

**Genetic variability and character association studies in
sprouting broccoli (*Brassica oleracea* L. var. *italica*
Plenck.) under low hill conditions of Himachal Pradesh**

Thesis

by

**SHIVALIKA RANI
(NH-2020-40-M)**

Submitted to



**Dr. YASHWANT SINGH PARMAR UNIVERSITY OF
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Dr. Shiv Pratap Singh
Associate Professor
(Vegetable Science)

Dr. Yashwant Singh Parmar University
of Horticulture and Forestry,
College of Horticulture and Forestry,
Neri, Hamirpur-177 001 (HP)

CERTIFICATE-I

This is to certify that the thesis on entitled “Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh” submitted in partial fulfilment of the requirements for the award of degree of MASTER OF SCIENCE (HORTICULTURE) VEGETABLE SCIENCE in the discipline of HORTICULTURAL SCIENCES of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) -173230 is a bonafide research work carried out by Ms. SHIVALIKA RANI (NH-2020-40-M) daughter of Mr. Kuldeep Singh under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

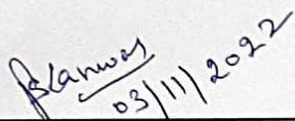
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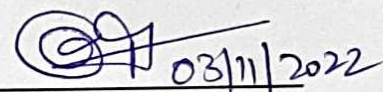
Dr. Shiv Pratap Singh
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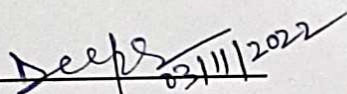

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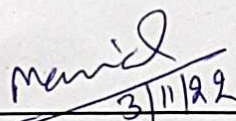

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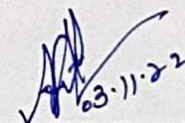
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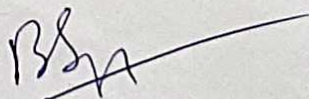
Dr. Deepa Sharma
(Senior Scientist)
Department of Vegetable
Science


3/11/22

Dr. Monica Sharma
(Associate Professor)
Department of Plant
Pathology


03.11.22

Dr. Amit Sharma
(Assistant Professor)
Department of Basic
Sciences



Professor and Head
Department of Vegetable Science

Countersigned

Dean
College of Horticulture and Forestry,
Neri, Hamirpur (HP)

CERTIFICATE - III

This is to certify that all the mistakes and errors pointed out by external examiner have been incorporated in the thesis entitled “**Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh**” submitted by **Ms. SHIVALIKA RANI (NH-2020-40-M)** daughter of Shri Kuldeep Singh to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) – 173230 in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE (HORTICULTURE) VEGETABLE SCIENCE** in the discipline of **HORTICULTURAL SCIENCES**.

Dr. Shiv Pratap Singh
Chairman
Advisory Committee

Professor and Head
Department of Vegetable Science
College of Horticulture and Forestry
Neri, Hamirpur (H.P.)

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Place: Neri, Hamirpur

Shivalika Rani

Date:

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ABBREVIATIONS

%	:	Per cent
=	:	Equal to
×	:	Multiplication
°C	:	Degree Celsius
ANOVA	:	Analysis of Variance
C.V.	:	Coefficient of Variation
CD	:	Critical Difference
<i>et al.</i>	:	Co-workers
<i>etc.</i>	:	<i>et cetera</i>
H.P.	:	Himachal Pradesh
<i>i.e.</i>	:	That is
m ²	:	Meter square
SE	:	Standard Error
UHF	:	University of Horticulture and Forestry
COHF	:	College of Horticulture and Forestry
<i>viz.</i>	:	Videlicet (namely)
PCV	:	Phenotypic Coefficient of Variation
GCV	:	Genotypic Coefficient of Variation
m	:	Meter
cm	:	Centimeter
g	:	Gram
mg	:	Milligram
/	:	Per
GA	:	Genetic Advance
&	:	And
TSS	:	Total Soluble Solids

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Chapter-1

INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica* Plenck.) an important winter season vegetable belonging to the family brassicaceae or cruciferae commonly known as mustard family; has chromosome number $2n=2x=18$. “Broccoli” is an Italian word derived from ‘Brachium’ which refers to an arm of branch (Thakur *et al.* 2016). It is also known by various names like Italian Asparagus, Sprout Cauliflower and Little Sprouts (Habib *et al.* 2013). The crop is native to Southern Europe and Eastern Mediterranean region; however Italy is considered as its main center of origin. It has been derived from a common ancestor *Brassica oleracea* L. var. *sylvestris* (commonly known as wild cabbage, cliff cabbage or coleworts) as a result of selection and accumulation of mutations during the domestication process (Chaves Junior *et al.* 2021). Broccoli is basically a cross pollinated crop which can be easily distinguished from its related crop i.e. cauliflower by its head which is composed of differentiated immature flower buds (florets) rather than curd which is there in case of cauliflower (Singh *et al.* 2014).

Broccoli is a crop which is known for its taste, flavor, medicinal and nutritive value and thus it is sometimes called as the “Crown Jewel of Nutrition” (Kour, 2020). It is a rich source of ‘Sulphoraphane’ (having anti-cancerous properties), Vitamin-A (2500 I.U.), Vitamin-C (113 mg), protein (3.6 g), carbohydrates (5.9 g) and minerals like Calcium (103 mg), Iron (1.1 mg), Phosphorous (78 mg), Potassium (382 mg) and Sodium (15 mg) per 100 gm of edible portion. The leaves of the crop serve as good source of nutritious fodder for cattle (Tejaswini *et al.*, 2018). The nutritional importance of the crop is further enhanced by the fact that broccoli contains more Vitamin A than Cabbage and Cauliflower and the highest amount of Proteins among the Cole crops (Chaurasiya and Pandey, 2020). It is also known to protect humans against certain specific chronic ailments including cancer, cardiovascular diseases and age-related sight degeneration (Habib *et al.* 2013). The crop has multiple uses and can be used for salad, pickle, soup making and for other culinary purposes.

Broccoli being one of the most nutritive cole crops and with change in food habit; increasing nutrition consciousness of consumers, this crop is gaining popularity in various parts of the country and is widely being consumed in hotels and Indian

households. It is mostly cultivated in the hilly areas of Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Nilgiri hills and Northern plains of India (Habib *et al.* 2013). At world level Broccoli and Cauliflower together are grown over an area of 1357.18 thousand hectare with an annual production of 25531.27 thousand metric tonnes (Anonymous, 2020a). In India cauliflower occupies an area of 459 thousand hectare with a total production of 8844 thousand metric tonnes (Anonymous, 2020b). Whereas, in Himachal Pradesh broccoli is grown on an area of 490.20 ha with a production of 11232.23 metric tonnes (Anonymous, 2020c). It's off season cultivation fetches lucrative remuneration to the growers during summer season, in hills when it cannot be grown in plains due to prevailing high temperatures at that time.

There is however, less incidence of disease in broccoli crop in the low hills of Himachal Pradesh but still all the genotypes under study were closely monitored to record any prevalence of disease under natural epiphytotic conditions. Such genotypes with relatively less incidence of disease can help the farmer in lowering cost of production and can on other hand, make it possible for the consumer to obtain pesticide residue free vegetable for consumption purpose.

Broccoli being an exotic crop, the variability present in India is limited. Therefore, it is essential to collect the new genotypes with diverse horticultural traits; for this purpose the evaluation and characterization of the collected germplasm is a prerequisite. Hence, keeping this in view the present study was carried out to assess the extent of variability in the broccoli germplasm. Further, estimates of heritability and genetic advance with respect to various important horticultural traits were worked out to know the suitability of a character for direct selection among the genotypes under study (Burton and De Vane, 1953 and Allard, 1960). The Phenotypic and Genotypic coefficients help in adjudging the amount of variability which is there; in the given germplasm either due to environmental or genetic factors (Burton and De Vane, 1953). The knowledge of genetic correlation among different horticultural traits of a crop can help the breeder in the selection of the desirable combinations of horticultural traits in a given genotype and thus it helps in decreasing the retarding effect of negative correlations (Al-Jibouri *et al.*, 1958). Path coefficient analysis determines the direct and indirect influence of the various independent variables on the dependent variable like yield and separates the correlation coefficient into two different components *viz.* direct and indirect effects (Wright, 1921 and Dewey and Lu, 1959). The knowledge thus, gathered helps in

knowing the inheritance pattern of the various horticultural traits, thus this can be used for developing superior varieties of broccoli either by direct selection or by using the genotypes in the further breeding involving various crossing programmes.

Therefore, the present investigation entitled “**Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh**” was carried out by using 12 genotypes of broccoli including Palam Samridhi as check variety at Experimental Farm of Department of Vegetable Science, College of Horticulture and Forestry, Neri with the following objectives:

- To estimate the performance and extent of genetic variability in various broccoli genotypes for important horticultural characters.
- To find heritability and genetic advance.
- To perform correlation and path coefficient studies with respect to different horticultural traits in given genotypes of broccoli.
- To identify the promising genotypes with desirable horticultural traits.

Chapter-2

REVIEW OF LITERATURE

The relevant literatures available on various aspects pertaining to the broccoli and related crop cauliflower with respect to the present study entitled “**Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh**” are briefly reviewed under the following subheads:

2.1 Genetic variability

2.2 Heritability and genetic advance

2.3 Correlation coefficient analysis

2.4 Path coefficient analysis

2.1 Genetic variability

In this investigation Mihov and Antonova (2001) determined the variability and its components for eight morphological characteristics in some broccoli hybrids. The hybrids were Beaufort F1, Sumosun F1, Skiff F1, Neptune F1 and Tribute F1. Significant differences between the investigated genotypes and the years, which affect the variance of the morphological characteristics, had been established. The highest genotypic coefficient of variation-38.08%, has been established for curd diameter, and the lowest-9.03% for the diameter of the leaf rosette.

This study was done by Hamed *et al.* (2010) with objective to partition the phenotypic variance of yield and quality traits in broccoli into component sources associated with genotype, environment and genotype by environment interaction. Three broccoli genotypes were evaluated in three different growing seasons for yield and both nitrate and vitamin C content. The results revealed a phenotypic variation in all studied traits among broccoli genotypes. A greater proportion of the phenotypic variation was associated with differences among environments. Analysis of variance uncovered a significant effect of genotypes for yield and chemical quality traits which indicated the existence of a high degree of genetic variability in the tested genotypes. Genotype by

environment interaction was significant for yield and chemical quality traits indicating that these traits are modified to different levels by the environments where they grow.

A field experiment was conducted by Bhangra *et al.* (2011) to study the variability in different varieties of broccoli *viz.* Ganesh Broccoli and Pusa KTS-1. The data revealed that cv. Ganesh Broccoli performed superior over the cv. Pusa KTS-1 with respect to the characters days to 50% harvest (53.4 days), days to last harvest (68.4 days), curd diameter (10.81cm), average weight of curd (154.80 g) and yield per hectare (70.75q) while, cv. Pusa KTS -1 recorded significantly highest values for growth parameters.

Santhosha *et al.* (2011) performed studies related to genetic divergence in 51 genotypes of cauliflower. The genotypes of cauliflower studied were grouped into 14 discrete clusters. Majority of the genotypes were grouped together in Cluster 14 (14 genotypes), followed by Cluster 12 (with 8 genotypes). Intra-cluster value was found maximum in the Cluster 8 and minimum in Cluster 2. Maximum inter-cluster distance was observed between Clusters 8 and 10, followed by that between Clusters 10 and 13 and between Clusters 8 and 12. Hence, genotypes IIHR-323-13, IIHR-2145 and IIHR-277-14 of Cluster 8; genotypes IIHR-263 and IIHR-272 of cluster 10 presented the best choice for hybridization. Highest mean value for the characters *viz.* plant weight, leaf number, curd diameter, curd size, net curd-weight, net plot yield, yield per hectare and marketable curd-weight was also observed in Cluster 10, which indicated that the genotypes included in this cluster could be used as potential parents for future hybridization programmes aiming at increasing the cauliflower yields.

