) and W-253cp (14.13°Brix) and minimum was observed in W-498 (10.86°Brix). TSS showed a range from 10.86 to 14.60°Brix with a general mean of 12.41°Brix (Table 4.2).



Plate 3. Highest TSS recorded by W-246 cp genotype

4.2.9. Average bulb weight (g)

The general mean for the character was 93.45 g within the range of 58.96 g to 129.60 g. Maximum average bulb weight was observed in genotype 1770 (129.60 g) followed by 1774 (117.68 g) and 1745 (115.73 g) and minimum was observed in W-405 (58.96 g) (Table 4.2).

4.2.10. Yield (t ha⁻¹)

The highest yield was reported by genotype 1770 (57.59 t ha⁻¹), followed by 1774 (53.85 t ha⁻¹) and Bhima Shwetha (53.77 t ha⁻¹). Whereas lowest yield was shown by W-405 (26.20 t ha⁻¹). The mean yield was 41.96 t ha⁻¹ distributed in the range of 26.20 t ha⁻¹ to 57.59 t ha⁻¹ (Table 4.2).

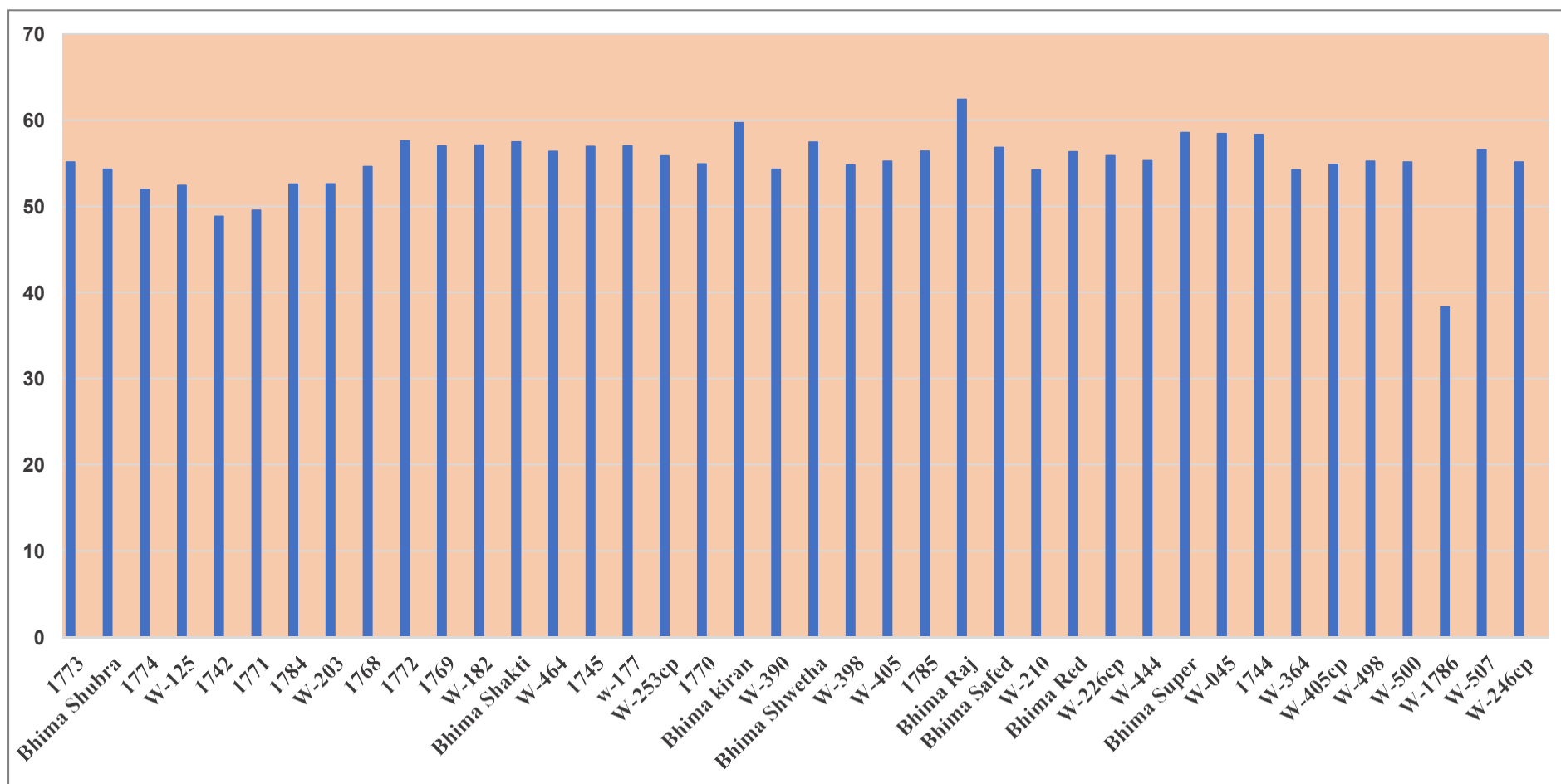


Fig 4.1. Plant height (cm) in forty genotypes of onion

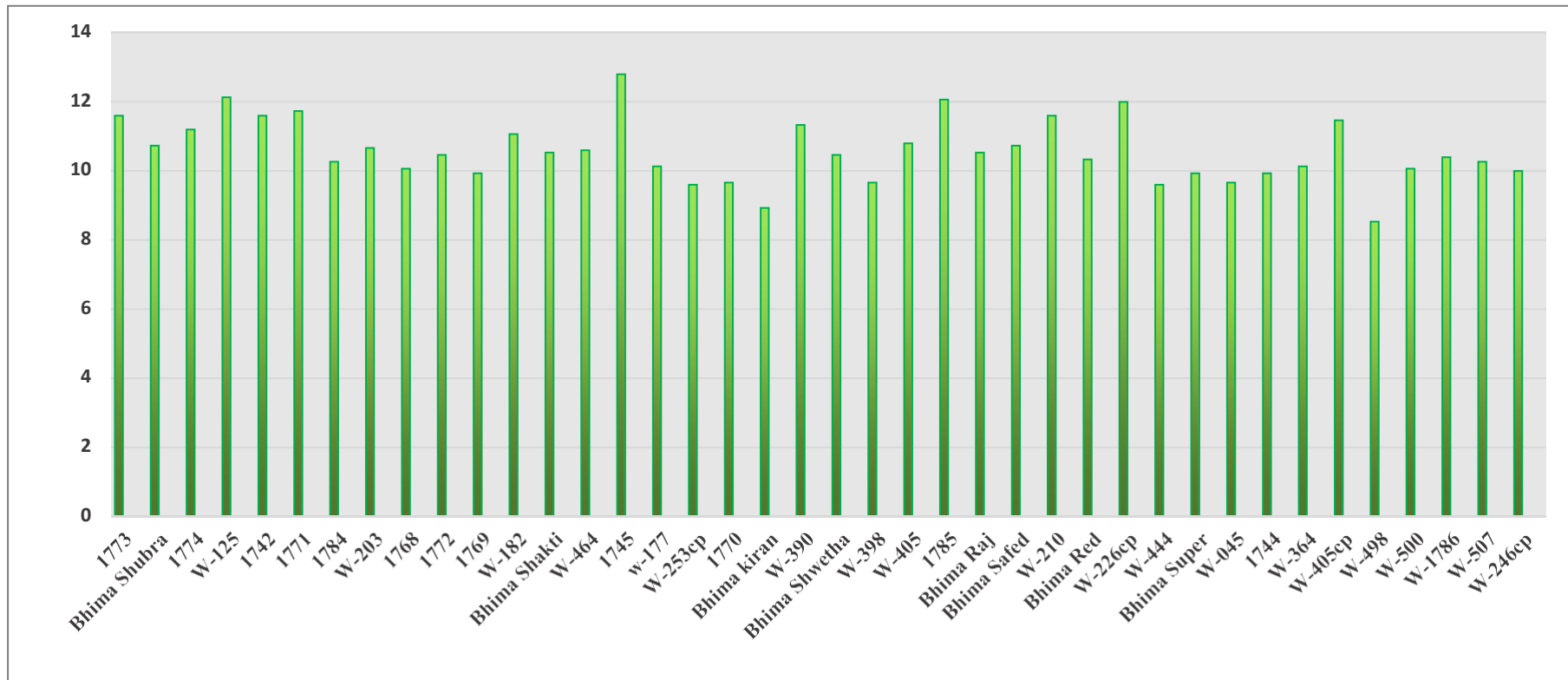


Fig 4.2. Number of leaves per plant in forty genotypes of onion

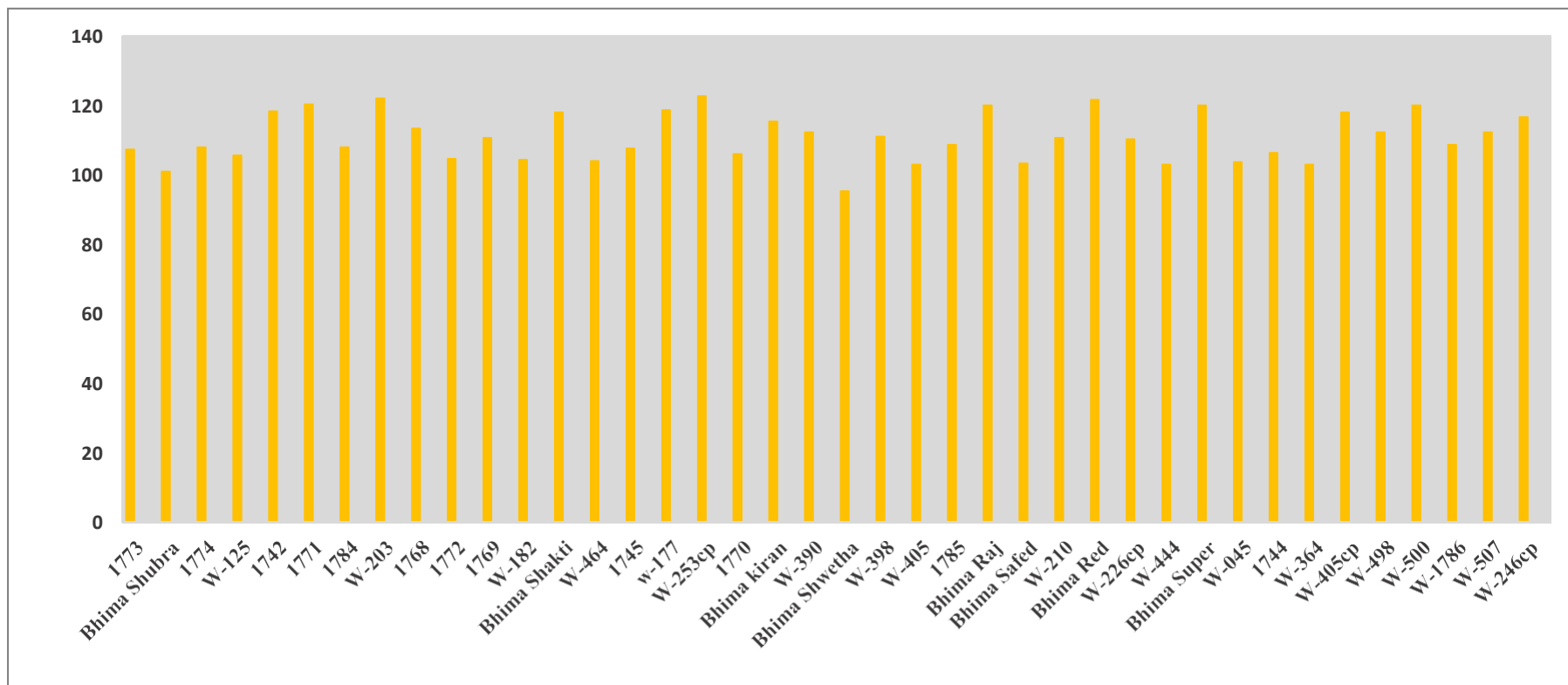


Fig 4.3. Days to maturity (days) in forty genotypes of onion

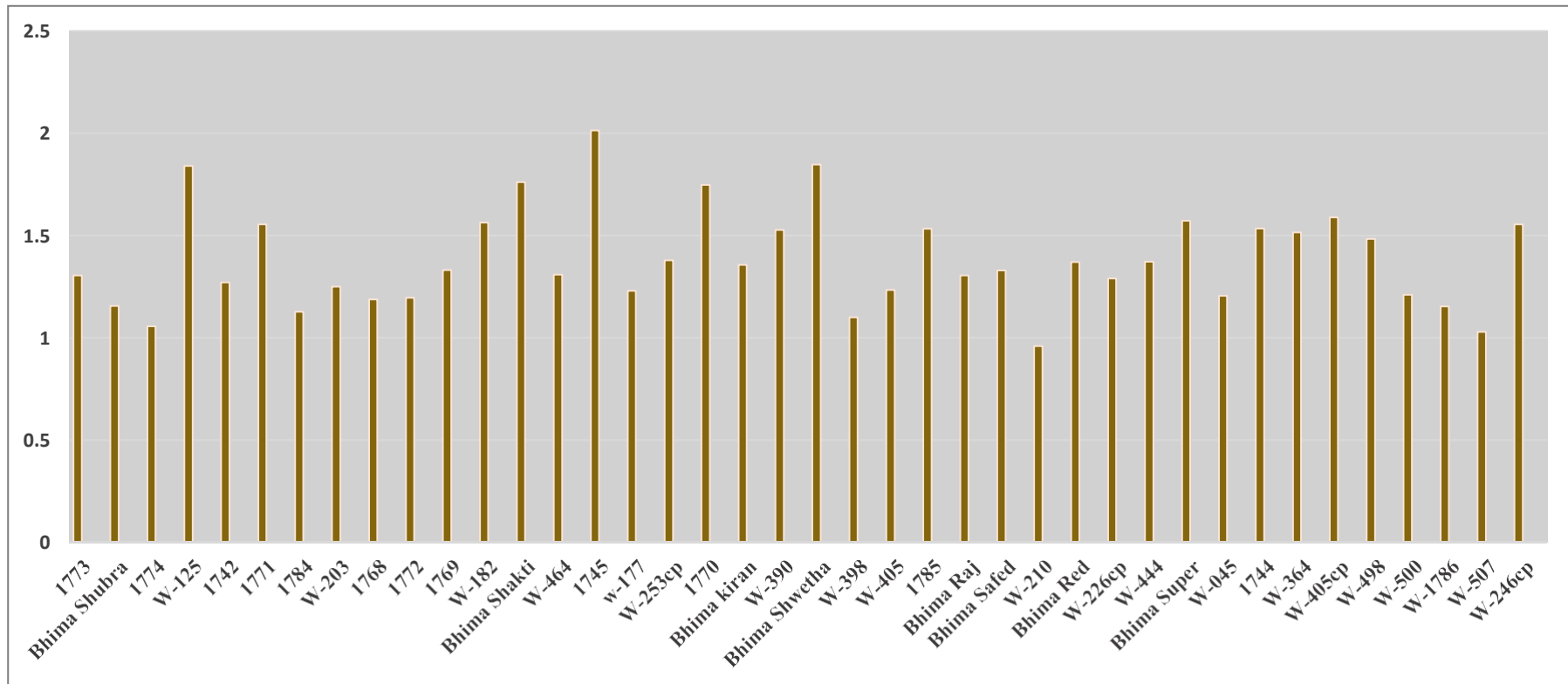


Fig 4.4. Neck thickness (cm) in forty genotypes of onion

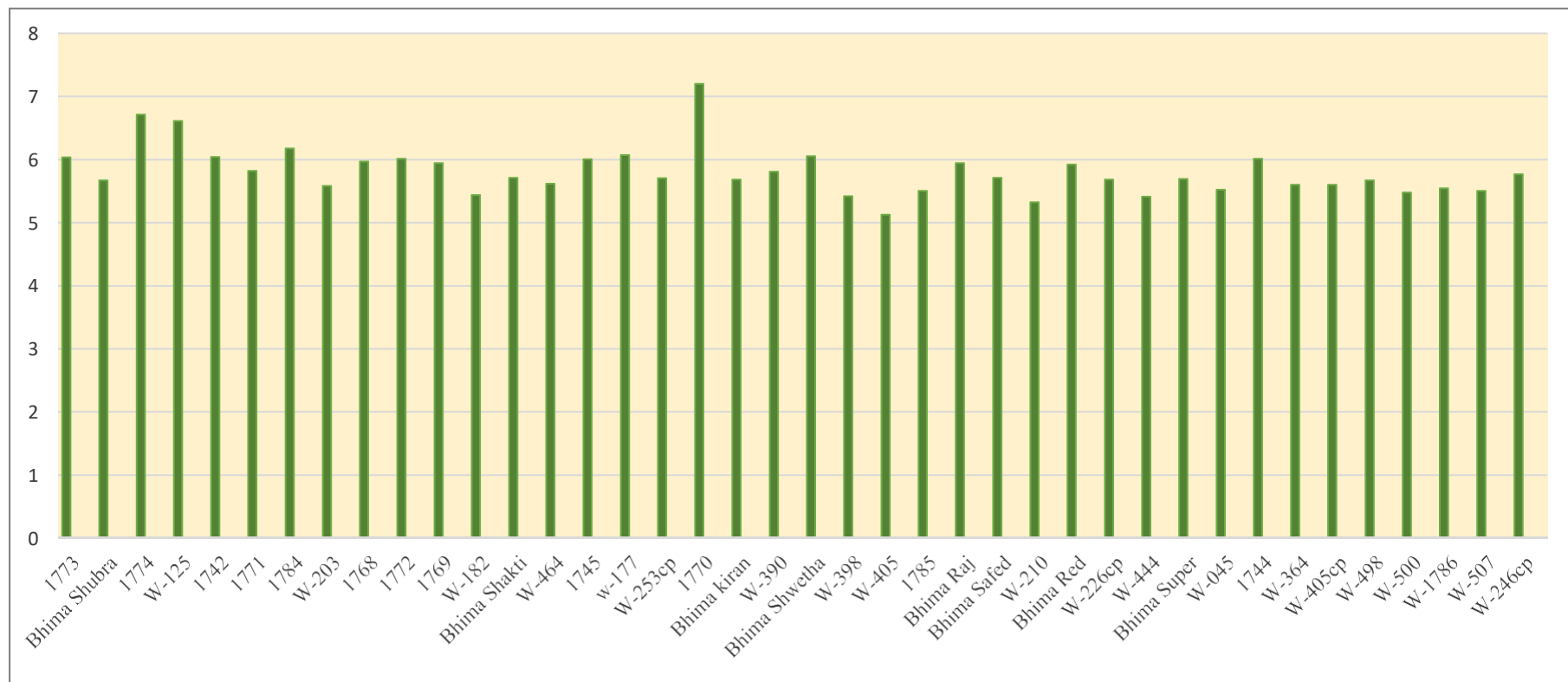


Fig 4.5. Equatorial bulb diameter (cm) in forty genotypes of onion

Table 4.2. Mean performance of growth, yield and quality characters in forty genotypes of onion

S. No.	Genotype	Plant height (cm)	No. of leaves per plant	Days to maturity (days)	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	Total Soluble Solids (°Brix)	Average bulb weight (g)	Yield (t ha ⁻¹)
1	1773	55.11	11.60	107.33	1.30	6.03	5.22	10.25	14.27	90.30	40.13
2	Bhima Shubra	54.28	10.73	101.00	1.16	5.67	4.81	11.29	12.57	85.00	39.42
3	1774	51.93	11.20	108.00	1.06	6.71	6.01	9.10	13.17	117.68	53.85
4	W-125	52.40	12.13	105.67	1.84	6.61	5.88	11.53	12.50	114.69	53.58
5	1742	48.81	11.60	118.33	1.27	6.04	5.40	9.26	13.53	108.63	48.28
6	1771	49.55	11.73	120.33	1.55	5.82	5.16	10.31	11.03	100.50	44.66
7	1784	52.57	10.27	108.00	1.13	6.17	5.67	11.13	12.30	114.17	50.74
8	W-203	52.58	10.67	122.00	1.25	5.58	4.88	8.75	13.27	82.47	36.65
9	1768	54.59	10.07	113.33	1.19	5.97	5.36	10.19	12.27	104.07	46.25
10	1772	57.60	10.47	104.67	1.20	6.01	5.34	9.30	13.23	115.50	53.46
11	1769	57.00	9.93	110.67	1.33	5.94	5.27	8.37	11.00	102.93	45.74
12	W-182	57.08	11.07	104.33	1.56	5.44	4.78	10.18	12.13	77.57	34.47