Kumar *et al.* (2011) reported significant difference among the genotypes in early Indian cauliflower suggesting sufficient variability for yield and quality characters. The genotypes DC-98-4, DC-98-10 and DC-124 were found superior with respect to yield and quality characters. The overall values of PCV were higher than those of GCV. The highest estimate of GCV was observed for the trait vitamin C contents (54.58) followed by duration of curd availability (49.04), while highest heritability was recorded for the traits days to 50% curd formation (0.992). High heritability along with high genetic advance as per cent of mean was estimated for the traits, *viz.* curd compactness, net curd weight and vitamin C content.

In a study of twelve varieties of broccoli, *viz.* Fiesta, Princess, Sultan, Nokguk, Early You, KE-180, Priya, Puspa, Grandsino, Rapido, Prema and Packman, Thapa and Rai (2012) recorded some observations pertaining to the physical and chemical parameters. Among all the genotypes of broccoli 'Nokguk' was found superior, which gave higher yield (145.47 q/ha) along with best head formation. Whereas, the chemical analysis showed that the genotype KE-180 was found outstanding in terms of chlorophyll b, reducing sugar, total sugar and carotene content.

In a study involving 51 genotypes of cauliflower, Santhosha *et al.* (2014) found that high coefficient of variation (C.V) was exhibited by the various yield characters like gross curd weight (26.03 %), net curd weight (26.02 %) followed by curd size index (24.95 %); suggesting that these traits should be given top priority during selection programme. Genotypes, *viz.* IIHR-272, IIHR-263, IIHR-266 and IIHR-390 showed superior performance for above parameters; hence, these lines may be directly released as a variety or as a source of desirable traits in further breeding programmes.

Singh *et al.* (2014) conducted 56 demonstrations on four different broccoli varieties having different colored heads (i.e. Palam Samridhi (green head), Palam Kanchan (yellowish green head), Palam Vichitra (purple head) and Palam Haritika (green head) for their performance. The broccoli varieties Palam Vichitra yielded the highest (210.7 q/ ha) followed by Palam Kanchan (206.9 q/ha). An average weight of terminal head of Palam Kanchan was the highest i.e. 357.5 g, whereas, Palam Samridhi produced the earliest head under low hill conditions of Himachal Pradesh.

Seasonal variation in the contents of sugars (fructose, glucose, and sucrose) in the floret, leaf, and stem of broccoli were studied in ten commercial broccoli cultivars by Bhandari and Kwak (2015). Plants were grown in the spring and fall seasons in both seasons, glucose was the major constituent, comprising about 50% of the total sugar content in the floret and leaf tissue of most cultivars, whereas the broccoli stem showed an unusual pattern of accumulation. 'Grandeur' broccoli contained a significantly greater amount of total sugar in both floret and leaf tissues in both seasons, whereas 'YuDoRi No.1' broccoli exhibited the highest total content of sugar in stem tissue. Overall, the results showed significant influences of genotype, plant part and growing season on sugar content in broccoli.

Seventeen genotypes of broccoli were evaluated for different horticultural and yield traits by Thakur *et al.* (2016). On the basis of the performance of the varieties it may be concluded that genotype Early White Sprouting produced highest yield per plant along with good number of lateral heads, bigger central head size as compared to check varieties, *viz.* Green Head and Palam Samridhi.

Genetic variability of sixteen quantitative traits in fifty seven genotypes of mid-season cauliflower was studied by Kumar *et al.* (2017). Analysis of variance revealed significant difference for majority of the characters. The genotypes, *viz.* INBPCF 120, 2013/CAUMVAR-6, PCF- 93, PG-5, PCF- 7, INBPCF 117 were found more promising as they had more than one desirable trait. INBPCF 120 recorded highest curd yield per hectare (192.5q), whereas PCF 29 required least days to maturity (85). Appreciable level of phenotypic and genotypic coefficient of variation (PCV and GCV) were reported for the characters stalk length, gross plant weight, net curd weight, curd yield per hectare, marketable curd weight, harvest index and curd size index. However, lowest coefficient of variation (PCV and GCV), was recorded for the characters number of leaves per plant and days required to maturity.

An investigation done by Manaware *et al.* (2017) in cauliflower showed that the mean performance of the genotypes had a wide range of variability for all the traits. The variation was the highest for total plant weight (572.27-1220.87 kg), curd weight (238.58-508.83 g), net curd weight (169.80-392.97 g), marketable curd yield (76.86-169.13 q/ha), curd yield per hectare (79.21-172.45 q/ha), curd circumference (9.17-40.40 cm), days to 50 percent curd formation (25.00-47.33), days to harvest (40.67-59.33) and curd length (3.40-14.88 cm). The phenotypic coefficient of variation were observed to be higher than the corresponding genotypic coefficient of variation for all the characters studied, however the differences were narrow which implied their relative resistance to environmental variation. The phenotypic coefficient of variations was highest for characters *viz.* curd length, curd circumference, core length, curd width, net curd weight, curd yield per hectare, marketable curd yield, curd yield per plot, total plant weight and curd weight. High genotypic coefficient of variation was noted for curd length, curd circumference, core length, curd width, net curd weight, curd yield per hectare, marketable curd yield, curd yield per plot, curd weight and total plant weight.

Chatterjee *et al.* (2018) observed twenty mid-late and late group cauliflower genotypes. In this study it was found that the magnitude of PCV was higher than the

corresponding GCV for all the characters studied. Moderate estimates of GCV was recorded for leaf number per plant (19.12%), curd depth (15.76%), plant height (20.85%), leaf size index (19.44%), curd size index (26.51%), gross weight per plant (19.56%), and marketable yield per plant (18.63%).

The present investigation was conducted by Kaur *et al.* (2018) with fifteen diverse genotypes of cauliflower. Genetic variability was studied for different quantitative characters. It was concluded that there was a wide range of variation among the germplasm lines for all the characters under study. Moderate values of PCV were found in net curd weight, curd yield, marketable curd weight, harvest index, plant stalk length, curd index, gross plant weight, while the remaining parameters exhibit low PCV. Out of fifteen genotypes, five genotypes, *viz.* Pahuja (41.96 q/ha), Infinity 77 (39.98 q/ha), Neha (39.76q/ha), Jyoti (32.35q/ha) and IG-25(36.37q/ha) were found promising for curd yield per hectare than other genotypes.

Sharma *et al.* (2018) evaluated twenty five genotypes of cauliflower including Madhuri as check. Analysis of variance revealed significant variability for most of the traits. High estimates of PCV and GCV were observed for the character curd solidity; which indicated that there was substantial variability ensuring ample scope for improvement of the trait through selection.

N and A (2018) observed significant differences among genotypes for all the characters studied in early Indian cauliflower suggesting sufficient variability for curd yield and quality characters. Among the varieties, NS 60N was superior for curd yield, depth, diameter and curd size index followed by G 45. Earliest among the varieties was Himshort followed by NS 60N while Himpriya-60 was superior in plant height, leaves per plant, gross plant weight, leaf length, leaf breadth and leaf size. Significant differences were observed among treatments for all quality characters except vitamin C. Phenotypic and genotypic coefficients of variation were high for curd compactness and curd size index. The top ranking varieties based on selection index were NS 60N, G 45, White Snow, Himpriya 60 and Pusa Meghna.

Tejaswini *et al.* (2018) in four varieties of broccoli *viz.* Palam Samridhi (V1), Palam Vichitra (V2), Pusa Broccoli KTS-1 (V3) and Palam Haritika (V4) recorded some observations on growth, yield and quality parameters. The results revealed that the variety V2 (Palam Vichitra) recorded significantly maximum plant height at 45 days

after transplanting (40.77 cm), number of leaves at 45 days after transplanting (11.11), fresh weight of head (311.9 g), maximum yield per plot (4.67 kg), yield per hectare (188.7 q), highest head diameter (15.00 cm), maximum dry matter percent (20.68%), protein content (3.53%), potassium content (507.7 mg) and calcium content (47.05 mg). While significantly maximum plant height at harvest (63.07 cm), number of leaves at harvest (22.71) and maximum plant spread at 45 days after transplanting [E-W (49.53 cm) and N-S (46.88 cm)] and at the stage of head harvest [E-W (60.94 cm) and N-S (60.94 cm)] were recorded with the variety V4 (Palam Haritika) and the treatment V1 (Palam Samridhi) recorded minimum days taken for head initiation (50.49 days) and for first head harvest (71.11 days).

Gariya *et al.* (2019a) studied 22 genotypes of cauliflower to know the nature and magnitude of variability, heritability and genetic advance as per cent of mean for various horticultural traits. The analysis of variance showed significant variation among different genotypes for all the traits under study. Genotypes Golden Agahani, Pusa Snowball, Pusa Deepali, Poosi, Haridwar Local, KT-9, Faizabad Local, Rajasthan Local, Pant Gobhi-3 recorded highest curd weight and also performed better for other horticultural traits than check cultivar (Pusa Himjyoti). Genetic analysis indicated that phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) in all of the attributes studied.

Working with five genotypes of broccoli *viz.* Palam Kanchan, Pusa Broccoli KTS-1, Palam Vachitra, Palam Samridhi and Palam Haritika, Kour (2020) observed that Palam Kanchan performed better than other varieties in respect of the characters *viz.* plant height (57.30 cm), number of leaves (23.39), plant spread (60.30 cm), head weight (438.68 g), head diameter (17.27 cm) and head yield (263.20 q/ha). However, minimum number of days taken to head initiation and first head harvesting were recorded in the variety Pusa Broccoli KTS-1. Therefore, the variety Palam Kanchan emerged as superior over all other varieties in respect of growth and yield characters. As far as earliness was concerned Pusa broccoli KTS-1 was found to be the best.

An experiment was performed by Nandhini *et al.* (2020) with thirteen broccoli genotypes. Analysis of variance revealed that there was considerable variability among the genotypes for all the fourteen characters. High genotypic and phenotypic coefficients of variation were recorded for the traits leaf length (23.89 and 24.25), curd weight/plant (35.34 and 35.47) and curd yield (33.67 and 34.85).

Chaurasiya and Pandey (2020) studied nine genotypes of broccoli *viz.* Palam Samridhi, Green Giant, Green Speed, KTS-1, Puspa, Palam Haritika, Priya, Aiswarya and Prema for best performance. Among all the genotypes of broccoli studied, the variety Palam Samridhi was found superior, which gave highest yield (184.5 q/ha) followed by Green Speed (173.7 q/ha), Green Giant (156.23 q/ha) and Palam Haritika (144.84q/ha).

Fifteen genotypes of cauliflower were evaluated by Pramila *et al.* (2020a) to study the magnitude of genetic variability. The genotypes were evaluated for fourteen quantitative characters *viz.* plant height (cm), plant spread (cm), no. of leaves, leaf length (cm) leaf blade width (cm), days to 1st curd initiation, days to 50% curd initiation, net curd weight (g), gross curd weight, curd length, curd width, harvest duration, harvest index (%), total yield (q/ha). The present study showed that PCV was higher than GCV for all the traits; which indicated the presence of environmental effect for trait expression. The genotypes were grouped into 4 clusters. Hence, genotypes Sabour Agrim of cluster 4 and genotypes RCEF4 of cluster 2 present the best choice for hybridization. Highest mean value for the traits *viz.* plant spread, leaf length, leaf blade width, days to 50% curd initiation, net curd weight, gross curd weight, curd length, curd width, harvest duration, total yield (q/ha) was observed in cluster 3. Therefore, cluster 3 and cluster 2 were used for heterosis breeding and improvement of traits.