13	Bhima Shakti	57.46	10.53	118.00	1.76	5.71	4.91	11.02	11.53	89.75	40.52
14	W-464	56.34	10.60	104.00	1.31	5.62	4.93	11.48	12.23	84.03	37.35
15	1745	56.95	12.80	107.67	2.01	6.00	5.35	9.97	12.40	115.73	51.43
16	W-177	57.01	10.13	118.67	1.23	6.07	5.34	11.95	11.23	111.60	49.59
17	W-253cp	55.84	9.60	122.67	1.38	5.70	4.97	9.43	14.13	92.13	40.94
18	1770	54.90	9.67	106.00	1.75	7.20	6.63	11.78	12.23	129.60	57.59
19	Bhima Kiran	59.68	8.93	115.33	1.36	5.68	5.01	11.05	11.83	87.68	42.15
20	W-390	54.29	11.33	112.33	1.53	5.80	5.27	10.17	11.63	98.60	43.82
21	Bhima Shwetha	57.43	10.47	95.33	1.85	6.05	5.24	12.52	12.47	115.54	53.77
22	W-398	54.79	9.67	111.00	1.10	5.42	4.73	9.85	13.47	72.70	32.31

Table 4.2. Contd.

S. No.	Genotype	Plant height (cm)	No. of leaves per plant	Days to maturity (days)	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	Total Soluble Solids (°Brix)	Average bulb weight (g)	Yield (t ha ⁻¹)
23	W-405	55.22	10.80	103.00	1.23	5.12	4.53	10.06	13.30	58.96	26.20
24	1785	56.37	12.07	108.67	1.53	5.50	4.89	11.02	12.13	80.90	35.95
25	Bhima Raj	62.39	10.53	120.00	1.30	5.94	4.95	11.26	10.87	87.69	39.58
26	Bhima Safed	56.82	10.73	103.33	1.33	5.71	4.99	9.42	13.10	91.47	42.14
27	W-210	54.21	11.60	110.67	0.96	5.32	4.74	11.06	12.27	63.80	28.35
28	Bhima Red	56.32	10.33	121.67	1.37	5.92	5.15	10.00	12.00	92.47	41.69
29	W-226cp	55.87	12.00	110.33	1.29	5.68	5.07	9.63	12.13	90.63	40.28
30	W-444	55.28	9.60	103.00	1.37	5.41	4.77	11.17	13.17	72.50	32.22
31	Bhima Super	58.54	9.93	120.00	1.57	5.69	5.01	10.96	11.46	89.87	40.25
32	W-045	58.41	9.66	103.66	1.20	5.52	4.79	10.52	12.13	78.20	34.75
33	1744	58.34	9.93	106.33	1.53	6.01	5.26	11.30	11.30	107.10	47.59
34	W-364	54.23	10.13	103.00	1.51	5.60	5.05	10.43	12.26	85.20	37.86
35	W-405cp	54.83	11.46	118.00	1.58	5.59	4.91	11.05	13.43	105.26	46.74
36	W-498	55.21	8.53	112.33	1.48	5.67	4.97	11.98	10.86	84.03	37.35
37	W-500	55.11	10.06	120.00	1.21	5.47	4.79	11.38	11.30	80.56	35.80
38	W-1786	38.32	10.40	108.66	1.15	5.54	4.91	10.06	12.26	88.80	39.46
39	W-507	56.54	10.26	112.33	1.02	5.50	4.92	11.97	13.30	77.03	34.23
40	W-246cp	55.13	10.00	116.66	1.55	5.76	5.25	9.09	14.60	92.76	41.23
Grand Mean		55.13	10.58	110.91	1.38	5.81	5.13	10.53	12.41	93.45	41.96
SEm±		2.85	0.33	2.01	0.04	0.15	0.16	0.15	0.13	2.83	1.17
CV (%)		8.95	5.37	3.14	4.68	4.45	5.51	2.52	1.79	5.25	4.83
CD (P=0.05)		8.02	0.92	5.66	0.11	0.42	0.46	0.43	0.36	7.98	3.30