Chaves Junior *et al.* (2021) characterized 19 broccoli genotypes for different biochemical traits (content of total phenolic compounds, total flavonoids and antioxidant activity) and AFLP (Amplified Fragment Length Polymorphism) molecular markers. The phenotypic data was subjected to analysis of variance ($p \leq 0.05$), Scott-Knott average clustering method ($p \leq 0.05$) and principal component analysis (PCA). Using molecular data, Ward's hierarchical clustering, Bayesian clustering and principal coordinate analysis (PCoA) were performed. Molecular data showed genetic diversity among the genotypes (three groups), also a wide variability in the total phenolic compounds, total flavonoids content and antioxidant activity using FRAP method. HT3010, Hanabi and Bonanza genotypes showed desirable biochemical traits for the demanding functional food consumers, in addition to being promising genotypes to be exploited in plant breeding programs.

In this study Li *et al.* (2021) utilized a doubled haploid population consisting of 176 lines derived from two inbred lines (86,101 and 90,196) with significant differences in sulforaphane content, coupled with extensive genotypic and phenotypic data from two

independent environments. A linkage map consisting of 438 simple sequence repeats markers was constructed, covering a length of 1168.26 cm. A total of 18 QTLs for sulforaphane metabolism in broccoli florets were detected. The LOD values of all QTLs (quantitative trait loci) ranged from 3.06 to 14.47, explaining 1.74–7.03% of the biochemical variation between two years. Finally, 6 QTLs (*qSF-C3-1*, *qSF-C3-2*, *qSF-C3-3*, *qSF-C3-5*, *qSF-C3-6* and *qSF-C7*) were stably detected in more than one environment, each accounting for 4.54–7.03% of the phenotypic variation explained (PVE) and a total of 30.88–34.86% of PVE.

This investigation was done by Savita and Singh (2021) where twenty-six genotypes of cauliflower were tested to check their performance for all the quantitative traits. ANOVA (Analysis of Variance) displayed a highly significant difference for all the quantitative characters in the twenty-six cultivars. Among the cultivars, Snow White was highest in plant height (52.99 cm), leaf length (36.77 cm), curd weight (1092.22 g), curd circumference (63.72 cm) and yield (200.35t/ha) followed by Sweta-44 for leaf width (21.27 cm), curd weight (930 g), curd circumference (60.27 cm) and yield (180.56 t/ha), but low in stalk length (11.66 cm), Snowball-16 outperformed for curd weight (800 g), curd circumference (58.16 cm), stalk length (16.66 cm), yield (170.44 t/ha) while Sonakshi showed the best result for leaves per plant (22.88) and IG-25 for stalk length (17.11 cm). Therefore, Snow White, Sweta-44 and Snowball-16 were recommended for further improvement.

Singh *et al.* (2021) used large genetic stock of cauliflower encompassing 76 cytoplasmic male sterile (CMS) lines along with homozygous doubled haploid (DH) inbreds in their study. The variance analysis accompanied with k-means clustering revealed high genetic variability among these 76 genetic stocks of cauliflower under study. The CMS lines, Ogu402-6A, Ogu76-33A and Ogu76-4A were identified for development of early maturing hybrids. While the CMS lines, Ogu13-85-6A, Ogu309-2A and Ogu2A were selected as parents for generation of the hybrids with highly compact curds. Superior agronomic traits, abundant pollen production and good seed setting in the DH lines DH-53-1 and DH-53-10 revealed their potential for genetic and genomic studies in cauliflowers. The slightly higher magnitude of phenotypic coefficient of variation than corresponding genotypic coefficient of variation for majority of traits indicated influence of environment in expression of these traits to lesser extent.

2.2 Heritability and genetic advance

In this investigation, Mihov and Antonova (2001) determine the variability and its components for eight morphological characteristics in some broccoli hybrids. The hybrids are Beaufort F1, Sumosun F1, Skiff F1, Neptune F1 and Tribute F1. Heritability was high for the diameter of the leaf rosette (89.91%) and the number of rosette leaves (99.05%). Genetic advance varied from 3.24% for stem weight to 165.64% for curd diameter. Using the characteristics curd diameter as a breeding index, assuring an effective breeding process is perspective.

Sixteen biparental progenies (developed from a cross PSB-1 x KT-9) in late cauliflower (*Brassica oleracea* var. *botrytis* L.) were evaluated by Kanwar and Korla (2002) for horticultural and quality traits. BIPs 13, 17 and 19 possessed good yield and quality traits. PCV was low for all the traits except gross plant weight and net curd weight. High heritability and low genetic gain recorded for the trait days to marketable maturity indicated the absence of additive gene effects for this trait. Rest of the traits studied showed low to moderate heritability with low genetic gain which indicated the influence of environment.

In a study undertaken by Habib *et al.* (2013) involving ten diverse broccoli genotypes, it was found that phenotypic and genotypic coefficients of variation were moderate to high for the characters *viz.* lateral head yield, lateral head number, main head yield and total carotenoids; low for the traits like days to central head harvest, days to central head initiation, plant height and plant spread. Whereas, broad sense heritability was comparatively moderate to higher for the traits plant height, head length, days to central head initiation, lateral head yield, main head yield, total head yield and total carotenoids content; but low for the traits *viz.* ascorbic acid content, plant spread and dry matter content. Genetic advance was high (> 20%) for the traits lateral head yield and total carotenoids content; while it was low (<5%) for the traits ascorbic acid, peduncle length and dry matter content.

A study was conducted by Chittora and Singh (2015) to study the eighteen quantitative characters and five qualitative characters in forty genotypes of early cauliflower. Analysis of variance revealed significant differences among the genotypes for all the characters. The genotypes *viz.* PCF-95, PCF-106, Inb-9-5 and Inb-10-1 were found promising as they possessed more than one desirable quantitative and qualitative

trait. The genotype PCF-95 recorded maximum curd yield per hectare (271.87 q); while the genotype PCF-101 exhibited earliest harvestable curd maturity (115.33 days). Good level of phenotypic and genotypic coefficients of variation (PCV and GCV), broad sense heritability and genetic advance as per cent of mean were observed for characters *viz.* net curd weight, marketable curd weight, and curd yield per hectare, harvest index and gross plant weight. However, lowest value of coefficient of variation, heritability and genetic advance were observed for the characters days to curd initiation and days to curd maturity.

Genetic variability of sixteen quantitative traits in fifty seven genotypes of mid-season cauliflower was studied by Kumar *et al.* (2017). Analysis of variance revealed significant difference for majority of the characters. The genotypes, *viz.* INBPCF 120, 2013/CAUMVAR-6, PCF- 93, PG-5, PCF- 7, INBPCF 117 were found more promising as they had more than one desirable trait. INBPCF 120 recorded highest curd yield per hectare (192.5q) whereas PCF 29 required least days to maturity (85). However, lowest heritability in broad sense, genetic advance and genetic advance as a percent of mean was recorded for the characters number of leaves per plant and days required to maturity.

An investigation done by Manaware *et al.* (2017) in cauliflower showed that the mean performance of the genotypes had a wide range of variability for all the traits. The variation was highest for total plant weight (572.27-1220.87 kg), curd weight (238.58-508.83 g), net curd weight (169.80-392.97 g), marketable curd yield (76.86-169.13 q/ha), curd yield per hectare (79.21-172.45 q/ha), curd circumference (9.17-40.40 cm), days to 50% curd formation (25.00-47.33), days to harvest (40.67-59.33) and curd length (3.40-14.88 cm). The value of heritability(broad sense) was recorded very high for curd length, days to harvest, days to curd initiation, curd circumference, days to 50% curd formation, number of leaves per plant at 45 DAT, curd yield per hectare, marketable curd yield, curd yield per plot. Core length, curd weight, total plant weight, number of leaves per plant at 30 DAT, curd width and net curd weight. Genetic advance as percentage of mean ranged between 13.84% for stalk length at 45 DAT to 103.65% for curd length. The highest estimate of genetic advance as percentage of mean was recorded for curd length, curd circumference, core length, curd width, curd yield per hectare, curd yield per plot, marketable curd yield, net curd weight, curd weight and total plant weight.

Twenty mid-late and late group cauliflower genotypes were evaluated by Chatterjee *et al.* (2018). In this study, high heritability (>80%) coupled with high genetic

gain (>50%) was found for the trait curd size index. Whereas, high heritability coupled with moderate genetic gain was shown by the traits, *viz.* leaf number per plant, curd depth, leaf size index, gross weight per plant and marketable yield per plant.

Sharma *et al.* (2018) evaluated twenty five genotypes of cauliflower including Madhuri as check. High heritability coupled with high genetic advance was observed for the trait ascorbic acid content and curd solidity. The results suggested the importance of additive gene action for the inheritance of these characters; thus, improvement can be brought about by phenotypic selection for these characters.

N and A (2018) observed significant differences among genotypes for all the characters studied in early Indian cauliflower suggesting sufficient variability for curd yield and quality characters. Among the varieties, NS 60N was superior for curd yield, depth, diameter and curd size index followed by G 45. Earliest among the varieties was Himshort followed by NS 60N, while Himpriya-60 was superior in plant height, leaves per plant, gross plant weight, leaf length, leaf breadth and leaf size. Significant differences were observed among treatments for all quality characters except vitamin C. Heritability along with genetic advance were high for gross plant weight. The top ranking varieties based on selection index were NS 60N, G 45, White Snow, Himpriya 60 and Pusa Meghna.

Gariya *et al.* (2019b) studied 22 genotypes of cauliflower to know the nature and magnitude of variability, heritability and genetic advance as per cent of mean for various horticultural traits. Genotypes *viz.*, Golden Agahani, Pusa Snowball, Pusa Deepali, Poosi, Haridwar Local, KT-9, Faizabad Local, Rajasthan Local, Pant Gobhi-3 recorded highest curd weight and also performed better for other horticultural traits than check cultivar (Pusa Himjyoti). High heritability (broad sense) estimates coupled with high genetic advance as per cent of mean were observed for the most important character i.e. yield.

A field experiment was performed by Kumar *et al.* (2019) with eight genotypes of cauliflower to study the magnitude of genetic variability, heritability and genetic advance. The evaluation was done for fifteen quantitative characters, *viz.* plant height at harvest (cm), number of leaves per plant, stalk length (cm), gross curd weight (g), marketable curd weight (g), net curd weight (g), curd depth (cm), curd diameter (cm), curd size index (cm²), days to 50% curd initiation, days to 50% curd maturity, days to 1st flowering, days to 50% flowering, harvest index (%) and curd yield (t/ha). High

heritability coupled with high genetic advance was observed for the traits, *viz.* curd diameter, days to 50% curd maturity, days to 50% flowering, days to 1st flowering, days to 50% curd initiation, curd size index, net curd weight, curd yield, marketable curd weight and gross curd weight; indicating that most likely the heritability was due to additive gene effects and selection of these characters may be effective for crop improvement.

An experiment was performed by Nandhini *et al.* (2020a) with thirteen broccoli genotypes. High heritability combined with high genetic advance as percent mean were observed for the traits, *viz.* number of leaves (89.60 and 29.08 %), leaf length (97.00 and 48.47 %), leaf width (84.60 and 24.74 %), days to curd initiation (91.50 and 20.74%), curd length (97.00 and 30.36 %), curd width (98.10 and 41.07 %), curd weight/plant (99.20 and 72.52 %), curd yield (93.40 and 67.02 %) and Ascorbic acid (96.70 and 24.68 %).

Fifteen genotypes of cauliflower were evaluated by Pramila *et al.* (2020) to study the magnitude of heritability and genetic advance. The genotypes were evaluated for fourteen quantitative characters *viz.* plant height (cm), plant spread (cm), No. of leaves, leaf length (cm), leaf blade width (cm), days to 1st curd initiation, days to 50% curd initiation, net curd weight (g), gross curd weight, curd length, curd width, harvest duration, harvest index (%) and total yield (q/ha). High heritability coupled with high genetic advance was observed for the characters number of leaves, leaf blade width, net curd weight, gross curd weight, curd width harvest index and total yield; thus indicating that they were governed by additive genes and could be effectively improved through selection.