Plate 4. Some of high yielding onion genotypes

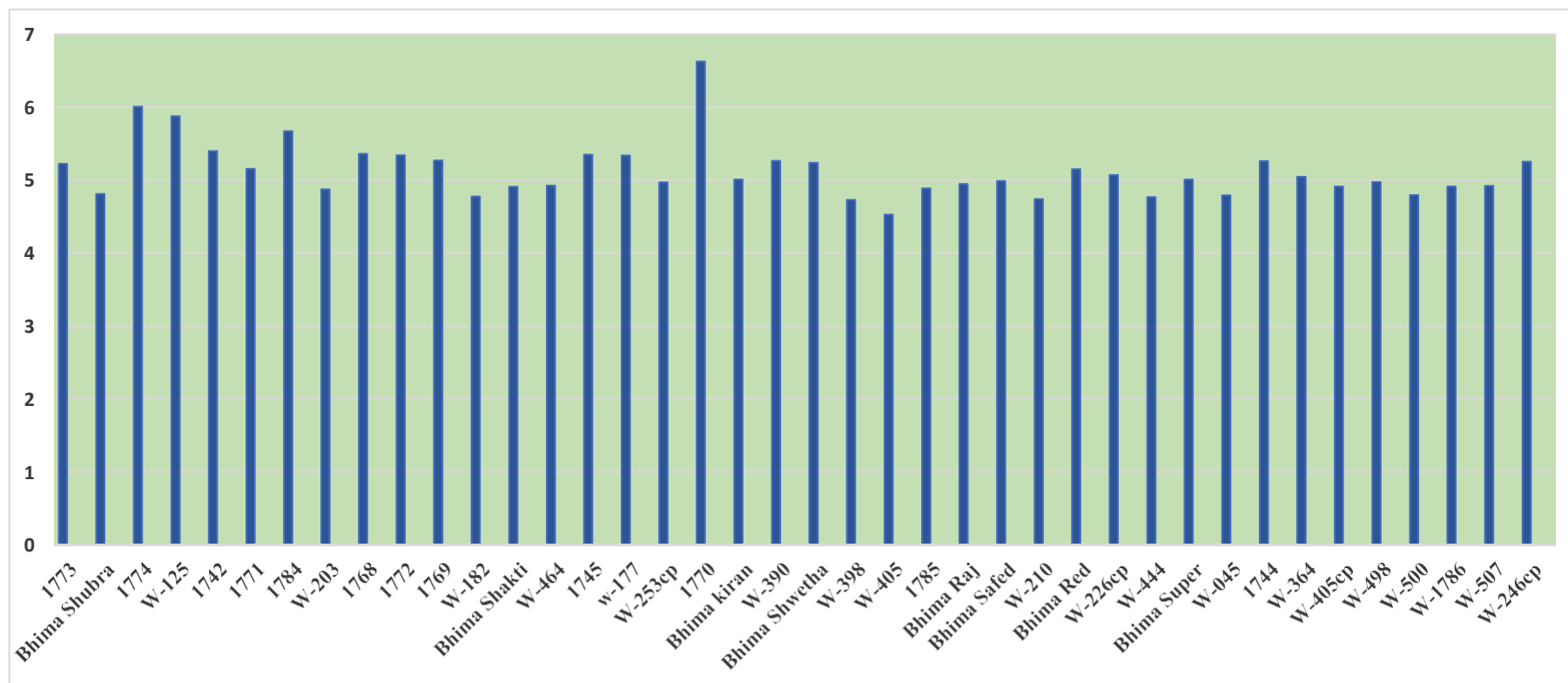


Fig 4.6. Equatorial bulb diameter (cm) in forty genotypes of onion

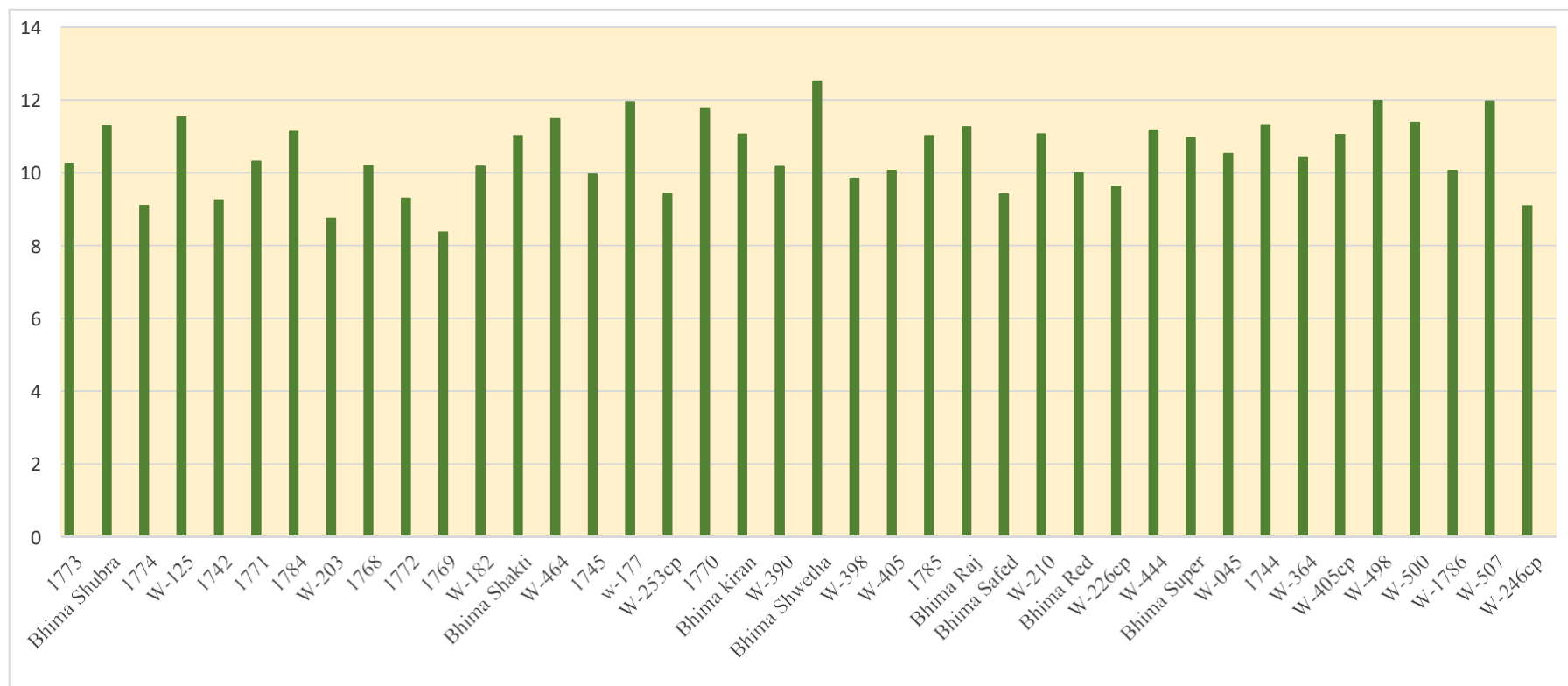


Fig 4.7. Ascorbic acid (mg 100⁻¹ g) in forty genotypes of onion

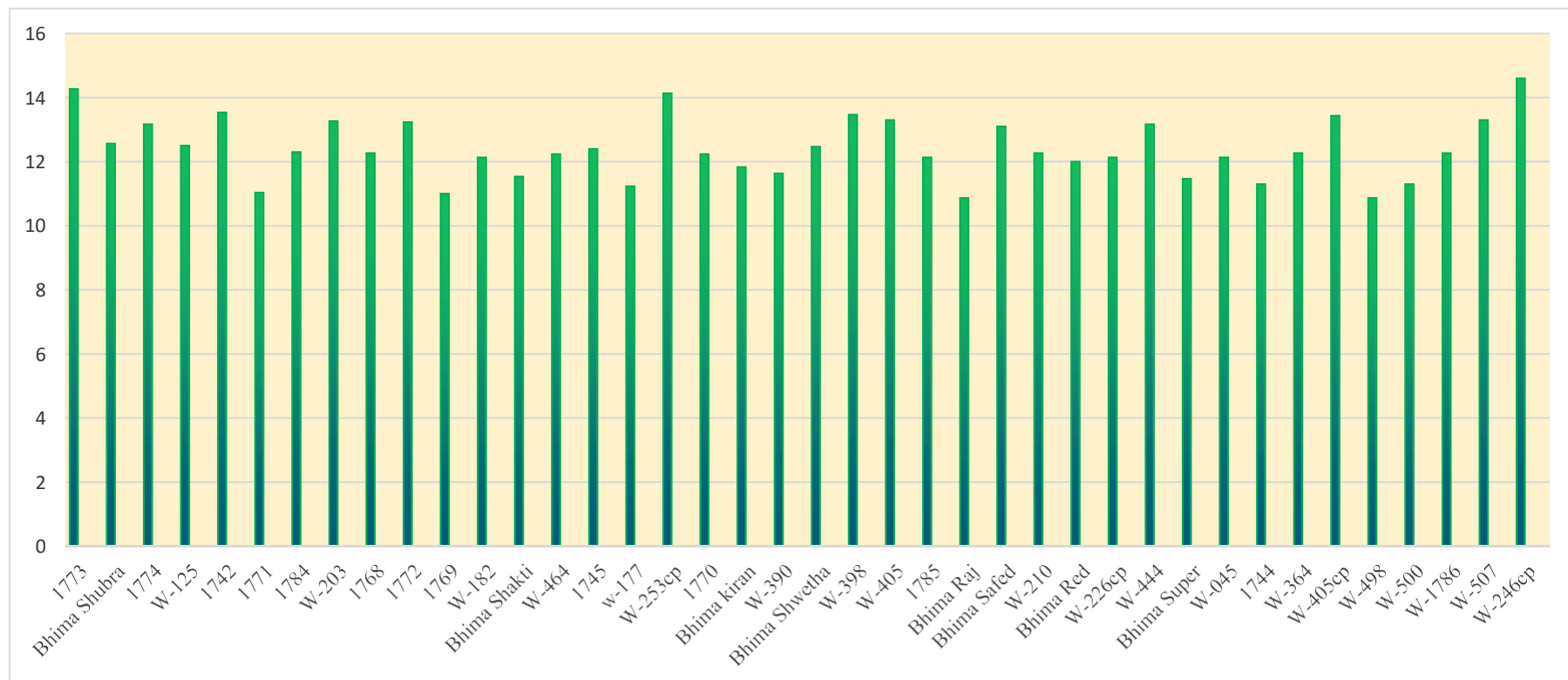


Fig 4.8. Total Soluble Solids (°Brix) in forty genotypes of onion

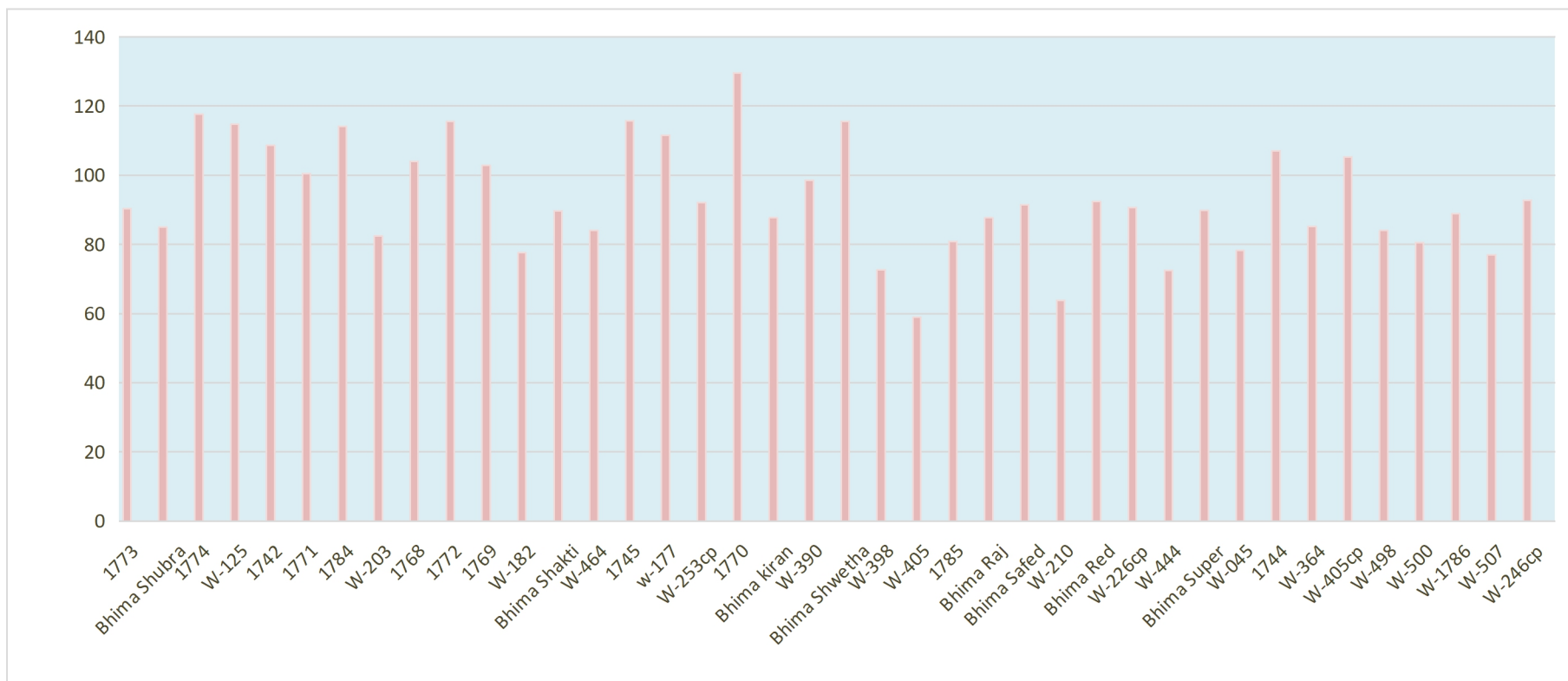


Fig 4.9. Average bulb weight (g) in forty genotypes of onion

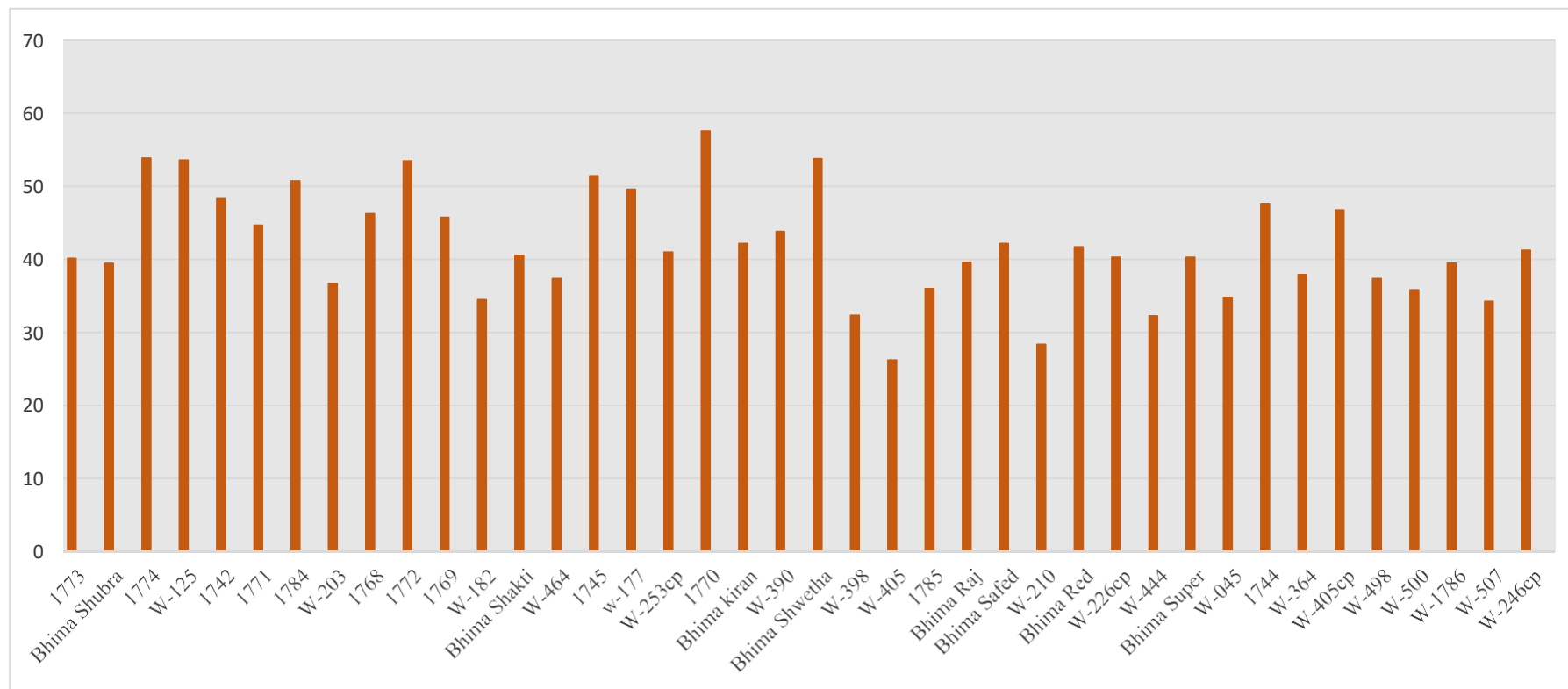


Fig 4.10. Yield (t ha⁻¹) in forty genotypes of onion

The result on mean performance of forty genotypes for ten characters revealed that the genotype 1770 was the superior genotype for yield and yield contributing characters *i.e.*, average bulb weight, equatorial bulb diameter, polar bulb diameter and yield per hectare as compared to all other genotypes.

The genotype 1745 was found superior to number of leaves per plant and neck thickness. The genotype Bhima Raj was found superior to plant height and the genotype W-253 cp took maximum days to maturity.

When the quality parameters of onion were considered the genotype W-246 cp was found to be superior for TSS. The genotype Bhima Shwetha was found to be superior for ascorbic acid content.

4.3 Variability, heritability (h^2_{bs}) and genetic advance

Estimating variability in a population is an effective tool for the breeder to design the selection procedures more accurately for identifying superior genotypes. Variability helps to choose the potential genotype, since it indicates the extent of recombination for implementing effective selection. The magnitude of phenotypic and genotypic coefficients of variation has been assessed to know the real worth of the source material.

Genotypic coefficient of variation would be a useful tool for the assessment of variability, since it depends upon the heritable portion of the total variability (Allard., 1960). Heritability estimates give a measure of transmission of characters from one generation to another, thus giving an idea of heritable portion of variability and enabling the plant breeder in isolating the elite genotype in the crop. The heritability expresses the portion of total variances that was attributed to the average effect of genes and that determines the degree of resemblance between parents and off springs. It also expresses the reliability of phenotypic values as a guide to the breeding value.

Heritability in broad sense is the portion of genotypic variance to phenotypic variance, which indicates the relative success of selection. It is

useful in selection of elite genotype from diverse genetic population. High heritability estimates are helpful in selecting superior genotypes on the basis of performance of quantitative characters. In the present study, the heritability in broad sense was found to be high for all the characters. High heritability estimates indicated the presence of large number of fixable additive genes and hence these traits can be improved by selection.

Heritability coupled with genetic advance is an important selection parameter. Johnson *et al.* (1955 b) reported that heritability along with genetic gain is more useful than the heritability alone, in predicting the resultant effect for selecting the best individuals. He categorized the heritability values, as the values greater than 60 per cent indicate the high heritability, the values ranged between 30 to 60 per cent indicate the moderate heritability, while the values less than 30 per cent indicate the low heritability. Similarly, the values greater than 20 per cent indicate high genetic advance, the values ranged between 10 to 20 per cent indicate moderate genetic advance, while the values less than 10 per cent indicate low genetic advance.

The simple measure of variability like mean, range and the major components of variability such as phenotypic and genotypic coefficients of variation (PCV and GCV), heritability in broad sense (h^2 bs), genetic advance and genetic advance as per cent of mean are presented in Table 4.3. All the ten characters under study exhibited high variability except plant height as evident from the estimates of mean, range, coefficients of variation, heritability and genetic advance.

4.3.1. Plant height (cm)

Plant height was recorded with high phenotypic and genotypic variances of 29.96 per cent and 5.61 per cent respectively, coupled with low phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) of 9.93 per cent and 4.29 per cent, respectively. This trait showed low heritability (18.73 %), low genetic advance (2.11) and low genetic advance (GA) as per cent

mean (3.83 %) estimates were also recorded for this trait. Similar results were also reported by Ghetia and Singh (2000) and Golani *et al.* (2006) in onion.

4.3.2. Number of leaves per plant

This trait showed low phenotypic and genotypic variances (1.04 and 0.72 %, respectively) with low phenotypic coefficients of variation (9.65 %) and genotypic coefficients of variation (4.29 %). High heritability (69.03 %) and low genetic advance (2.11 %) and moderate genetic advance (GA) as per cent mean (13.72 %) estimates were also recorded for this trait. Present findings are conformity with Ram *et al.* (2000) in onion.

4.3.3. Days to maturity (days)