Singh *et al.* (2021) used large genetic stock of cauliflower encompassing 76 cytoplasmic male sterile (CMS) lines along with homozygous doubled haploid (DH) inbreds in their study. The variance analysis accompanied with k-means clustering revealed high genetic variability among these 76 genetic stocks of cauliflower under study. The CMS lines, Ogu402-6A, Ogu76-33A and Ogu76-4A were identified for development of early maturing hybrids. While the CMS lines, Ogu13-85-6A, Ogu309-2A and Ogu2A were selected as parents for generation of the hybrids with highly compact curds. Superior agronomic traits, abundant pollen production and good seed setting in the DH lines DH-53-1 and DH-53-10 revealed their potential for genetic and genomic studies in cauliflowers. High estimates of heritability (> 80%) accompanied with high genetic

advance for total yield and earliness traits indicated the scope of reliable selection in the present germplasm.

2.3 Correlation coefficient analysis:

This study was done by Farnham and Kopsell (2009) showed that lutein was the most abundant carotenoid in broccoli heads ranging from 65.3 to 139.6 $\mu\text{g}\cdot\text{g}^{-1}$ dry mass (DM) among nine inbreds tested in three environments. Genotype had a highly significant effect on lutein levels in broccoli heads and the ratio of σ_2/σ_p for this carotenoid was 0.84. Violaxanthin also exhibited a significant genotype effect, but it was found at lower levels (17.9 to 35.4 $\mu\text{g}\cdot\text{g}^{-1}$ DM) than lutein. β -carotene and neoxanthin were detected at levels similar to violaxanthin, but genotypic differences were not detected when all environments were compared. This was also true for antheraxanthin, which was detectable in all genotypes at lower levels (mean of 13.3 $\mu\text{g}\cdot\text{g}^{-1}$ DM) than the other carotenoids. Significant genotypic differences were observed for both chlorophyll a and b among the studied inbreds, however, no environment or genotype-by-environment effects were observed with these compounds. Results indicated that most carotenoids measured were positively and significantly correlated with one another, indicating that higher levels of one carotenoid were typically associated with higher levels of others.

A total of 80 commercial broccoli samples were collected over a 2 year period by Koh *et al.* (2009) to determine seasonal variation in the levels of ascorbic acid (AA), vitamin C (the sum of AA and dehydroascorbic acid [DHAA]), the predominant flavonoids quercetin and kaempferol, and total phenolics at the consumer level. Levels of AA and vitamin C varied between 13.37-110.30 and 57.35-131.35 mg/100gm fresh weight respectively. The levels of quercetin and kaempferol ranged from 0.03 to 10.85 and 0.24 to 13.20 mg/ 100gm fresh weight respectively. Total phenolic activity ranged from 48.15 to 157.77mg/100g of fresh weight. Significant seasonal variation and year to year variability were observed in the content of all phytochemicals examined. Total phenolic levels correlated positively with levels of vitamin C, quercetin and, kaempferol.

The association studies conducted by Sheemar *et al.* (2012) in cauliflower revealed that net curd weight was significantly and positively correlated with total plant weight at phenotypic and genotypic levels, respectively.

A field study was carried out by Habib *et al.* (2013) to study various traits in sprouting broccoli *viz.* the plant spread, head diameter, leaf number, leaf area, lateral head number and main head yield; it was found that the character lateral head yield possessed positive correlation with the total yield at genotypic level while the traits plant height, head length, ascorbic acid and total carotenoids exhibited negative correlation with the character total yield at genotypic level. However, the characters main head yield, lateral head yield, head diameter and lateral head number recorded highly significant positive correlation with the character total head yield.

Katoch *et al.* (2014) conducted correlation studies in 16 genotypes of broccoli which revealed that the character marketable yield/plant was significantly and positively correlated with the characters terminal head weight/plant, harvest index, gross weight/plant, head size index, days to first harvest, leaf size with leaf stalk, plant frame and leaf size without leaf stalk; which could be considered as the important selection criteria in the improvement of marketable yield.

This study encompassing 16 experiments was to compare 23 broccoli cultivars for the content of phytochemicals grown under organic and conventional management in spring and fall plantings in two broccoli growing regions by Renaud *et al.* (2014). The phytochemicals quantified included: glucosinolates (glucoraphanin, glucobrassicin, neoglucobrassicin), tocopherols (δ -, γ -, α -tocopherol) and carotenoids (lutein, zeaxanthin, β -carotene). They observed that the cultivars with the highest concentrations of glucoraphanin had the lowest for glucobrassicin and neoglucobrassicin. The genotypes with high concentrations of glucobrassicin and neoglucobrassicin were the same cultivars and were early maturing F₁ hybrids. Cultivars highest in tocopherols and carotenoids were open pollinated or early maturing F₁ hybrids. Correlations among horticulture traits and phytochemicals demonstrated that glucoraphanin was negatively correlated with the carotenoids and the carotenoids were correlated with one another.

Correlation analysis on 'Pushi' variety of cauliflower was conducted by Singh *et al.* (2014) and it was found that yield was significantly and positively correlated with all the ancillary characters, *viz.* curd weight (0.9941), number of leaves (0.9674), leaf area (0.9661), curd diameter (0.9412), plant spread (0.9161), plant height (0.8239) and curd depth (0.8068). All the ancillary characters also showed significant positive correlations among themselves.

In a study conducted by Brandelero *et al.* (2016) for the 11 characters in 365 plants of broccoli, spaced with 0.8 x 0.5m, the characters of group 1 (height, number of leaves, stem height, stem diameter) were evaluated on the 21 and 58 day after transplanting (DAT) and the leaf area was evaluated on the 17 and 32 DAT. The characters of group 2 were quantity of fresh head mass and canopy area. At the initial stage of cultivation, on the 17 and 21 DAT, variations in the plants characters did not lead to any variation in production. The higher number of leaves and the larger stem diameter on the 58 DAT determined the greater mass of the broccoli heads. The highest linear correlation ($r = 0.83$) was obtained between the head mass and the canopy area of broccoli. At the initial stages of cultivation, 17 and 21 days after transplanting, the variations in the plant's characteristics are not determining of the variation in the plants' final production. A greater number of leaves and a larger stem diameter on the 58 day after transplanting determine the greater mass of the broccoli head.

An investigation done by Manaware *et al.* (2017) in cauliflower showed that the mean performance of the genotypes have a wide range of variability for all the traits. Stalk length at 45 DAT showed significant and negative correlation with days to curd initiation, days to 50% curd formation and number of leaves per plant at 45 DAT. Number of leaves per plant at 45 DAT showed significant and positive correlation with curd circumference, curd width, days to curd initiation, total plant weight, curd weight, curd length, days to 50% curd formation, core length and days to harvest. Net curd weight showed significant and positive correlation with curd weight.

Nine varieties of broccoli from four nurseries were evaluated by analyzing both agronomic and quality parameters by Ordiales *et al.* (2017). Total yield and number of harvests were monitored. Parameters defining quality like diameter, weight, and height of the heads were determined. Granulometry, compactness, and the presence of internal leaves in the heads were also analyzed. Diameter and height of sprouts were complementarily estimated. Results revealed that both first and second principal components explained more than 75% of the variance and grouped data according their cultivar and commercial origin. Additionally, correlations between the scores of those components and the values of the phenotypic parameters suggested that head weights are main determinants of the phenotypic differences observed among the cultivars whereas the presence of internal leaves and granulometry and head weight appear to be key traits defining nurseries.

N and A (2018) observed significant differences among genotypes for all the characters studied in early Indian cauliflower suggesting sufficient variability for curd yield and quality characters. Among the varieties, NS 60N was superior for curd yield, depth, diameter and curd size index followed by G 45. Earliest among the varieties was Himshort followed by NS 60N while Himpriya-60 was superior of plant height, leaves per plant, gross plant weight, leaf length, leaf breadth and leaf size. Significant differences were observed among treatments for all quality characters except vitamin C. At genotypic level, net curd weight showed high positive correlation with leaves per plant. Similar results were obtained in Path coefficient analysis also. The top ranking varieties based on selection index were NS 60N, G 45, White Snow, Himpriya 60 and Pusa Meghna.

Zablotskaya *et al.* (2018) studied the correlation relationship between quantitative traits in 42 broccoli hybrids. Significant influence on growth and development was provided by the developing weather conditions during the growing period. Based on the results of the research, it was concluded that the value of the correlation coefficients and the strength of the correlation relationship between the characteristics (mass, diameter, head height, plant height, vegetation period) were different and depend on the set of test specimens and growing conditions. A significant stable manifestation of positive correlation was revealed during all the years of research and the time of planting between; the diameter and mass of the head ($r = 0.45-0.96$).

Singh *et al.* (2019) carried out study in cauliflower cv. 'Pusa Dipali' to find out the correlation and multiple regression coefficients. Yield was found to be highly significant and positively correlated with all the ancillary characters, *viz.* curd depth (0.9180), curd diameter (0.9050), weight of curd (0.8990), plant height (0.8898), weight of plant (0.8768) and plant girth (0.6880). The multiple regression coefficients were found to be non-significant due to multi collinearly between the characters. The step wise regression analysis showed that the character curd depth exhibited highest contribution towards field followed by curd weight, curd diameter and plant height while the lowest contribution was due to the character plant girth and weight of plant respectively.

Pramila *et al.* (2020b) evaluated fifteen genotypes of cauliflower and observed that the genotypic correlation coefficient was significantly higher than the corresponding phenotypic correlation coefficient for almost all of the parameters studied. Estimates of phenotypic correlation revealed that the character total yield (quintal per hectare) was

highly significant and positively correlated with the characters, viz. net curd weight, gross curd weight, curd length, curd width and harvest index.

Twenty five cauliflower genotypes were studied by Kumar *et al.* (2021) and significant variations were observed for almost all the traits. Net curd weight had the highest positive significant correlation with the curd yield indicating that the net curd weight was the optimum parameter for selection of high yielding genotypes. However, days to marketable maturity imposed negative non-significant correlation on curd yield. Among the twenty five genotypes, curd yield (kg/plot and q/ha) was greater in local genotypes namely Jachh CF-2, Jachh CF-7 and Jachh CF-17, hence these local varieties can be utilized in further breeding programmes.

2.4 Path coefficient analysis

A path analysis study undertaken by Kanwar and Korla (2002) in sixteen biparental progenies (developed from a cross PSB-1 x KT-9) in late cauliflower (*Brassica oleracea* var. *botrytis* L.) for horticultural and quality traits revealed that contributions of the horticultural traits, viz. gross plant weight and harvest index were maximum (directly and indirectly) on the dependent character i.e. yield and BIPs 13, 17 and 19 possessed good yield and quality traits.

Kumar *et al.* (2011) conducted path analysis studies in early Indian cauliflower and their studies revealed that the characters net curd weight and curd compactness showed highest positive contribution towards the dependent trait i.e. total yield.

Studies on path analysis conducted by Sheemar *et al.* (2012) with respect to various economic traits in cauliflower showed that the traits net curd weight, harvest index and curd depth had positive direct effect on the dependent character total plant weight.

The study conducted by Katoch *et al.* (2014) pertaining to path analysis in 16 genotypes of broccoli revealed that the maximum positive direct effect on the dependent character marketable yield/plant was exhibited by the trait terminal head weight per plant followed by the characters harvest index, gross weight per plant and head size index. This indicated that a selection procedure based on high terminal head weight/plant along with

high harvest index, high gross weight/plant and high head size index may be effective in improving marketable yield.

The path analysis studies carried out by Singh *et al.* (2014) in cauliflower showed that the maximum positive direct effect occurred due to the character leaf count followed by the characters curd weight, plant height and curd depth. Whereas, the characters plant spread, leaf area and curd diameter showed direct negative effect over the dependent trait i.e. yield. The value of residual effect was found to be 0.0801, indicating that the characters included for path analysis were sufficient for inducing the maximum yield of cauliflower.