With respect to days to maturity, high phenotypic and genotypic variances (56.42 and 44.31 %, respectively) with low phenotypic coefficients of variation (6.77 %) and low genotypic coefficients of variation (4.29 %). High heritability (78.55 %) and moderate genetic advance (12.15 %) and moderate GA as per cent mean (10.95 %) estimates were also recorded for this trait. These findings are in line with the reports of Gurjar and Singhania (2006) and Singh *et al.* (2010) in onion.

4.3.4. Neck thickness (cm)

Neck thickness at harvest showed low phenotypic and genotypic variances (0.06 and 0.05 %, respectively) with moderate phenotypic coefficients of variation (17.85 %) and low genotypic coefficients of variation (4.3 %). High heritability (93.12 %) and low genetic advance (0.47 %) and high genetic advance as per cent mean (34.24 %) estimates were also recorded for this trait. These results were in conformity with findings of Mohanty (2002) and Trivedi *et al.* (2006 a) in onion.

4.3.5. Equatorial bulb diameter (cm)

For this character, low phenotypic and genotypic variances (0.19 and 0.12 %, respectively) were recorded with low phenotypic coefficients of variation

(7.59 %) and low genotypic coefficients of variation (4.30 %). High heritability (65.72 %) and low genetic advance (0.59 %) and moderate genetic advance as per cent mean (10.28 %) estimates were also recorded for this trait. Present findings are conformity with Ram *et al.* (2010), Mohanty and Prusti (2002) and Gurjar and Singhania (2006) in onion.

4.3.6. Polar bulb diameter (cm)

This trait showed low phenotypic and genotypic variances (0.20 and 0.12 %, respectively) with low genotypic coefficients of variation (4.30 %). High heritability (61.30 %) and low genetic advance (0.57 %) and moderate genetic advance as per cent mean (11.17 %) estimates were also recorded for this trait. Similar results were also reported by Trivedi *et al.* (2006 a) in onion.

4.3.7. Ascorbic acid (mg 100⁻¹g)

Ascorbic acid showed low phenotypic and genotypic variances (1.04 and 0.96 %, respectively) with low phenotypic coefficients of variation (9.68 %) and low genotypic coefficients of variation (4.30 %). High heritability (93.22 %) and low genetic advance (1.95 %) and moderate genetic advance as per cent mean (18.59 %) estimates were also recorded for this trait.

4.3.8. Total soluble solids (°Brix)

With respect to total soluble solids, low phenotypic and genotypic variances (0.93 and 0.88 %, respectively) with low phenotypic coefficients of variation (7.77 %) and low genotypic coefficients of variation (4.30 %). High heritability (94.68 %) and low genetic advance (1.88 %) and moderate genetic advance as per cent mean (15.16 %) estimates were recorded for this trait. These findings in line with the reports of Hosamani *et al.* (2010) in onion.

4.3.9 Average bulb weight (g)

This character recorded high phenotypic and genotypic variances (272.52 and 248.44 %, respectively) with moderate phenotypic coefficients of variation (17.66 %) and low genotypic coefficients of variation (4.31 %). High heritability

(91.16 %) and high genetic advance (31 %) and high genetic advance as per cent mean (33.17 %) estimates were also recorded for this trait. Present findings are conformity with Magdum (1981), Patil (1983), Hosamani *et al.* (2010) in onion.

4.3.10. Yield (t ha⁻¹)

With regard to yield, high phenotypic and genotypic variances (57.56 and 53.44 %, respectively) with moderate phenotypic coefficients of variation (18.08 %) and low genotypic coefficients of variation (4.32 %). High heritability (92.85 %) and moderate genetic advance (14.51 %) and high genetic advance as per cent mean (34.58 %) estimates were also recorded for this trait. The present findings comparable with that of Shintre (1994), Singh *et al.* (2010) and Ibrahim *et al.* (2013) in onion.

Table 4.3. Estimation of variability, heritability and genetic advance as per cent (%) of mean for ten characters in forty genotypes of onion

Characters	Range		Mean	Variance		PCV (%)	GCV (%)	$h^2_{bs}(\%)$	Genetic Advance	GA as per cent of mean
	Minimum	Maximum		Phenotypic	Genotypic					
Plant height (cm)	38.32	62.39	55.13	29.96	5.61	9.93	4.29	18.73	2.11	3.83
No. of leaves per plant	8.53	12.80	10.58	1.04	0.72	9.65	4.29	69.03	2.11	13.72
Days to maturity	95.33	122.66	110.91	56.42	44.31	6.77	4.29	78.55	12.15	10.95
Neck thickness at harvest (cm)	0.95	2.01	1.38	0.06	0.05	17.85	4.30	93.12	0.47	34.24
Equatorial bulb diameter (cm)	5.12	7.20	5.81	0.19	0.12	7.59	4.30	65.72	0.59	10.28
Polar bulb diameter (cm)	4.53	6.63	5.13	0.20	0.12	8.85	4.30	61.30	0.57	11.17
Ascorbic acid (mg 100 ⁻¹ g)	8.37	12.52	10.53	1.04	0.96	9.68	4.30	93.22	1.95	18.59
TSS (°Brix)	10.86	14.6	12.41	0.93	0.88	7.77	4.30	94.68	1.88	15.16
Average bulb weight (g)	58.96	129.6	93.45	272.52	248.44	17.66	4.31	91.16	31.00	33.17
Yield (t ha ⁻¹)	26.2	57.59	41.96	57.56	53.44	18.08	4.32	92.85	14.51	34.58

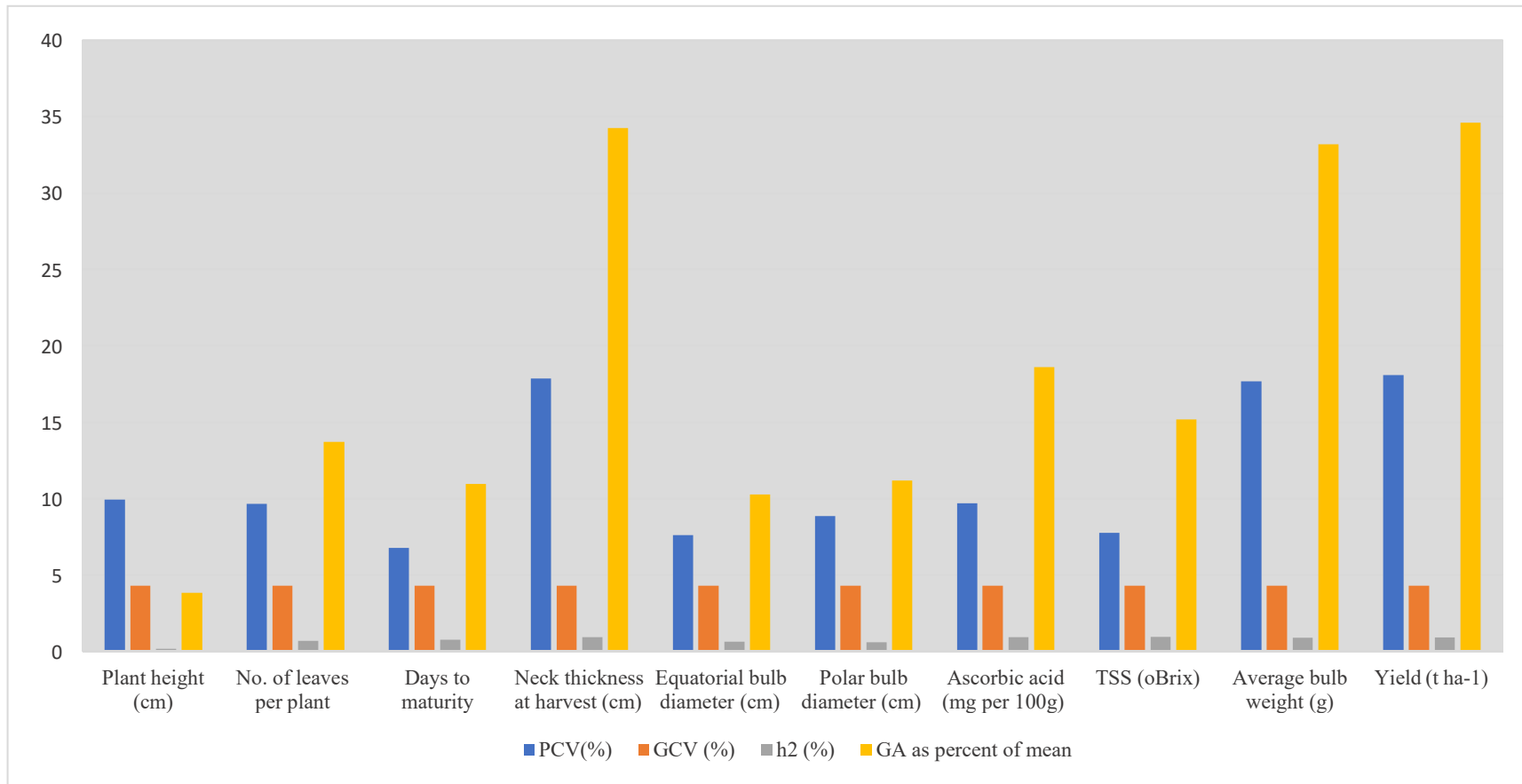


Fig 4.11. Estimation of variability, heritability and genetic advance as per cent of mean for ten characters in forty genotypes of onion

The study revealed that phenotypic coefficients of variation (PCV) was higher than the corresponding genotypic coefficients of variation (GCV) for all the characters indicating that all characters had interacted with environment to some degree. In the present study the high heritability observed for the characters *i.e.*, number of leaves per plant, days to maturity, neck thickness at harvest, equatorial bulb diameter, polar bulb diameter, average bulb weight, yield per hectare and indicates the significance of these characters to be used for selecting superior genotypes.