Nandhini *et al.* (2019) carried out path analysis studies in 13 broccoli genotypes with respect to 14 quantitative traits to ascertain the traits involved in enhancing curd weight. The studies revealed that the characters curd weight/plant, days to curd initiation, leaf width, curd length, curd dry matter, leaf dry matter and Vitamin C showed the positive direct effect on the dependent character yield and hence these traits should be considered, while practicing selection aimed at improvement of yield in broccoli.

Pramila *et al.* (2020b) studied path coefficient analysis among 15 genotypes of cauliflower and their studies revealed that positive direct effects were exhibited by the traits net curd weight and gross curd weight respectively on the dependent trait total yield (q/ha). The negative direct effects were exhibited by the characters, *viz.* curd length, curd width and harvest index. High positive indirect effects were recorded by the characters net curd weight and gross curd weight respectively. Whereas, high negative indirect effects were shown by the characters curd length, leaf length and plant spread on the dependent trait i.e. total yield.

Singh *et al.* (2021) used large genetic stock of cauliflower encompassing 76 cytoplasmic male sterile (CMS) lines along with homozygous doubled haploid (DH) inbreds in their study. The CMS lines, Ogu402-6A, Ogu76-33A and Ogu76-4A were identified for development of early maturing hybrids. While the CMS lines, Ogu13-85-6A, Ogu309-2A and Ogu2A were selected as parents for generation of the hybrids with highly compact curds. Superior agronomic traits, abundant pollen production and good seed setting in the DH lines DH-53-1 and DH-53-10 revealed their potential for genetic and genomic studies in cauliflowers. The PCA analysis revealed the maximum contribution of numbers of silique per plant and seed yield in total variation.

Chapter-3

MATERIALS AND METHODS

The present investigation entitled “Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh” was conducted during *Rabi* season of 2021-22 at the Experimental Research Farm of Department of Vegetable Science, College of Horticulture and Forestry, Neri, District Hamirpur of Himachal Pradesh in order to adjudge the amount of variability present in the various genotypes under study.

3.1 About Experimental Site:

The Experimental Research Farm of Department of Vegetable Science, COH&F Neri, Hamirpur, Himachal Pradesh is situated in the low hill zone of Himachal Pradesh within latitude 31°41’47.6” N and longitude of 76°28’6.3” E. This area is located at an altitude of 650m above mean sea level.

3.1.2 Climate:

This region is characterized with mild winters and hot summers. More than 90% rainfall is received during July- August. Data recorded for mean monthly weather parameters during the present investigation have been presented on table 3.1 and figure 3.1.

Table 3.1 Agro-metrological data during the cropping period:

Month	Rainfall (mm)	Relative Humidity (%)	Maximum Temperature (°C)	Minimum Temperature (°C)
October, 2021	1.43	66.77	28.81	20.10
November, 2021	0.01	46.66	25.66	14.29
December, 2021	0.03	39.51	20.68	9.75
January, 2022	5.20	62.08	17.79	8.61
February, 2022	1.418	54.96	20.80	9.64

Source: Metrological observatory, COH&F Neri, Hamirpur.

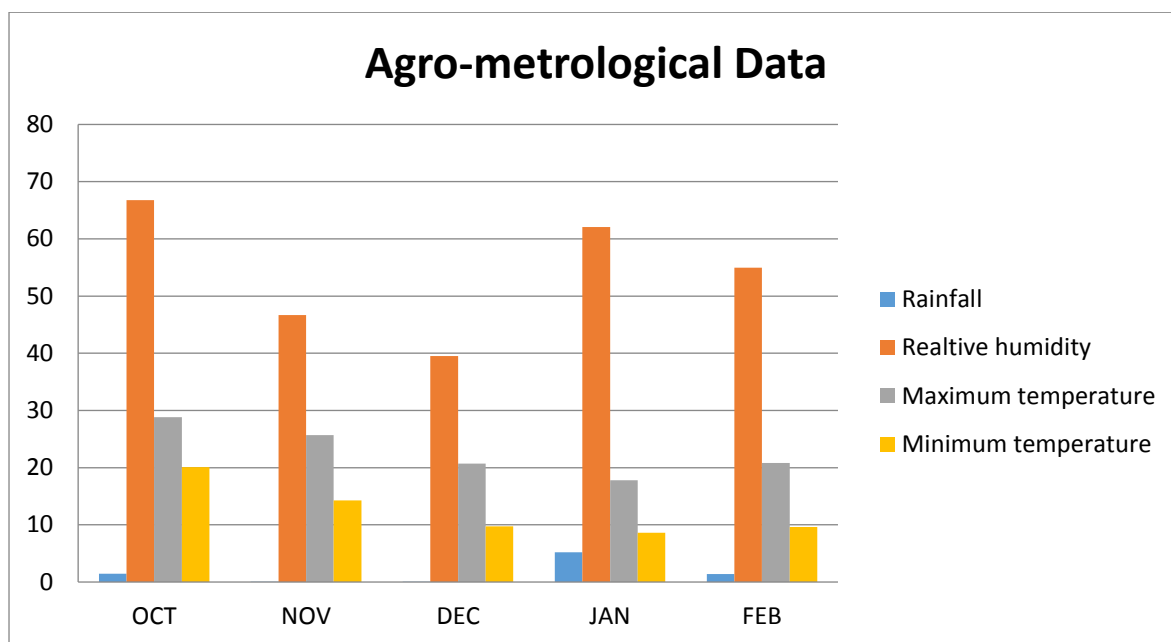


Figure 3.1 Agro-metrological data during the present investigation

3.2 Experimental Design and layout:

Number of genotypes	: 12 (including check)
Plot Size	: 1.8 × 2.25 m
Spacing	: 45 × 45cm
Design	: Randomized Complete Block Design
No. of Replications	: 3
Number of plants/plot	: 20
Check variety	: Palam Samridhi
Date of transplanting	: 11 Novenmber, 2021

3.3 Planting Material:

Present investigation comprised of 12 (10 local and 2 commercial) different genotypes of sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) which are as follows:

Table 3.2. List of genotypes of sprouting broccoli used in the present investigation

S. no.	Genotype	Source
1.	BR-NERI-1	Department of Vegetable Science, COH&F Neri, Hamirpur
2.	BR-NERI-2	Department of Vegetable Science, COH&F Neri, Hamirpur
3.	BR-NERI-3	Department of Vegetable Science, COH&F Neri, Hamirpur
4.	BR-NERI-4	Department of Vegetable Science, COH&F Neri, Hamirpur
5.	BR-NERI-5	Department of Vegetable Science, COH&F Neri, Hamirpur
6.	BR-NERI-6	Department of Vegetable Science, COH&F Neri, Hamirpur
7.	BR-NERI-7	Department of Vegetable Science, COH&F Neri, Hamirpur
8.	BR-NERI-8	Department of Vegetable Science, COH&F Neri, Hamirpur
9.	BR-NERI-9	Department of Vegetable Science, COH&F Neri, Hamirpur
10.	BR-NERI-10	Department of Vegetable Science, COH&F Neri, Hamirpur
11.	Pusa Broccoli KTS-1	IARI, Regional Station, Katrain, Kullu
12.	Palam Samridhi (check)	CSKHPKV, Palampur

3.4 NURSERY RAISING, TRANSPLANTING AND CULTURAL PRACTICES

3.4.1 Nursery raising

The seeds of all the genotypes of sprouting broccoli were sown at experimental farm under special care in $3 \times 1 \times 0.15$ m seed beds. Before sowing, the soils of seed beds were prepared to obtain good tilth to provide favorable conditions for vigorous growth of young seedlings. Weeds, stubbles and dried roots of previous crops were removed. The seeds were drenched with Bavistin as a precautionary measure against damping off disease and for raising healthy nursery.



Plate:1 Seed germination

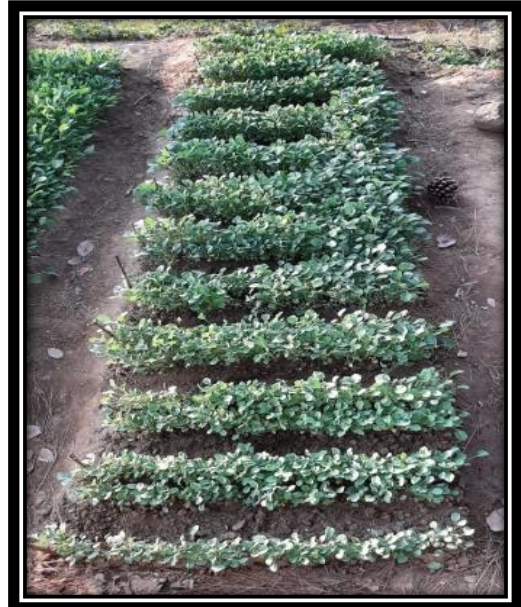


Plate: 2 Seedlings ready for transplanting

3.4.2 Field preparation

The experimental field was ploughed thoroughly with the help of power tiller. Stones, pebbles and crop residues of previous crop were removed manually. The field was brought to the fine tilth and it was leveled for proper drainage of water. Well rotten farm yard manure was applied at the time of field preparation. After levelling, plots were made according to the layout plan.

3.4.3 Transplanting

After four weeks of seed sowing, transplanting was done. 20 plants were planted in each plot of size 1.8 m × 2.25 m. The seedlings were transplanted in the field on 11 November, 2021 at spacing of 45 cm × 45cm. The transplanting was done in the afternoon hours and immediately irrigation was done for proper establishment of seedlings.



Plate: 3 Crop after few days of transplanting



Plate: 4 Experimental field of broccoli

3.4.4 Cultural practices

Recommended package of practices were followed during growth period of the crop. Besides the application of farmyard manure @ 200q/ha, chemical fertilizers were applied as per the recommended package of practices (271kg/ha Urea, 475kg/ha SSP, 85kg/ha MOP). Half dose of N and full dose of P₂O₅ and K₂O were applied at the time of field preparation and remaining half dose of N was top dressed one month after transplanting. The intercultural operations, irrigations and pest-control were carried out in accordance with the recommended schedule.

3.5 Observations recorded:

The observations were recorded on 5 randomly marked competitive plants from each replication and then average of these five plants was taken to record the reading for most of the traits under study. The detailed methodology of recording observations with respect to various horticultural traits studied is as follows:

3.5.1. Leaf length (cm):

The leaf length was measured as the distance of the leaf from the main stem to the top of the leaf (with petiole) at harvest stage and expressed in centimeter. Leaf is selected at random from the middle whorls in each plant.

3.5.2. Leaf width (cm):

Leaf width of same leaf used for recording the length was taken at the region of maximum width at harvest stage and expressed in centimeters.

3.5.3. Leaf area (cm²):

Leaf area was recorded by multiplying length (in cm) and the width (in cm) of the 5 randomly selected leaves from the middle whorls in each of the 5 tagged plants. The area was expressed in cm² and mean value was calculated.

3.5.4. Number of leaves per plant:

The leaves were counted in number at maturity of the head. Only the fully grown leaves were taken into consideration, while the small leaves in the inner whorl were not counted.

3.5.5. Plant height (cm):

Plant height was measured in centimeters from the base of the plant (ground level) to the tip of the largest leaf at the time of harvesting and average value was calculated for each replication.

3.5.6. Plant frame (cm²):

Plant frame was calculated at the time of harvest of the plant and the extent of plant spread in east to west and north to south directions was recorded in centimeters for each of the tagged plant. Then these values were multiplied and averaged for the 5 plants tagged to get plant frame (in cm²).

3.5.7. Central head size (cm²):

Length and breadth of the head was measured in centimeters at the time of harvesting and accordingly size was calculated.

3.5.8. Central head weight (g):

At the marketable maturity, the central head was cut with long stalk length approximately 6 inches of stem and weighed.

3.5.9. Number of lateral heads per plant:

Lateral heads those appeared in the axils of leaves present on the central stalk after removal of central head were counted.

3.5.10. Lateral head weight (g):

The single mature lateral head was harvested and weighed to arrive at the total weight of spears per plant.

3.5.11. Days to first harvest:

Five random plants were selected from each plot and tagged. Days taken from transplanting till first harvest of central head when the head attained marketable maturity was recorded. The average value was computed of all the five plants in the given plot.

3.5.12. Harvest duration (days):

The number of days taken from first harvest of central head to the last harvest of the lateral heads in a given plant.

3.5.13. TSS (⁰B):

Total Soluble Solid (TSS) values were recorded with the help of the hand refractometer in ⁰Brix by putting few drops of the juice extracted from the broccoli head at the time of its harvest by crushing it with mortar and pestle.

3.5.14. Dry matter (%):

The head was chopped and 100g of fresh material were kept in hot air oven at 50-60°C for drying and finally, dry matter percentage was calculated after complete drying of sample.

$$\text{Dry matter content} = (\text{Dry weight} / \text{Fresh weight}) \times 100$$

3.5.15. Ascorbic acid (mg/100g):

Ascorbic acid content of the fresh broccoli head was estimated at the time of harvest with the help of the procedure given in Association of Official Agricultural Chemists (AOAC, 1980) by using the dye 2, 6-dichlorophenol indophenol. Ascorbic Acid was calculated by using the following formula:

$$\text{Ascorbic Acid (mg/100g)} = \frac{\text{Dye factor} \times \text{Titre value} \times \text{Volume made up}}{\text{Volume of aliquat} \times \text{Volume of sample taken for estimation}} \times 100$$

3.5.16. Total yield per plant (g):

The yield data pertaining to central heads and lateral heads which were recorded on 5 randomly marked competitive plants were added and total yield per plant was calculated.

3.5.17. Leaf shape:

Leaf shape was observed visually at the time of harvesting and mainly three types of leaf shapes were found, viz. oblong, elliptic, and lanceolate.

3.5.18. Color of the head:

Color of the head was observed visually and was grouped into 3 groups, *viz.* dark green, green and light green.

3.5.19. Central head compactness:

This observation was taken visually and the heads were grouped in two categories *viz.* compact and loose.

3.5.20. Prevalence of disease (if any):

Daily observations were recorded in the field to note any disease incidence in the field on the 5 tagged plants in each plot for the purpose. These plants were not given any pesticide spray during the course of investigation.

3.6. Statistical Analysis:

Present investigation was conducted in the field with three replications and the result was statistically recorded using Randomized Complete Block Design (RCBD).

3.6.1 Analysis of Variance (ANOVA)

The analysis of variance was carried out for different quantitative characters as per the procedure given by Panse and Sukhatme (2000).

$$Y_{ab} = \mu + g_a + r_b + e_{ab}$$

Where,

Y_{ab} = Phenotypic observation of a^{th} entry grown in b^{th} replication

μ = General population mean

g_a = Effect of a^{th} entry

r_b = Effect of b^{th} replication

e_{ab} = Error component

ANOVA for RBD shall be as follows:

Source of variation	Degree of Freedom	Sum of square	Mean sum of square	Expected mean sum of squares
Replication (r)	r-1	S _r	S _r /(r-1)=M _r	σ ² e+gσ ² r
Genotypes (g)	g-1	S _g	S _g /(g-1)=M _g	σ ² e+rσ ² g
Error (e)	(r-1) (g-1)	S _t	S/(r-1)(g-1)=M _t	σ ² e

Where,

r = Number of replications

g = Number of genotypes

S_r = Sum of squares due to replications

S_g = Sum of squares due to treatments

S_t = Sum of squares due to errors

M_r = Mean sum of squares due to replications

M_g = Mean sum of squares due to treatments

M_t = Mean sum of squares due to error

σ²r = Variance due to replications

σ²g = Variance due to entries

σ²e = Error variance

Tests were conducted for the replications and genotypes mean sum of squares against error mean sum of squares by 'F' test for (r-1), (r-1) (g-1) and (g-1), (r-1) (g-1) degree of freedom at P= 0.05. Comparison between calculated F-value and tabulated F-value were done. When significant F-test was found, calculation of critical difference was done to find out the superiority of one genotype over the other. The standard error and critical differences will be calculated as follows:

$$SE (m) \pm = \pm \sqrt{\frac{Me}{r}}$$

$$SE (d) \pm = \pm \sqrt{\frac{2Me}{r}}$$

$$CD_{0.05} = SE (d) \times t_{0.05} (r-1) (g-1) df$$

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of differences

CD_{0.05} = Critical difference at 5% level of significance

3.7 Parameters of variability

Parameters of variability shall be estimated as per formula given by Burton and De Vane (1953) as follows:

3.7.1 Phenotypic coefficient of variation (PCV)

$$\text{PCV (\%)} = \frac{\sqrt{\text{Phenotypic variance}(V_p)}}{\text{General mean of population}(GM)} \times 100$$

3.7.2 Genotypic coefficient of variation (GCV)

$$\text{GCV (\%)} = \frac{\sqrt{\text{Genotypic variance}(V_g)}}{\text{General mean of population (GM)}} \times 100$$

Where:

$$V_e = M_e$$

$$V_g = \text{Genotypic variance } (M_g - M_e)/r$$

$$V_p = \text{Phenotypic variance } (V_g + V_e)$$

The estimation of PCV and GCV for all the traits under study were categorized as low (< 10 %), moderate (10-20 %) and high (> 20 %) as per given by Sivasubramanian and Menon (1973).

3.8 Heritability

Heritability in broad sense will be calculated as per formula given by Burton and De Vane (1953) and Allard (1960).

$$H (\%) = \frac{V_g}{V_p} \times 100$$

Where,

$$H = \text{Heritability (\%)}$$

$$V_g = \text{Genotypic variance } [V_g = (M_g - M_e) / r]$$

$$V_p = \text{Phenotypic variance } (V_g + V_e)$$

The estimates of heritability in broad sense were categorized as low (< 80 %), moderate (80-90 %) and high (> 90 %).

3.9 Genetic advance

The expected genetic advance resulting from selection of five percent superior individuals shall be calculated as per Allard (1960):

$$GA = H \times \sigma_p \times K$$

Where,

H = Heritability (%)

σ_p = Phenotypic standard deviation

K = Selection differential at 5% selection index (K = 2.06)

3.10 Genetic Advance as percentage of mean/Genetic Gain:

Genetic Advance as percentage of mean was calculated as per the formula given by Johnson *et al.* (1955):

$$\text{Genetic Advance as percentage of mean (\%)} = (GA / \mu) \times 100$$

Where,

GA = Genetic Advance

μ = General mean of population

The estimates of Genetic advance as percentage of mean were classified as low (<10%), moderate (10-30%) and high (30%).

3.11 Correlation Analysis

The correlations between all characters under study, at genotypic, phenotypic and environmental level will be estimated as per the method described by Al-Jibouri *et al.* (1958).

a. Genotypic correlation between characters x and y

$$r_{xy}(g) = \frac{Cov_{xy}(g)}{\sqrt{V_x(g) \times V_y(g)}}$$

b. Phenotypic correlation between characters x and y

$$r_{xy}(p) = \frac{Cov_{xy}(p)}{\sqrt{V_x(p) \times V_y(p)}}$$

Where,

$Cov_{xy}(g)$ = Genotypic co-variance between x and y characters

$Cov_{xy}(p)$ = Phenotypic co-variance between x and y characters

$V_x(g)$ = Genotypic variance of character 'x'

$V_x(p)$ = Phenotypic variance of character 'x'

$V_y(g)$ = Genotypic variance of character 'y'

$V_y(p)$ = Phenotypic variance of character 'y'

The test of significance for association between characters was done by comparing tabulated 'r' values at n-2 error degree of freedom for phenotypic and genotypic correlations with estimated values, respectively.

3.12 Path Coefficient Analysis

Path coefficient was studied as per the procedure suggested by Wright (1921) and was elaborated by Dewey and Lu (1959).

Yield components were included in the path coefficient analysis to reveal their direct and indirect effects upon yield. Residual factor was also included in the causal system which represents all other factor, which might affect yield. For estimation of direct and indirect effects, following formula was used:

$$r_{iy} = r_{in}P_{iy} + \dots + P_{iy} \dots + r_{in}P_{ny}$$

Where,

r_{iy} = coefficient of correlation between causal factor X_i and dependent character Y .

r_{in} = coefficient of correlation among all possible combinations of causal factors.

P_{iy} = direct effect of character X_i upon the character Y .

Residual factor was worked out as follows:

$$P_{zY_n} = \sqrt{1 - R^2}$$

Where,

$$R^2 = \sum_{t=1} P_{2iy} + 2 \sum_{i < j} P_{iy} P_{jy} r_{ij}$$

Which is the square of the multiple correlation coefficient (R) and is known as coefficient of determination.

Chapter-4

RESULTS AND DISCUSSION

Broccoli is one of the important cool season vegetable crop belonging to the family cruciferae whose heads are rich source of various Vitamins and Minerals. The results with respect to the present investigation entitled “Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh” comprising 12 different genotypes of Broccoli have been presented in the following text and discussed elaborately with the help of appropriate tables, graphs etc. wherever, necessary in the subsequent text under the following heads:

4.1 Analysis of Variance

4.2 Variability Studies

4.3 Heritability and Genetic Advance

4.4 Correlation coefficient analysis studies

4.5 Path Coefficient Analysis Studies

4.1 Analysis of Variance

The perusal of Analysis of Variance (ANOVA) (Appendix-I) with respect to 16 different quantitative traits of broccoli showed that mean sum of squares due to genotypes were significant for all the horticultural traits studied viz. leaf width (3.05), leaf length (90.55), leaf area (38185.44), number of leaves per plant (3.17), plant height (220.13), plant frame (349658.4), central head size (6799.59), central head weight (27222.32), number of lateral heads per plant (16.53), lateral head weight (445.15), days to first harvest (112.21), harvest duration (155.81), TSS (7.31), dry matter (13.01), ascorbic acid (313.32) and total yield per plant (23230.04) thus, indicating that sufficient genetic variability exists among the various genotypes of broccoli studied. However, mean sum of squares due to replications were not significant for any of the horticultural characters; thus, indicating the absence of variation among different replications. None of the diseases affected the present genotypes, under study; hence, the character prevalence of disease was not included in Analysis of Variance and no further analysis for the character was carried out.

4.2 Variability Studies

Studies pertaining to variability were carried out with respect to only 16 quantitative traits *viz.* leaf width (cm), leaf length (cm), leaf area (cm²), number of leaves per plant, plant height (cm), plant frame (cm²), central head size (cm²), central head weight (g), number of lateral heads per plant, lateral head weight (g), days to first harvest, harvest duration (days), TSS (⁰B), dry matter (%), ascorbic acid (mg/100g) and total yield per plant (g) in 12 genotypes of broccoli (*Brassica oleracea* L. var. *italica* Plenck.). The observations with respect to 3 qualitative traits leaf shape, color of head and central head compactness were also recorded in the above genotypes of broccoli. During the course of investigation no disease was observed; therefore, no observation was recorded for the character prevalence of diseases (if any). The results pertaining to all the quantitative and qualitative characters studied in the present investigation have been discussed under the suitable headings as follows:

4.2.1 Mean performance of genotypes

Mean performance of the 12 genotypes of broccoli studied, during the present investigation, with respect to 16 quantitative traits has been presented in Table 4.1 and the observations pertaining to 3 qualitative traits has been compiled in Table 4.2. The elaborate discussion on the mean performance of the various genotypes, with respect to various horticultural traits is as follows:

4.2.1.1 Leaf width (cm)

Considerable variation in terms of leaf width was observed in different genotypes of broccoli studied. The values for the character ranged from 16.04 to 19.15 cm with an overall mean of 17.35 cm. The maximum leaf width was recorded in the genotype BR-NERI-8 (19.15 cm) which was found to be statistically at par with the genotypes BR-NERI-7 (18.69 cm), BR-NERI-3 (18.32 cm), Pusa Broccoli KTS-1 (17.97 cm), BR-NERI-10 (17.66 cm) and Palam Samridhi (17.45 cm). Whereas, the minimum leaf width was found in the broccoli genotype BR-NERI-4 (16.04 cm) which was preceded by the genotypes BR-NERI-1 (16.44 cm), BR-NERI-6 (16.48 cm) and BR-NERI-5 (16.52 cm). These results were in conformity to those obtained by Santhosha *et al.* (2014); Kaur *et al.* (2018); Chittora and Singh (2015) in different genotypes of cauliflower which is a closely related crop of broccoli.