Moderate phenotypic coefficients of variation (PCV) and low genotypic coefficients of variation (GCV) estimates were recorded for average bulb weight and yield per hectare. The difference between phenotypic coefficients of variation and genotypic coefficients of variation values were minimum, indicating that the traits under study were less influenced by environment and these characters could be improved by following phenotypic selection.

High heritability coupled with high genetic advance as per cent of mean indicates operation of additive gene action which was observed in characters *viz.*, neck thickness at harvest, average bulb weight and yield per hectare.

Hence, directional selection for these traits in genetically diverse material could be effective for desired genetic improvement. Moderate genetic advance as per cent of mean with high or moderate heritability suggests the action of both additive and non additive genes thereby favorable influence of environment in the expression. The same was reported in case of number of leaves per plant, days to maturity, equatorial bulb diameter, polar bulb diameter, ascorbic acid content and total soluble solids.

Genetic advance which estimates the degree of gain in a trait obtained under a given selection pressure is an important parameter that guides the breeder in choosing a selection programme (Hamdi *et al.*, 2003). High heritability and high genetic advance for a given trait indicates that, it is governed by additive gene action and consequently provides the most effective condition for selection.

Hence, the breeder should adopt suitable breeding methodology to utilize both additive and non-additive gene effects simultaneously, since varietal and hybrid development will go a long way in the breeding programmes.

4.4 Correlation studies

The phenotypic (P) and genotypic correlation (G) coefficients were worked out for ten characters and the results are presented in Table 4.4 a and 4.4 b respectively.

4.4.1. Plant height (cm)

Plant height showed positive correlation both in phenotypic and genotypic level with neck thickness (0.1166P, 0.3160G) and ascorbic acid content (0.1340P, 0.3741G), it showed negative correlation with polar bulb diameter (-0.0966P, -0.1819G), total soluble solids (-0.1317P, -0.2872G), average bulb weight (-0.0421P, -0.1379G), number of leaves per plant (-0.0605P, -0.4445) and yield per hectare (-0.0106P, -0.1193). Days to maturity showed negative correlation at phenotypic and positive correlation at genotypic level (-0.0508P, 0.0403G). Equatorial bulb diameter showed positive correlation at phenotypic level and negative correlation at genotypic level (0.0310P, -0.1521G). Present findings are in conformity with Raghuwanshi *et al.* (2016) in onion and Kamal (2015) in garlic.

4.4.2. Number of leaves per plant

Number of leaves per plant exhibited positive correlation in both phenotypic and genotypic level with neck thickness (0.1721P, 0.2548G), equatorial bulb diameter (0.1052P, 0.0783G), polar bulb diameter (0.0879P, 0.1010G), total soluble solids (0.1294P, 0.1565G), average bulb weight (0.1589P, 0.1628G) and yield per hectare (0.1288P, 0.1670G). It showed negative correlation in both phenotypic and genotypic level with days to maturity (-0.0651P, -0.0999G) and ascorbic acid content (-0.1732P, -0.1950G). Similar results were also reported by Suthanirapandian and Muthukrishnan (1982) in onion.

4.4.3. Days to maturity (days)

Days to maturity registered negative correlation with neck thickness (-0.0801P, 0.0842G), polar bulb diameter (-0.0746P, -0.0974G), ascorbic acid content (-0.01774P, -0.2053G), total soluble solids (-0.1349P, -0.1278G), average bulb weight (-0.0036P, -0.0363G), equatorial bulb diameter (-0.0444P, -0.0897G) and yield per hectare (-0.0641P, -0.0497G). Present findings are conformity with Yaso (2007), Chattoo *et al.* (2015) in onion.

4.4.4. Neck thickness (cm)

Neck thickness showed positive significant correlations with equatorial bulb diameter (0.02537**P, 0.3416G), polar bulb diameter (0.2393**P, 0.03149G), ascorbic acid content (0.2108*P, 0.2166G), average bulb weight (0.3857**P, 0.4182G) and yield per hectare (0.3900P, 0.4158G). It showed negative correlation only with total soluble solids both at genotypic and phenotypic level (-0.1664P, -0.1710G). The present findings are in line with the reports of Patil (1984) and Gurjar and Singhania (2006) in onion.

4.4.5. Equatorial bulb diameter (cm)

Equatorial bulb diameter showed positive and significant correlations with polar bulb diameter (0.7837**P, 0.9011G), ascorbic acid content (0.0429P, 0.0801G), average bulb weight (0.7730**P, 0.9386G) and yield per hectare (0.7526P, 0.9525G). It showed negatively correlation with total soluble solids both at genotypic and phenotypic level (-0.0654P, -0.0413G). Present findings are in conformity with the Magar (1995) in onion. Similar results were also reported by Haydar *et al.* (2007), Hosamani *et al.* (2010), Saini and Maurya (2014) in onion.

Table 4.4a. Phenotypic (P) correlation coefficients among growth, yield and quality attributes in forty genotypes of onion

Characters	Plant height (cm)	No. of leaves per plant	Days to maturity	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	Total Soluble Solids (°Brix)	Average bulb weight (g)	Yield (t ha ⁻¹)
Plant height (cm)	1.0000	-0.0605	-0.0508	0.1166	0.0310	-0.0966	0.1340	-0.1317	-0.0421	-0.0106
No. of leaves per plant		1.0000	-0.0651	0.1721	0.1052	0.0879	-0.1732	0.1294	0.1589	0.1288
Days to maturity			1.0000	-0.0801	-0.0444	-0.0746	-0.1774	-0.1349	-0.0036	-0.0641
Neck thickness (cm)				1.0000	0.2537 **	0.2393 **	0.2108 *	-0.1664	0.3857 **	0.3900
Equatorial bulb diameter (cm)					1.0000	0.7837 **	0.0429	-0.0654	0.7730 **	0.7526
Polar bulb diameter (cm)						1.0000	0.0118	-0.0107	0.7038 **	0.7318
Ascorbic acid (mg 100⁻¹ g)							1.0000	-0.3742 **	-0.0044	0.0138
Total Soluble Solids (°Brix)								1.0000	-0.0694	-0.0616
Average bulb weight (g)									1.0000	0.9469
Yield (t ha⁻¹)										1.0000

* and** and = Significant at 1 per cent and 5 per cent level of significance

Table 4.4b. Genotypic (G) correlation coefficients among growth, yield and quality attributes in forty genotypes of onion

Characters	Plant height (cm)	No. of leaves per plant	Days to maturity	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	Total Soluble Solids (°Brix)	Average bulb weight (g)	Yield (t ha ⁻¹)
Plant height (cm)	1.0000	-0.4445	0.0403	0.3160	-0.1521	-0.1819	0.3741	-0.2872	-0.1379	-0.1193
No. of leaves per plant		1.0000	-0.0999	0.2548	0.0783	0.1010	-0.1950	0.1565	0.1628	0.1670
Days to maturity			1.0000	-0.0842	-0.0897	-0.0974	-0.2053	-0.1278	-0.0363	-0.0497
Neck thickness (cm)				1.0000	0.3416	0.3149	0.2166	-0.1710	0.4182	0.4158
Equatorial bulb diameter (cm)					1.0000	0.9011	0.0801	-0.0413	0.9386	0.9525
Polar bulb diameter (cm)						1.0000	0.0234	0.0016	0.9691	0.9344
Ascorbic acid (mg 100 ⁻¹ g)							1.0000	-0.3931	0.0062	0.0196
Total Soluble Solids (°Brix)								1.0000	-0.0700	-0.0661
Average bulb weight (g)									1.0000	0.9010
Yield (t ha ⁻¹)										1.0000

* and** and = Significant at 1 per cent and 5 per cent level of significance

4.4.6. Polar bulb diameter (cm)

Positive and significant correlations were registered by polar bulb diameter with ascorbic acid content (0.0118P, 0.0234G), average bulb weight (0.7038**P, 0.9691G) and yield per hectare (0.7318P, 0.9344G), negative correlation was with total soluble solids at phenotypic level (-0.0107P) and positive correlation at genotypic level (0.0016). Present findings are conformity with the Rahman *et al.* (2002) and Haydar *et al.* (2007) in onion.

4.4.7. Ascorbic acid content (mg 100⁻¹g)

Ascorbic acid content registered positive correlations with plant height (0.1340P, 0.3741G), neck thickness (0.2108*P, 0.2166G), equatorial bulb diameter (0.0429P, 0.0801G), polar bulb diameter (0.0118P, 0.0234G) and yield per hectare (0.0138P, 0.0196G) and negative significant correlation with total soluble solids (-0.3742**P, -0.3931G) and number of leaves per plant (-0.1732P, -0.1950G). Average bulb weight showed negative correlation at phenotypic level (-0.0044P), positive correlation at genotypic level (0.0062G). The present findings are in line with the reports of Bhatt (2015) in onion.

4.4.8. Total soluble solids (°Brix)

This trait recorded significant negative correlations with plant height (-0.1317P, -0.2872G), days to maturity (-0.1349P, -0.1278G), neck thickness (-0.1664P, -0.1710G), equatorial bulb diameter (-0.0654P, -0.0413G), ascorbic acid content (-0.3742**P, -0.3931G), average bulb weight (-0.0694P, -0.0700G) and yield per hectare (-0.0616P, -0.0661G). Similar results were also reported by Ravankar *et al.* (1998) and Ram *et al.* (2000) in onion.

4.4.9. Average bulb weight (g)

Average bulb weight showed positive significant correlations with yield (0.9469P, 0.9010G), number of leaves per plant (0.1589P, 0.1628G), neck thickness (0.3857**P, 0.4182G), equatorial bulb diameter (0.7730**P, 0.9386G) and polar bulb diameter (0.7038**P, 0.9691G). Negative significant correlation with plant height (-0.0421P, -0.1379G) and total soluble solids (-0.0694P, -

0.0700G) and days to maturity (-0.0363 G, -0.0036 P). These findings are in line with the reports of Magdum (1981), Patil (1983) and Shaha (1985) in onion.

4.4.10. Yield (t ha⁻¹)

This trait recorded positive correlations with number of leaves per plant (0.1288P, 0.1670G), neck thickness (0.3900P, 0.4158G), equatorial bulb diameter (0.7526P, 0.9525G), polar bulb diameter (0.7318P, 0.9344G), ascorbic acid content (0.0138P, 0.0196G) and average bulb weight (0.9469P, 0.9010G). It registered negative correlations with plant height (-0.0106P, -0.1193G), days to maturity (-0.0641P, -0.0497G) and total soluble solids (-0.0616P, -0.0661G). Similar results were reported by Rajalingam and Haripriya (2000), Mohanty and Prusti (2002) and Navaldey *et al.* (2011) in onion.

The phenotypic (P) and genotypic correlation (G) coefficients were worked out for ten characters and the results are presented in Table 4.4a and 4.4b respectively.

In general, it was observed that genotypic correlation coefficients were higher than that of phenotypic correlation coefficients. This could be interpreted on the basis, that there was a strong inherent genotypic relationship between the traits studied, but their phenotypic expression was impeded by influence of environmental factors. Golani *et al.* (2006) also observed high magnitude of genotypic correlation than the corresponding phenotypic correlation for most of the characters combinations, establishing predominant role of heritable factor.

Understanding of the interaction of the traits among themselves and with the environment is of great use in plant breeding. Correlation studies provide information on the nature and extent of association between any two quantitative traits and it would be useful for genetic enhancement of a trait through selection of a correlated trait (associated response).

Yield is a complex character and jointly determined by a number of related traits. An insight into the association between yield and other correlated traits helps to improve the efficiency of selection. In general, the correlation

between yield and other characters as well as among the component characters will vary with the material handled by the breeder. The only significant correlations either in positive or negative directions are described.