4.2.1.2 Leaf length (cm)

Leaf length was recorded by measuring the length of leaf from the tip of the leaf to its base upto main stem in cm. The range of leaf length in various genotypes of sprouting broccoli varied from 35.26 to 57.42 cm with an overall mean of 47.20 cm. The maximum leaf length was observed in the genotype BR-NERI-8 (57.42 cm) which was statistically at par with the genotypes BR-NERI-7 (51.96 cm) and BR-NERI-10 (51.33 cm). Minimum leaf length was however, exhibited by the genotype BR-NERI-5 (35.26 cm). Similar findings have also been reported by Santhosha *et al.* (2014); Kaur *et al.* (2018); Chittora and Singh (2015) in the studies conducted by them in cauliflower.

4.2.1.3 Leaf area (cm²)

Leaf area is an important character as it is a measure of the photosynthetic active area; the more is the leaf area the more photosynthates are produced which thus help in obtaining higher yields. Leaf area in various genotypes of sprouting broccoli studied was recorded and varied from 662.06 to 1003.74 cm² with mean value of 829.61 cm². The highest value in terms of leaf area was recorded in the genotype BR-NERI-8 (1003.74 cm²); which was statistically at par with the genotypes BR-NERI-7 (992.56 cm²), BR-NERI-3 (896.87 cm²), Pusa Broccoli KTS-1 (896.86 cm²), Palam Samridhi (878.78 cm²) and BR-NERI-10 (870.11 cm²); indicating that all these genotypes performed well for leaf area. The least leaf area was exhibited by the genotype BR-NERI-4 (662.06 cm²) which was statistically at par with genotypes BR-NERI-5 (665.55 cm²), BR-NERI-1 (743.31 cm²), BR-NERI-2 (759.71 cm²), BR-NERI-6 (790.01 cm²) and BR-NERI-9 (795.82 cm²). Similar variation in terms of leaf area has been reported by Thapa and Rai (2012).

4.2.1.4 Number of leaves per plant

Number of leaves per plant in different genotypes of sprouting broccoli under study ranged from 10.8-14.26; the maximum number of leaves were found in the broccoli genotype BR-NERI-10 (14.26) which was statistically at par with the broccoli genotype BR-NERI-9 (13.6). While, the minimum number of leaves were recorded in the genotype BR-NERI-2 (10.8); which was statistically at par with the broccoli genotypes *viz.* BR-NERI-4 (11), BR-NERI-3 (11.2) and Palam Samridhi (11.86). These findings were in line to those obtained by Thapa and Rai (2012) and Chaurasiya and Pandey (2020) in broccoli genotypes.

4.2.1.5 Plant height (cm)

Plant height in various genotypes of broccoli studied during the present investigation ranged from 40.43 to 75.06 cm; however, the overall mean value for the character was 60.63 cm. The maximum plant height was observed in the genotype BR-NERI-10 (75.06 cm); which was statistically at par with genotypes BR-NERI-8 (68.46 cm), BR-NERI-4 (65.90 cm) and BR-NERI-1 (65.28 cm). The minimum plant height was exhibited by the genotype BR-NERI-5 (40.43 cm). These results were in line to those obtained by Chaurasiya and Pandey (2020), Thakur *et al.* (2016), Kour (2020), Tejaswini *et al.* (2018) and Habib *et al.* (2013) in their studies involving different genotypes of broccoli.

4.2.1.6 Plant frame (cm²)

Plant frame determines the amount of space covered by the plant along with its leaves. It is an important character for the proper interception of light by the leaves and affective photosynthesis. Plant frame in various genotypes varied from 2913.53 to 3952.66 cm² with an overall mean value of 3419.08 cm². The maximum plant frame was recorded in the genotype Palam Samridhi (3952.66 cm²) which was found statistically at par with the genotypes BR-NERI-10 (3766.73 cm²), BR- NERI-7 (3733.66 cm²), BR-NERI-3 (3699.73 cm²), BR-NERI-8 (3677.6 cm²), Pusa Broccoli KTS-1 (3378.13 cm²) and BR-NERI-6 (3327.3 cm²); suggesting that these genotypes have almost same plant frame as the genotype having maximum plant frame i.e. Palam Samridhi. However, the minimum plant spread was observed by the genotype BR-NERI-2 (2913.53 cm²), which was statistically at par with the genotypes BR-NERI-4 (2933.63 cm²), BR-NERI-1 (3166.40 cm²), BR-NERI-9 (3204.70 cm²), BR-NERI-5 (3274.86 cm²), BR-NERI-6 (3327.30 cm²) and Pusa Broccoli KTS-1 (3378.13 cm²). Similar findings were obtained by Tejaswini *et al.* (2018); Thapa and Rai (2012) in their studies conducted on broccoli crop.

4.2.1.7 Central head size (cm²)

The range exhibited by the character i.e. Central head size was 71.08 to 186.15 cm² in various genotypes of broccoli; while, the overall mean value for the character was 133.14 cm². The maximum central head size was observed in the genotype BR-NERI-7 (186.15 cm²); which was statistically at par with genotypes BR-NERI-8 (183.98 cm²), BR-NERI-3 (182.27 cm²), BR-NERI-5 (173.50 cm²), Pusa Broccoli KTS-1 (160.45 cm²), BR-NERI-9 (152.67 cm²) and Palam Samridhi (145.91 cm²). Whereas, the minimum central head size

was exhibited by the genotype BR-NERI-2 (71.08 cm²) which was preceded by the genotypes BR-NERI-1 (72.25 cm²), BR-NERI-10 (75.45 cm²) and BR-NERI-4 (78.21 cm²). These results were in accordance to those obtained by Thakur *et al.* (2016) in their studies carried out involving various genotypes of broccoli.

4.2.1.8 Central head weight (g)

Central head weight in various genotypes of broccoli showed a range from 60.46 to 334.13g; however, the overall mean value for the character was equal to 179.29g. The maximum central head weight was observed in the genotype BR-NERI-8 (334.13 g); which was statistically at par with genotypes BR-NERI-7 (282.4 g), BR-NERI-3 (266.26 g) and BR-NERI-5 (241.66 g); thus, indicating that these genotypes were equally important as the genotype showing maximum central head weight. The minimum central head weight was exhibited by the genotype BR-NERI-1 (60.46 g) which was statistically at par with the genotypes BR-NERI-2 (61.20 g), BR-NERI-4 (71.13 g) and BR-NERI-10 (72.26 g). These results were in line to those obtained by Thapa and Rai (2012) in broccoli.

4.2.1.9 Number of lateral heads per plant

Lateral heads which appear in the axils of leaves, present on the central stalk after, removal of central heads were counted. The character number of lateral heads per plant exhibited the values in the range of 1.33 to 7.60 and the overall mean value shown by the various genotypes under study was 4.25. The highest number of lateral heads per plant were found in the genotype BR-NERI-1 (7.60) which was statistically at par with the genotype BR-NERI-10 (7.40) and BR-NERI-4 (7.20). The least number of lateral heads per plant were found in the genotype BR-NERI-7 (1.33) which was statistically at par with the genotypes BR NERI-8 (1.46), BR-NERI-3 (1.53) and BR-NERI-5 (2.20). Studies conducted by Chaurasiya and Pandey (2020); Thapa and Rai (2012); Habib *et al.* (2013) found similar results in broccoli.

4.2.1.10 Lateral head weight (g)

Lateral head weight is an important character which influences yield. In the present investigation, lateral head weight exhibited the values in the range of 14.66 to 48.23g and the overall mean value shown by the various genotypes of broccoli was 27.04g. The highest lateral head weight was observed in the genotype Palam Samridhi (48.23 g), which was

statistically at par with the genotype BR-NERI-9 (46.26 g); which indicated that the variety BR-NERI-9 was equally good in terms of the character lateral head weight to the check variety Palam Samridhi. The lowest lateral head weight was found in the genotype BR-NERI-2 (14.66 g) which was preceded by the genotypes BR-NERI-10 (15.16 g), BR-NERI-4 (15.80 g), BR-NERI-7 (17.76 g) and BR-NERI-3 (19.13 g). Studies conducted by Chaurasiya and Pandey (2020); Thapa and Rai (2012) revealed similar findings in broccoli.

4.2.1.11 Days to first harvest

Days to first harvest is an important character in any crop and broccoli is not an exception; the early harvests fetch higher price in the market. Lesser number of days to first harvest is desirable character in broccoli. Days to first harvest ranged from 86.53 to 104.66 days with an overall mean of 93.88 days. Least number of days to first harvest was recorded in the genotype BR-NERI-4 (86.53 days). However, maximum number of days to first harvest was observed in the broccoli genotype BR-NERI-3 (104.66 days) which was statistically at par with the genotypes BR-NERI-8 (103.33 days) and BR-NERI-7 (102.86 days); which suggested that all these genotypes were comparable and not suitable in terms of the character days to first harvest; owing to more number of days taken by them for first harvest. Thakur *et al.* (2016), Kour (2020) and Tejaswini *et al.* (2018) recorded similar observations with respect to the trait i.e. days to first harvest in broccoli.

4.2.1.12 Harvest duration (days)

The longer duration of availability of broccoli heads i.e. Central heads or lateral heads help in ensuring supply of the heads for longer time in market and tend to reduce gluts in the market. This trait was measured in days and the values for it ranged from 8.00 to 27.80 days with an overall mean of 16.36 days. Maximum, harvest duration was exhibited by the genotype BR-NERI-6 (27.80 days) which was found to be statistically at par with the genotype BR-NERI-9 (26.66 days); thus it indicated that both these genotypes were equally good for longer harvest duration. While, the least harvest duration was observed in the genotype BR-NERI-3 (8.00 days). Similar findings have been reported by Thakur *et al.* (2016) in their investigations carried out in broccoli.

4.2.1.13 TSS (° B)

Total Soluble Solids (TSS) is a measure of total sugar content in the heads of broccoli and it, was measured with the help of refractometer. TSS value among different genotypes of the broccoli studied varied from 5.19 to 9.58 ° B with an overall mean value of 7.67 ° B. The highest TSS was obtained in the broccoli genotype BR-NERI-10 (9.58° B) which was statistically at par with the genotypes *viz.* BR-NERI-4 (9.40° B) and BR-NERI-2 (9.36° B); thus suggesting that all these genotypes had comparable amount of TSS and could be used in the future breeding programmes for increasing TSS. Whereas, lowest TSS value was exhibited by the genotype BR-NERI-7 (5.19° B). Similar, findings have been reported by Thapa and Rai (2012) for the character under study in broccoli crop.

4.2.1.14 Dry matter (%)

In order to work out dry matter (%); the head was chopped and 100g of fresh material was kept in hot air oven at $60^0 \pm 5^0\text{C}$ for drying and finally, dry matter percentage was calculated after complete drying of the sample. Dry matter in various genotypes of broccoli in the present study ranged from 12.29-17.83%; however, the overall mean value for the character was 14.77%. The maximum value of dry matter was observed in the genotype Palam Samridhi (17.83%); which was statistically at par with genotype BR-NERI-2 (17.66%). Thus it lead to the conclusion that both the above genotypes were comparable in terms of dry matter and could be utilized for increasing dry matter in further breeding programmes. The minimum value was exhibited by the genotype BR-NERI-8 (12.29%); which was statistically at par with genotype BR-NERI-3 (12.79%). These results were in line to those obtained by Habib *et al.* (2013) and Tejaswini *et al.* (2018) in their studies involving various genotypes of broccoli.