The study on genotypic and phenotypic correlations is an important approach in crop improvement as Galtan (1988) emphasized the use of this index to describe the degree of association between two or more characters. It gives the total mutual relationship between two characters. Plant yield is a very complex character dependent on a number of components. Therefore, knowledge of magnitude of correlation of yield with its attributes is of immense practical utility and has profound significance in the field of crop improvement.

The results on character association indicated significant positive association of yield with number of leaves per plant, neck thickness at harvest, equatorial bulb diameter, polar bulb diameter, ascorbic acid content and average bulb weight which indicated that the adequate knowledge of interrelationship between bulb yield and its component themselves is useful for selection and simultaneous improvement in these characters.

4.5 Path coefficient analysis

Path coefficient is the ratio of standard deviation of the effect due to a given cause (independent variable) to the total standard deviation of the effect (dependant variable). This technique, which aims to improve a dependent character like yield when the independent characters have a significant relation in desirable direction and positive direct or indirect effect through other component traits on the dependent characters, it is used in plant breeding programs.

Path analysis was carried out at phenotypic and genotypic level considering bulb as dependent variable and its attributes *viz.*, plant height, number of leaves per plant, days to maturity, neck thickness at harvest, equatorial bulb diameter, polar bulb diameter, ascorbic acid content, total soluble solids and average bulb weight as independent variables.

Each component has two path actions viz., direct effect on yield and indirect effect through components which are not revealed by correlation studies. The results are presented in Table 4.5a and 4.5b and the path showing the cause and effect relationship is shown for phenotypic in Fig.4.8 and genotypic in Fig.4.9.

4.5.1. Plant height (cm)

Plant height showed negligible direct positive effect on bulb yield at phenotypic level (0.0357P) and genotypic level (0.0335G). Similar results were also observed by Rajalingam and Haripriya (2000), Yaso (2007), Gujar and Singhanian (2006) and Sharma *et al.* (2015) in onion.

4.5.2. Number of leaves per plant

This trait showed negligible direct positive effect on bulb yield at genotypic level (0.0103G) and negligible negative direct effect at phenotypic level (-0.025 P). The present findings are in line with the reports of Mohanty (2001b), Gurjar and Singhanian (2006) and Golani *et al.* (2006) in onion.

4.5.3. Days to maturity (days)

Negligible negative direct effect on bulb yield was exhibited by this trait at phenotypic level (-0.0503P) and genotypic level (-0.0149G). Present findings are conformity with Rajalingam and Haripriya (2000) in onion.

4.5.4. Neck thickness (cm)

This trait showed negligible positive on bulb yield (0.0270P) at phenotypic level and negligible negative direct effects at genotypic level (-0.0422G). Similar results were also registered by Suthanthirapandian and Muthukrishnan (1982) and Hosamani *et al.* (2010) in onion.

4.5.5. Equatorial bulb diameter (cm)

At both phenotypic and genotypic level, equatorial bulb diameter showed negligible negative direct effect (-0.0144P, -0.0458G) on bulb yield respectively.

Similar results were reported by Mohanty (2004), Hosamani *et al.* (2010) and Dewangan and Sahu (2012) in onion.

4.5.6. Polar bulb diameter (cm)

At both phenotypic and genotypic level, polar bulb diameter showed very high positive direct effect (0.1494P, 0.1429G) on bulb yield respectively. Present findings are conformity with Solanki *et al.* (2015) and Rahuwanshi *et al.* (2016) in onion.

4.5.7. Ascorbic acid (mg 100⁻¹g)

Ascorbic acid showed negligible and negative direct effect on bulb yield at phenotypic level (-0.0055P) and negligible direct positive at genotypic level (0.0373G).

4.5.8. Total soluble solids (°Brix)

This trait showed negligible positive direct effect on bulb yield both at phenotypic and genotypic (0.0011P, 0.0182G) levels. Similar results were also reported by Dewangan and Sahu (2012) and Chattoo *et al.* (2015) in onion.

4.5.9. Average bulb weight (g)

This trait showed high positive direct effect on yield both at phenotypic and genotypic (0.8721P, 1.2045G) levels. This suggested that direct selection based on these traits will be rewarding for yield improvement in onion. Present findings are in line with the reports of Chattoo *et al.* (2015) and Sharma *et al.* (2015) in onion.

Table 4.5a. Phenotypic (P) path coefficient analysis indicating direct and indirect effects of component characters on bulb yield

Characters	Plant height (cm)	No. of leaves per plant	Days to maturity (days)	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	Total Soluble Solids (°Brix)	Average bulb weight (g)
Plant height (cm)	<u>0.0357</u>	-0.0022	-0.0018	0.0042	0.0011	-0.0034	0.0048	-0.0047	-0.0015
No. of leaves per plant	0.0015	<u>-0.025</u>	0.0016	-0.0043	-0.0026	-0.0022	0.0043	-0.0032	-0.004
Days to maturity (days)	0.0026	0.0033	<u>-0.0503</u>	0.004	0.0022	0.0038	0.0089	0.0068	0.0002
Neck thickness (cm)	0.0031	0.0046	-0.0022	<u>0.027</u>	0.0068	0.0065	0.0057	-0.0045	0.0104
Equatorial bulb diameter (cm)	-0.0014	-0.0048	0.002	-0.0116	<u>-0.0458</u>	-0.0359	-0.002	0.003	-0.0354
Polar bulb diameter (cm)	-0.0144	0.0131	-0.0112	0.0358	0.1171	<u>0.1494</u>	0.0018	-0.0016	0.1052
Ascorbic acid (mg 100 ⁻¹ g)	-0.0007	0.0009	0.001	-0.0012	-0.0002	-0.0001	<u>-0.0055</u>	0.002	0.0000
Total Soluble Solids (°Brix)	-0.0001	0.0001	-0.0002	-0.0002	-0.0001	0.0000	-0.0004	<u>0.0011</u>	-0.0001
Average bulb weight (g)	-0.0368	0.1386	-0.0031	0.3364	0.6741	0.6138	-0.0039	-0.0605	<u>0.8721</u>

Phenotypical Residual effect =0.2990; Diagonal (under lined) values indicate direct effects

Table 4.5b. Genotypic (G) path coefficient analysis indicating direct and indirect effects of component characters on bulb yield in forty genotypes of onion

Characters	Plant height (cm)	No. of leaves per plant	Days to maturity	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	Total Soluble Solids (°Brix)	Average bulb weight (g)
Plant height (cm)	<u>0.0335</u>	-0.0149	0.0014	0.0106	-0.0051	-0.0061	0.0125	-0.0096	-0.0046
No. of leaves per plant	-0.0046	<u>0.0103</u>	-0.001	0.0026	0.0008	0.001	-0.002	0.0016	0.0017
Days to maturity	-0.0006	0.0015	<u>-0.0149</u>	0.0013	0.0013	0.0015	0.0031	0.0019	0.0005
Neck thickness (cm)	-0.0133	-0.0107	0.0036	<u>-0.0422</u>	-0.0144	-0.0133	-0.0091	0.0072	-0.0176
Equatorial bulb diameter (cm)	0.049	-0.0252	0.0289	-0.1101	<u>-0.3223</u>	-0.3598	-0.0258	0.0133	-0.3025
Polar bulb diameter (cm)	-0.026	0.0144	-0.0139	0.045	0.1595	<u>0.1429</u>	0.0033	0.0002	0.1385
Ascorbic acid (mg 100 ⁻¹ g)	0.014	-0.0073	-0.0077	0.0081	0.003	0.0009	<u>0.0373</u>	-0.0147	0.0002
Total Soluble Solids (°Brix)	-0.0052	0.0029	-0.0023	-0.0031	-0.0008	0.0000	-0.0072	<u>0.0182</u>	-0.0013
Average bulb weight (g)	-0.1661	0.1961	-0.0437	0.5037	1.1305	1.1673	0.0075	-0.0843	<u>1.2045</u>

Genotypical Residual effect =0.2820; Diagonal (under lined) values indicate direct effects

Path analysis developed by Wright (1921) is standardized partial regression coefficient and as such measures the direct influence of one variable upon another and permits the partitioning of correlation coefficient into components of direct and indirect effect (Dewey and Lu, 1959). It is apparent that many of the yield components have mutual association either positive or negative amongst each other. As more variables are considered in correlation studies indirect association become more complex and less obvious. The direct and indirect causes of association permit's a critical examination of specific forces acting to produce relative importance of each of the causal factors.

Although correlation coefficients indicate the nature of association among the characters, path analysis splits the correlation coefficients into measures of direct and indirect effects, thus providing an understanding on the direct and indirect contribution of each character towards yield.

The traits like polar bulb diameter, ascorbic acid content and average bulb weight exhibited positive direct effect on bulb yield and these traits also recorded positive correlation with yield. This suggests that direct selection based on these traits will be rewarding for crop yield improvement.

The residual factor determines how best the causal factors account for the variability of the dependent factor, the bulb yield in this case. The residual effects were 0.2990 and 0.2820, which were of low magnitude at phenotypic and genotypic levels.

In this study, it can be concluded that polar bulb diameter, ascorbic acid content and average bulb weight showed positive correlation and positive direct effect on bulb yield. These are identified as superior yield components. Hence, the genotypes which exhibited better performance for these characters can be used in further improvement in onion.

4.6 Genetic divergence (D^2 statistic)

The quantitative assessment of genetic divergence was made by adopting D^2 Mahalanobis statistic for yield and its contributing characters.

4.6.1 Grouping of genotypes into different clusters (D^2 analysis)

The D^2 values between any two genotypes was calculated as the sum of squares of the differences between the mean values of all the ten characters and used for the final grouping of the genotypes.

Procedure suggested by Tocher (Rao., 1952) has been used to group 40 genotypes into twelve clusters by treating the estimated D^2 values as the square of the generalized distance.

Based on D^2 values, the 40 genotypes were grouped into twelve highly divergent clusters (Table 4.6). Some of genotypes were so divergent in all the characters, hence each single genotype formed a separate cluster. Thus, eight clusters viz., II (Bhima Shakti), III (1771), VI (W-498), VII (W-405), IX (W-177), X (W-210), XI (W-507) and XII (1769) were solitary with one genotype in each cluster.

Table 4.6. Clustering pattern of forty genotypes of onion by Tocher's method

Cluster	No. of genotypes	Genotypes
I	17	Bhima Shubra, W-464, W-045, W-364, W-444, Bhima Kiran, 1785, W-182, W-226cp, Bhima Red, Bhima Super, W-390, W-1786, Bhima Safed, 1768, W-500, Bhima Raj
II	1	Bhima Shakti
III	1	1771
IV	4	1774, 1772, 1742, 1784
V	6	W-253cp, W-246cp, 1773, W-203, W-398, W-405cp
VI	1	W-498
VII	1	W-405
VIII	5	W-125, Bhima Shwetha, 1770, 1744, 1745
IX	1	W-177
X	1	W-210
XI	1	W-507
XII	1	1769

Clustering by Tocher's method

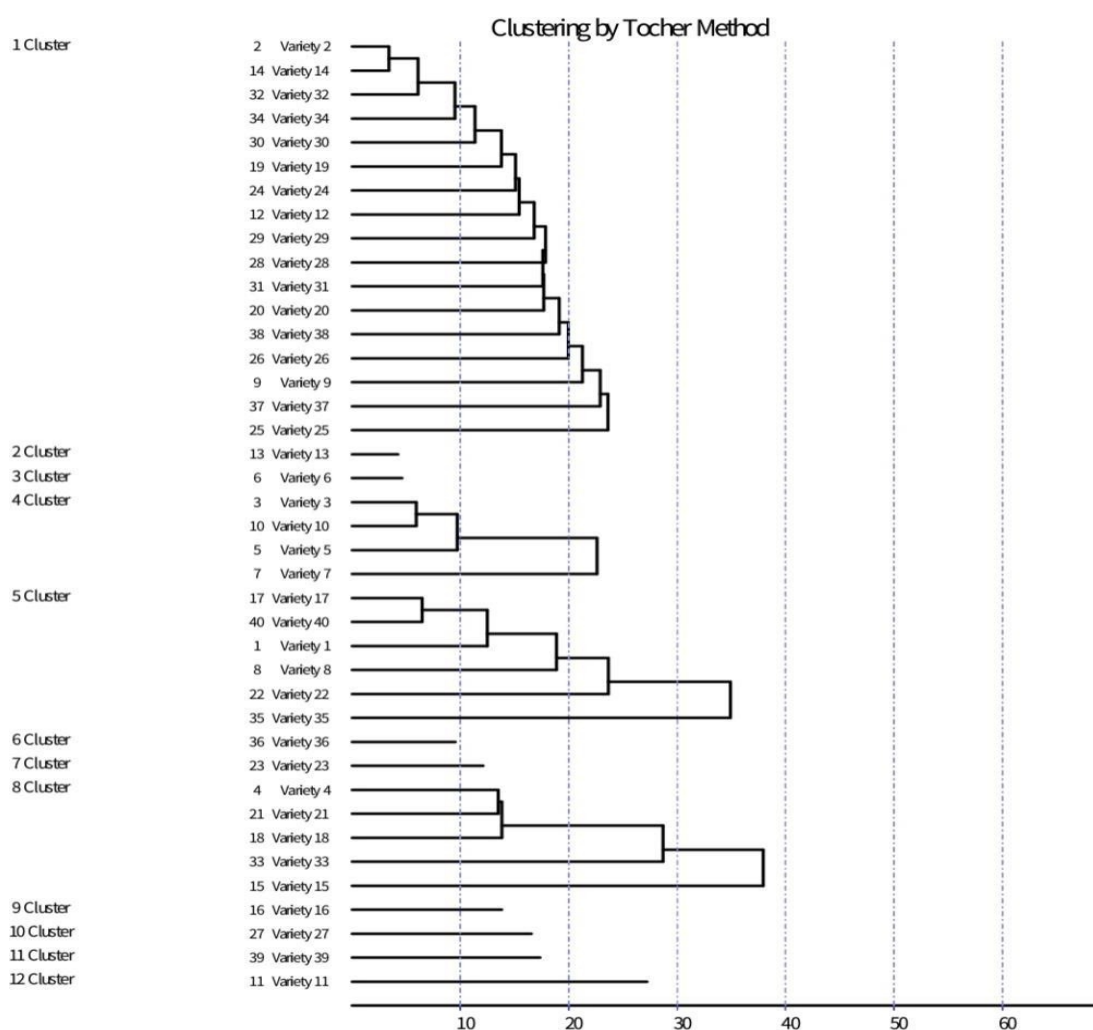


Fig 4.12. Dendrogram showing clustering pattern for divergence of forty onion genotypes

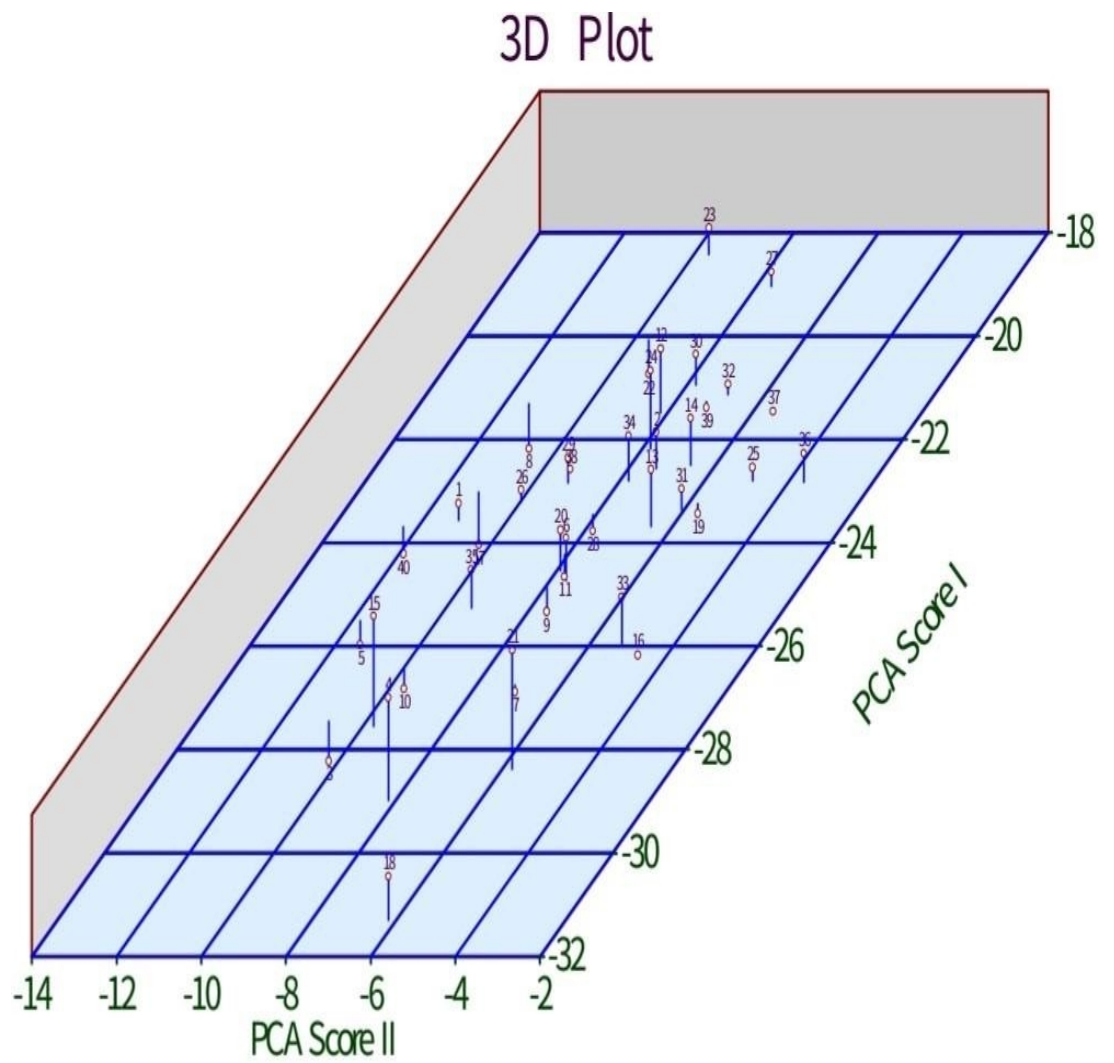


Fig 4.13. Three-dimensional plot showing clustering pattern for divergence of forty onion genotypes

The remaining four clusters were having maximum number of genotypes. Cluster I was biggest with 17 genotypes viz., Bhima Shubra, W- 464, W-045, W-W-390, W-1786, Bhima Safed, 1768, W-500 and Bhima Raj followed by Cluster V with 6 genotypes viz., W-253cp, W-246cp, 1773, W-203, W-398 and W-405cp then by Cluster VIII with 5 genotypes viz., W-125, Bhima Shwetha, 1770, 1744 and 1745, followed by cluster IV with 4 genotypes viz., 1774, 1772, 1742 and 1784 are presented in fig.4.6 in three dimensional plot diagram.

4.6.2 Cluster means of characters

The cluster means for the ten characters studied in onion genotypes revealed considerable differences among them (Table 4.7). From the present data, it was evident that plant height was highest in cluster II (57.46 cm) and lowest in cluster III (49.55 cm). Maximum number of leaves was recorded in cluster III (11.73), whereas minimum was recorded in cluster VI (8.53).

The cluster VII had the early days to maturity (103.00 days) followed by cluster VIII (104.20 days), while maximum neck thickness was recorded in cluster VIII (1.80 cm) and lowest in cluster X (0.96 cm).

The maximum equatorial bulb diameter was recorded by the genotype of cluster VIII (6.37 cm), followed by cluster IV (6.23 cm), whereas minimum value was recorded in the genotype of cluster VII (5.12 cm), followed by cluster X (5.32 cm). The genotype of cluster VIII registered more polar bulb diameter (5.67 cm), followed by cluster IV (5.61 cm), while the genotype of cluster VII (4.53 cm) observed less polar bulb diameter, followed by cluster X (4.74 cm).

Ascorbic acid content was maximum in cluster VI (11.99 mg 100⁻¹ g) and minimum value in cluster XII (8.37 mg 100⁻¹ g). The genotype of cluster V had maximum TSS value (13.86°Brix), whereas genotypes of the cluster VI have minimum TSS (10.87°Brix).

Average bulb weight was maximum in cluster VIII (116.53 g) and minimum value in cluster VII (58.97 g), Yield per hectare was highest in cluster IV (51.58 t ha⁻¹) and lowest in cluster VII (26.2 t ha⁻¹).

Cluster mean values showed a wide range of mean values among the characters studied indicating presence of wide variation among the genotypes studied.

4.6.3 Average intra and inter cluster distances

The mean intra and inter cluster D² values among the twelve clusters are given in the Table 4.8. The intra cluster D² values ranged from nil (Cluster II, III, VI, VII, IX, X, XI, XII) to 35.94 (Cluster VIII). The cluster VIII had the maximum D² value (35.94), followed by Cluster V (29.83), cluster IV (20.93) and Cluster I (20.44).

The inter cluster D² values of the twelve clusters revealed that highest inter cluster generalized distance (150.67) was between cluster VIII and VII followed by cluster X and VIII (149.97), while the lowest (13.56) was between cluster III and cluster II.

The inter cluster distance was minimum between cluster III and II indicating narrow genetic diversity, whereas maximum recorded between clusters VIII and VII indicating wider genetic diversity between these groups. Similar observations were reported by Patil (1984), Dhotre *et al.* (2010), Gurjar *et al.* (2003), Rashid *et al.* (2012), Singh *et al.* (2013), Kale *et al.* (2014), Akter *et al.* (2015) and Dangi *et al.* (2018a) in onion.

Table 4.7. Mean values of clusters for ten characters in forty onion genotypes

Cluster	Plant height (cm)	No. of leaves per plant	Days to maturity (days)	Neck thickness (cm)	Equatorial bulb diameter (cm)	Polar bulb diameter (cm)	Ascorbic acid (mg 100 ⁻¹ g)	TSS (°Brix)	Average bulb weight (g)	Yield (t ha ⁻¹)
I	55.52	10.48	110.16	1.35	5.66	4.97	10.60	12.09	86.78	39.03
II	57.46	10.53	118.00	1.76	5.71	4.91	11.02	11.53	89.75	40.52
III	49.55	11.73	120.33	1.55	5.82	5.16	10.31	11.03	100.50	44.66
IV	52.73	10.88	109.75	1.16	6.23	5.61	9.70	13.06	114.00	51.58
V	54.71	10.50	116.28	1.36	5.68	5.00	9.74	13.86	89.27	39.67
VI	55.21	8.53	112.33	1.48	5.67	4.98	11.99	10.87	84.03	37.35
VII	55.22	10.80	103.00	1.23	5.12	4.53	10.06	13.3	58.97	26.2
VIII	56.00	11.00	104.20	1.80	6.37	5.67	11.42	12.18	116.53	52.8
IX	57.01	10.13	118.67	1.23	6.07	5.34	11.95	11.23	111.60	49.59
X	54.21	11.60	110.67	0.96	5.32	4.74	11.06	12.27	63.80	28.35
XI	56.54	10.27	112.33	1.03	5.5	4.92	11.97	13.3	77.03	34.23
XII	57.00	9.93	110.67	1.33	5.94	5.27	8.37	11.00	102.93	45.74

Table 4.8. Average intra (bold) and inter-cluster D² values for twelve clusters in forty genotypes of onion

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
I	20.44	27.66	30.09	52.14	52.27	30.36	43.74	72.49	46.06	37.5	42.92	50.48
II		0	13.56	76.8	64.69	25.07	71.00	48.65	51.06	72.12	74.62	61.19
III			0	60.56	79.61	34.22	91.57	54.76	38.44	75.73	93.03	32.29
IV				20.93	52.88	92.61	101.11	70.02	53.22	97.15	71.26	63.15
V					29.83	100.85	50.73	100.37	103.96	77.93	54.89	98.4
VI						0	78.16	77.74	30.49	49.91	56.91	68.93
VII							0	150.67	131.08	22.06	41.27	101.83
VIII								35.94	59.84	149.97	116.03	107.2
IX									0	81.65	61.85	76.71
X										0	24.21	97.76
XI											0	132.73
XII												0

*** Bold diagonal values indicate intra cluster distance, rest of the values show the inter cluster distances**

Table 4.9. The nearest and farthest clusters from each cluster based on D² values in onion genotypes

Cluster	Nearest cluster with D ² values	Farthest cluster with D ² values
I	II (27.66)	VIII (72.49)
II	III (13.56)	XII (61.19)
III	XII (32.29)	XI (93.03)
IV	IV (52.14)	VII (101.11)
V	VII (50.73)	IX (103.96)
VI	II (25.07)	V (100.85)
VII	X (22.06)	VII (150.67)
VIII	II (48.65)	VIII (149.97)
IX	VI (30.49)	VII (131.08)
X	VII (22.06)	VIII (149.97)
XI	X (24.21)	VIII (116.03)
XII	III (32.29)	XI (132.73)

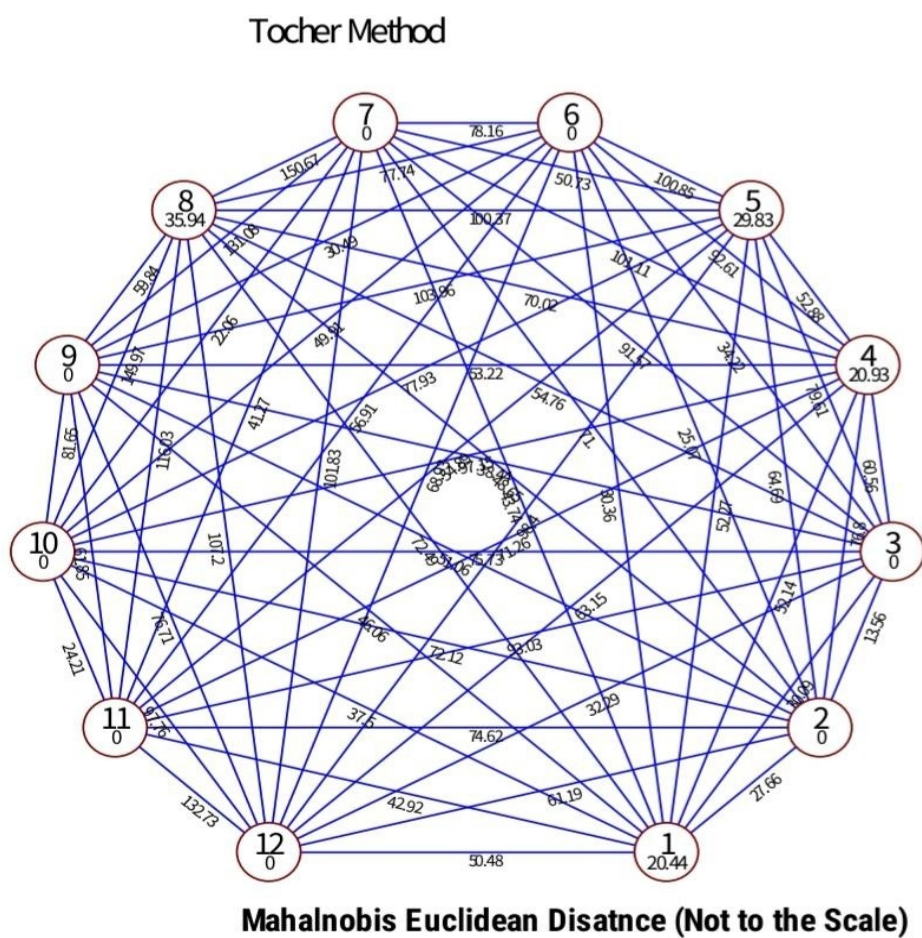


Fig 4.14. Cluster diagram showing average intra and inter-cluster D^2 values of onion genotypes

Table 4.10. Per cent contribution of different characters towards genetic divergence in forty onion genotypes

S.No	Source	Times ranked 1st	Contribution (%)
1	Plant height (cm)	5	0.64
2	No. of leaves per plant	15	1.92
3	Days to maturity (days)	32	4.10
4	Neck thickness (cm)	190	24.36
5	Equatorial bulb diameter (cm)	4	0.51
6	Polar bulb diameter (cm)	0	0.00
7	Ascorbic acid (mg 100 ⁻¹ g)	165	21.15
8	Total Soluble Solids (°Brix)	221	28.33
9	Average bulb weight (g)	110	14.10
10	Yield per hectare (t ha ⁻¹)	38	4.87

4.6.4 Relative contribution of different characters towards divergence

Number of times each of ten traits appeared in first rank and its respective per cent contribution towards genetic divergence are presented in Table 4.10. The results showed that the total soluble solids contributed maximum (28.33 %) towards diversity by taking 221 times first ranking, followed by neck thickness (24.36 %) by 190 times, ascorbic acid (21.15 %) by 165 times average bulb weight (14.10 %) by 110 times, yield per hectare (4.87 %) by 38 times, days to maturity (4.10 %), number of leaves per plant (1.92 %) by 15 times, plant height (0.64 %) by 5 times and equatorial bulb diameter (0.51 %) by 4 times. In contrast, the remaining trait *viz.*, polar bulb diameter did not contribute to the total divergence. Apart from the high divergence, the performance of the genotypes and the characters with maximum contribution towards divergence should also be given due consideration which appears as desirable for inclusion in onion improvement.

Mahalanobis D^2 statistics, a powerful tool has been used to quantify the genetic divergence between the genotypes and to identify diverse parents for crossing. This also helps to relate clustering pattern with the geographical origin. This technique has been employed widely to resolve divergence at inter varietal, species and subspecies levels in classifying problems in crop plants (FAO. 1997). In the present study, forty genotypes of onion were grouped into twelve clusters. The magnitude of D^2 values confirmed that there was considerable amount of diversity in the experimental material evaluated.

Statistical distance represents the extent of genetic diversity among clusters. The inter cluster distance was minimum between cluster III and cluster II indicating close relationship and similarity for most of the characters of the genotypes included in these clusters. The maximum inter cluster distance was observed between clusters cluster VIII and VII indicating wider genetic diversity among the genotypes included in these groups.

Selection of parents from these diverse clusters for hybridization programme would help in achieving novel recombinants. Cluster I displayed least intra cluster distance denoting the similarity of genotypes. While maximum intra cluster distance was recorded in cluster VIII and this might be due to limited gene exchange or selection practices among the genotypes for diverse characters.

Emphasis should be laid on characters contributing maximum D^2 values for choosing the cluster for the purpose of further selection and choice of parents for hybridization. Highest contribution towards divergence in this regard was put forth by total soluble solids (28.33 %), neck thickness at harvest (24.36 %), ascorbic acid (21.15 %), average bulb weight (14.10 %), yield per hectare (4.87 %), days to maturity (4.10 %), number of leaves per plant (1.92 %), plant height (0.64 %) and equatorial bulb diameter (0.51 %). Thus, these were the major traits contributing to divergence. Hence, selection for divergent parents based on these characters will be useful for further breeding programmes in onion. The remaining trait *viz.*, polar bulb diameter did not contribute to the total divergence. The present findings are in line with the reports of Patil (1983), Shaha (1985), Mohanty and Prusti (2002), Khar *et al.* (2006), Singh *et al.* (2013) and Kale *et al.* (2014) in onion.

Genetic divergence among the forty genotypes revealed that genotypes *viz.*, Bhima Raj, Bhima Kiran, W-045, 1774, W-364, Bhima Shakti, 1772, 1769, W-177, Bhima Shwetha, Bhima Super, 1773, W-253cp, W-405, W-226cp, W-444, W-500 and W-1786 were identified as genetically divergent for plant height and hence, these genotypes can be utilized in crop improvement programme.

The genotypes *viz.*, 1745, W-125, 1785 and W-226cp were more divergent for improving number of leaves per plant. The genotype Bhima Shwetha were found to be promising line for least number of days taken to maturity.

Three genotypes *viz.*, 1745, Bhima Shwetha and W-125 can be used for improving neck thickness. The genotypes *viz.*, 1770 and 1774 can be used for improving average bulb weight , bulb yield, equatorial bulb diameter and polar bulb diameter.

Quality parameters like TSS can be improved by using genotypes *viz.*, W-246cp and W-1773. The genotype Bhima Shwetha can be used for improving ascorbic acid.



Plate 5. contd.



Plate 5. contd.





Plate 5. Bulbs of Onion genotypes

CHAPTER V

SUMMARY AND CONCLUSIONS

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SUMMARY AND CONCLUSIONS

The present investigation entitled “Genetic characterization of onion (*Allium cepa* L.) genotypes” was undertaken to study the genetic diversity among the 40 genotypes of onion. Information regarding genetic diversity and genetic relationships among different genotypes is very valuable in crop improvement.

Forty onion genotypes were grown in Randomized Block Design with three replications during *rabi*, 2020 at PG Research block, College of Horticulture, Rajendranagar, Hyderabad. Biometrical observations were recorded on ten characters *viz.*, plant height (cm), number of leaves per plant, days to maturity (days), neck thickness (cm), equatorial bulb diameter (cm), polar bulb diameter (cm), average bulb weight (g), yield (t ha⁻¹), ascorbic acid (mg 100⁻¹ g) and total soluble solids (°Brix).

The analysis of variance (ANOVA) showed highly significant differences among the genotypes indicating thereby the presence of sufficient variability for all the traits in the experimental materials. The mean data was analyzed by following standard statistical techniques with the objective of studying the nature and magnitude of genetic diversity available in the genotypes, the degree and direction of relationship between yield and its component characters on yield. The genetic analysis assesses the variability, heritability, genetic advance as per cent of mean, magnitude of association between characters, their inter dependence, direct and indirect effect of traits on yield, existence of genetic diversity and relative contribution to divergence.

The mean sum of squares for genotypes was found to be significant for all the characters *viz.*, plant height (cm), number of leaves per plant, days to maturity (days), neck thickness (cm), equatorial bulb diameter (cm), polar bulb diameter (cm), average bulb weight (g), yield (t ha⁻¹), ascorbic acid (mg 100⁻¹ g) and total soluble solids (°Brix).

The result of mean performance of forty genotypes for ten characters revealed that the genotype 1770 was the superior for yield and yield contributing characters *i.e.*, average bulb weight (129.60 g), equatorial bulb diameter (7.20 cm), polar bulb diameter (6.63 cm) and yield per hectare (57.59 t). The genotype Bhima Raj was significantly superior for plant height (62.39 cm). The genotype 1745 recorded maximum neck thickness at harvest (2.01 cm). The genotype Bhima Shwetha was found to be superior for ascorbic acid (12.52 mg 100⁻¹ g) and early days to maturity (95.33 days). Highest TSS was found in W-246cp (14.60 °Brix).

Wide range of variability was observed for average bulb weight (769.40) followed by yield per hectare (164.45) and days to maturity (145.05) indicating the scope for selection of initial breeding material for further improvement. Moderate phenotypic coefficient of variation (PCV) and low genotypic coefficients of variation (GCV) estimates were recorded for average bulb weight and yield per hectare. The difference between phenotypic coefficients of variation and genotypic coefficients of variation values were minimum, indicating that the traits under study were less influenced by environment and these characters could be improved by following phenotypic selection. Heritability (b.s.) for all the characters in 40 genotypes was categorized as low to high ranging from 18.73 to 94.68 %. Genetic advance was found ranging from 0.47 to 31.00. Traits namely neck thickness, ascorbic acid, TSS, average bulb weight and yield showed high estimates of broad sense heritability indicating the effectiveness of selection in the genotypes for these traits.

High heritability coupled with high genetic advance as per cent of mean indicates operation of additive gene action which was observed in characters *viz.*, neck thickness, average bulb weight and yield per hectare. Hence, directional selection for these traits in genetically diverse material could be effective for desired genetic improvement. Moderate genetic advance as per cent of mean with high or moderate heritability suggests the action of both additive and non additive genes thereby indicating influence of environment in the expression. The same was reported in case of number of leaves per plant, days

to maturity, equatorial bulb diameter, polar bulb diameter, ascorbic acid content and total soluble solids.

In correlation studies, bulb yield exhibited positive association with number of leaves per plant, neck thickness, equatorial bulb diameter, polar bulb diameter, ascorbic acid content and average bulb weight. These characters should form selection criterion in breeding programmes. Direct selection based on these traits could result in simultaneous improvement of traits and bulb yield in onion.

In path coefficient analysis, the characters *viz.*, plant height, TSS, polar bulb diameter and average bulb weight exhibited positive direct effects on bulb yield and these traits also recorded positive correlation with bulb yield. These are identified as superior yield components. Hence, the genotypes which exhibited better performance for these characters can be used in further improvement of onion.

The magnitude of D^2 values confirmed that there was considerable amount of diversity in the experimental material evaluated. D^2 statistic indicated that the genotypes studied were genetically diverse. The 40 genotypes were grouped into twelve clusters. Eight clusters *viz.*, II (Bhima Shakti), III (1771), VI (W-498), VII (W-405), IX (W-177), X (W-210), XI (W-507) and XII (1769) were solitary with one genotype in each cluster.

The remaining four clusters were having maximum number of genotypes. Cluster I was biggest with 17 genotypes *viz.*, Bhima Shubra, W-464, W-045, W-W-390, W-1786, Bhima Safed, 1768, W-500 and Bhima Raj followed by Cluster V with 6 genotypes *viz.*, W-253cp, W-246cp, 1773, W-203, W-398 and W-405cp then by Cluster VIII with 5 genotypes *viz.*, W-125, Bhima Shwetha, 1770, 1744 and 1745, followed by cluster IV with 4 genotypes *viz.*, 1774, 1772, 1742 and 1784.

Statistical distance represents the extent of genetic diversity among clusters. The inter cluster distance was minimum between cluster III and II indicating close relationship and similarity for most of the characters of the

genotypes included in these clusters, whereas maximum recorded between clusters VIII and VII indicating wider genetic diversity among the genotypes included in these groups.

Emphasis should be laid on characters contributing maximum D^2 values for choosing the cluster for the purpose of further selection and choice of parents for hybridization. Highest contribution towards divergence in this regard was put forth by total soluble solids (28.33 %), neck thickness at harvest (24.36 %), ascorbic acid (21.15 %), average bulb weight (14.10 %), yield per hectare (4.87 %), days to maturity (4.10 %), number of leaves per plant (1.92 %), plant height (0.64 %) and equatorial bulb diameter (0.51 %). Thus, these were the major traits contributing to divergence. Hence, selection for divergent parents based on these characters will be useful for further breeding programmes in onion. The remaining trait *viz.*, polar bulb diameter did not contribute to the total divergence.

FUTURE LINE OF WORK

1. The promising genotypes *viz.*, 1770, 1774, Bhima Shwetha, W-125 and 1772 with high yield component may be utilized as parents in further improvement studies through various breeding strategies. After multilocation trials, may be recommended for commercial cultivation.
2. The superior most diverse genotypes identified could be utilized in breeding programs to improve and to widen the genetic base of onion cultivars.
3. Genotypes with multiple superior traits could be utilized for simultaneous transfer of multiple traits in crop improvement.

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APPENDIX

Monthly meteorological data recorded at ARI, Rajendranagar during November, 2020 to May, 2021.

Month	Temperature(°C)		Relative Humidity (%)		Rainfall (mm)	Rainy days	Sun Shine (hrs)	Wind Speed (km/hr)	Evaporation (mm)
	Maximum	Minimum	Morning	Evening					
NOVEMBER	29.4	16.7	88	47	15.2	3	7.3	3.6	3.1
DECEMBER	28.5	12.5	94	42	0.0	0	8.6	2.7	2.8
JANUARY	29.5	15.3	95	45	4.2	1	7.0	3.0	3.1
FEBRUARY	30.7	13.8	88	41	0.4	0	8.5	3.5	4.3
MARCH	35.9	17.0	80	30	0.0	0	8.0	3.6	6.0
APRIL	37.4	22.1	81	47	12.2	1	7.5	4.4	6.7
MAY	36.3	24.8	89	51	112.6	6	8.3	6.0	6.8