4.2.1.15 Ascorbic acid content (mg/100g)

Broccoli is a good source of ascorbic acid and its deficiency can lead to several diseases like scurvy in human beings; therefore high content of ascorbic acid in broccoli heads is a desirable character. The ascorbic acid content in different genotypes of broccoli varied from 51.20-82.06 mg/100g with an overall mean of 62.86 mg/100g. The highest amount of ascorbic acid content was found in the genotype BR-NERI-7 (82.06 mg/100g) which was statistically at par with the genotype Palam Samridhi (79.37 mg/100g); thus revealing that both these genotypes were equally good in terms of ascorbic acid content.

Whereas, the least content of ascorbic acid was estimated in the genotype BR-NERI-8 (51.20 mg/100g) however, it was statistically at par with the genotype BR-NERI-1 (51.42 mg/100g), BR-NERI-3 (53.77 mg/100g) and BR-NERI-6 (56.05 mg/100g). These findings were in accordance to those obtained by Habib *et al.* (2013) and Koh *et al.* (2009).

4.2.1.16 Total yield per plant (g)

Total yield per plant is the most important trait from breeding point of view in broccoli as it is the principal economic character. The values for this character varied from 132.86 to 412.06 g in different genotypes of broccoli; however, the overall mean value for this character was found to be equal to 262.28 g. The best genotype with respect to this character was BR-NERI-9 (412.06 g); which was statistically at par with genotypes BR-NERI-8 (360.86 g), BR-NERI-5 (306.66 g), BR-NERI-7 (306.6 g), BR-NERI-3 (296.46 g) and Palam Samridhi (294.8 g). Thus, indicating that all these genotypes were comparable to the check variety Palam Samridhi and were equally good in terms of total yield per plant and hence can be used in future breeding programmes to develop high yielding varieties of broccoli. The genotype poorest in terms of total yield per plant was BR-NERI-2 (132.86 g) which was statistically at par with the genotypes *viz.* BR-NERI-1 (152.13 g), BR-NERI-4 (153 g) and BR-NERI-10 (187.46 g). These findings were in accordance to those obtained by Chaurasiya and Pandey (2020) in broccoli.

4.2.1.17 Leaf shape

Leaf shape in different genotypes of broccoli was observed visually and on the basis of visual examination the 12 genotypes were divided mainly into three categories on the basis of their shape *viz.* oblong, elliptic and lanceolate. The five genotypes *viz.* BR-NERI-1, BR-NERI-4, BR-NERI-10, Pusa Broccoli KTS-1 and Palam Samridhi possessed “Lanceolate” leaf shape. Whereas, four genotypes *viz.* BR-NERI-2, BR-NERI-3, BR-NERI-5, BR-NERI-6 had “Elliptic” leaf shape. While, the remaining three broccoli genotypes *viz.* BR-NERI-7, BR-NERI-8 and BR-NERI-9 possessed “Oblong” type of leaf shape.

4.2.1.18 Color of head

Head color was observed visually for various genotypes of broccoli and depending upon the color, the 12 genotypes of broccoli studied, were classified into 3 groups i.e. “Green”, “Dark Green” and “Light Green”. Green colored heads were observed in 6

different genotypes *viz.* BR-NERI-1, BR-NERI-2, BR-NERI-4, BR-NERI-7, BR-NERI-10 and Palam Samridhi. While, the 5 genotypes BR-NERI-3, BR-NERI-5, BR-NERI-6, BR-NERI-8 and BR-NERI-9 showed “Dark Green” colored heads. Only one genotype i.e. Pusa Broccoli KTS-1 showed Light Green colored heads.

4.2.1.19 Central head compactness

Different genotypes of broccoli studied during the present investigation were classified into two groups i.e. “Loose” and “compact” on the basis of the head compactness exhibited by them. The four genotypes BR-NERI-1, BR-NERI-2, BR-NERI-4 and BR-NERI-10 possessed “Loose” central heads. Whereas, the remaining 8 genotypes *viz.* BR-NERI-3, BR-NERI-5, BR-NERI-6, BR-NERI-7, BR-NERI-8, BR-NERI-9, Pusa Broccoli KTS-1 and Palam Samridhi showed “Compact” type of central heads.

4.2.1.20 Prevalence of diseases (if any)

All the genotypes of broccoli which were studied during the present investigation were watched carefully, during the cropping period and examined for the prevalence of diseases if, any from time to time, till the final harvesting of the produce; under natural epiphytotic conditions. No, disease appeared in any of the broccoli genotypes studied and hence no, further analysis for the character i.e. prevalence of diseases was carried out.

Table: 4.1 Mean performance of various quantitative horticultural traits in different broccoli (*Brassica oleracea* L. var. *italica* Plenck.) genotypes.

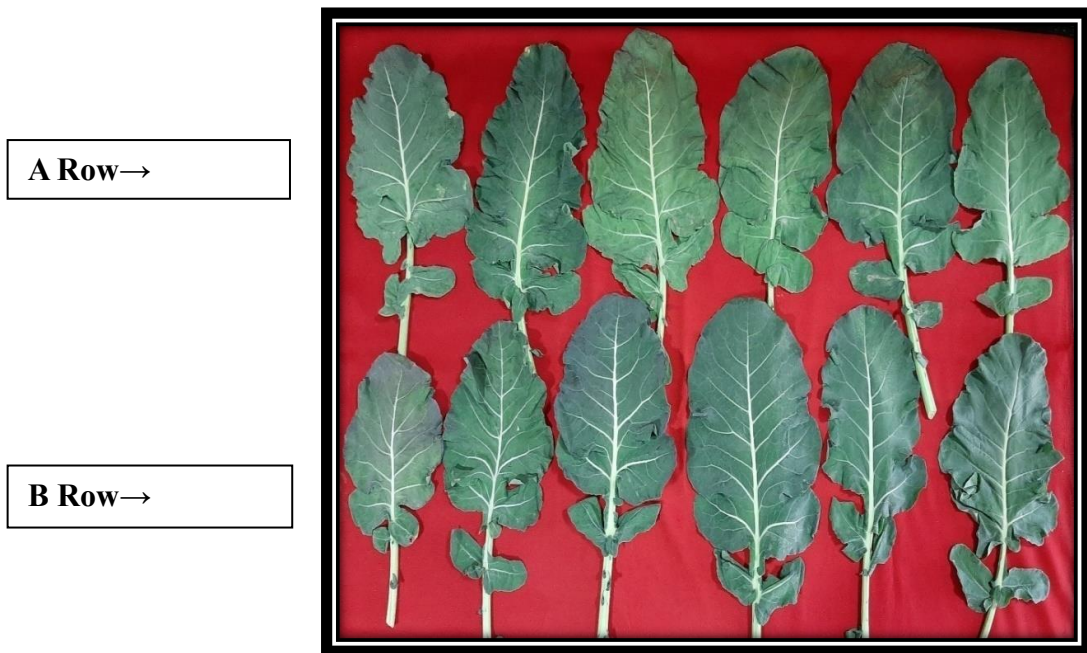
Genotypes	Parameters							
	Leaf width (cm)	Leaf length (cm)	Leaf area (cm ²)	Number of leaves per plant	Plant height (cm)	Plant frame (cm ²)	Central head size (cm ²)	Central head weight (g)
BR-NERI-1	16.44	44.84	743.31	12.00	65.28	3166.40	72.25	60.46
BR-NERI-2	16.84	45.07	759.71	10.80	64.33	2913.53	71.08	61.20
BR-NERI-3	18.32	49.92	896.87	11.20	57.04	3699.73	182.27	266.26
BR-NERI-4	16.04	44.61	662.06	11.00	65.90	2933.63	78.21	71.13
BR-NERI-5	16.52	35.26	665.55	12.20	40.43	3274.86	173.50	241.66
BR-NERI-6	16.48	43.40	790.01	12.20	57.10	3327.30	115.85	200.33
BR-NERI-7	18.69	51.96	992.56	12.40	61.44	3733.66	186.15	282.40
BR-NERI-8	19.15	57.42	1003.74	12.80	68.46	3677.60	183.98	334.13
BR-NERI-9	16.66	45.51	795.82	13.60	55.96	3204.70	152.67	222.80
BR-NERI-10	17.66	51.33	870.11	14.26	75.06	3766.73	75.45	72.26
Pusa Broccoli KTS-1	17.97	48.47	896.86	12.86	60.16	3378.13	160.45	171.00
Palam Samridhi (Check)	17.45	48.66	878.78	11.86	56.34	3952.66	145.91	167.86
Mean	17.35	47.20	829.61	12.27	60.63	3419.08	133.14	179.29
SE(m)	0.60	2.08	56.87	0.36	3.39	212.06	15.15	31.73
CD (0.05)	1.78	6.14	167.89	1.07	10.02	625.96	44.74	93.68
CV (%)	6.02	7.64	11.87	5.11	9.70	10.74	19.71	30.65

Table: 4.1 (Continued....) Mean performance of various quantitative horticultural traits in different broccoli (*Brassica oleracea* L. var. *italica* Plenck.) genotypes.

Genotypes	Parameters							
	Number of lateral heads per plant	Lateral head weight (g)	Days to first harvest	Harvest duration (days)	TSS (°B)	Dry matter (%)	Ascorbic acid (mg/100g)	Total yield per plant (g)
BR-NERI-1	7.60	24.53	91.66	16.80	8.84	15.45	51.42	152.13
BR-NERI-2	5.73	14.66	91.26	11.20	9.36	17.66	58.39	132.86
BR-NERI-3	1.53	19.13	104.66	8.00	5.83	12.79	53.77	296.46
BR-NERI-4	7.20	15.80	86.53	11.53	9.40	16.71	63.09	153.00
BR-NERI-5	2.20	39.66	88.40	15.06	6.96	13.12	64.87	306.66
BR-NERI-6	3.73	32.26	92.80	27.80	7.33	13.07	56.05	283.26
BR-NERI-7	1.33	17.76	102.86	9.26	5.19	13.04	82.06	306.60
BR-NERI-8	1.46	20.66	103.33	10.20	5.77	12.29	51.20	360.86
BR-NERI-9	4.60	46.26	90.40	26.66	7.59	13.13	62.06	412.06
BR-NERI-10	7.40	15.16	91.40	12.93	9.58	16.80	60.20	187.46
Pusa Broccoli KTS-1	3.73	30.33	91.73	21.06	7.16	15.33	71.82	261.26
Palam Samridhi (Check)	4.53	48.23	91.60	25.86	9.06	17.83	79.37	294.80
Mean	4.25	27.04	93.88	16.36	7.67	14.77	62.86	262.28
SE (m)	0.46	2.59	0.66	0.42	0.15	0.17	2.33	41.44
CD (0.05)	1.35	7.65	1.95	1.24	0.45	0.50	6.87	122.33
CV (%)	18.73	16.59	1.22	4.46	3.51	2.01	6.41	27.36

Table: 4.2 Observations with respect to various qualitative traits in different broccoli (*Brassica oleracea* L. var. *italica* Plenck.) genotypes.

Sr. No.	Genotype	Colour of Head	Leaf Shape	Central Head Compactness
1	BR-NERI-1	Green	Lanceolate	Loose
2	BR-NERI-2	Green	Elliptic	Loose
3	BR-NERI-3	Dark Green	Elliptic	Compact
4	BR-NERI-4	Green	Lanceolate	Loose
5	BR-NERI-5	Dark Green	Elliptic	Compact
6	BR-NERI-6	Dark Green	Elliptic	Compact
7	BR-NERI-7	Green	Oblong	Compact
8	BR-NERI-8	Dark Green	Oblong	Compact
9	BR-NERI-9	Dark Green	Oblong	Compact
10	BR-NERI-10	Green	Lanceolate	Loose
11	Pusa Broccoli KTS-1	Light Green	Lanceolate	Compact
12	Palam Samridhi (check)	Green	Lanceolate	Compact



A Row (From Left to Right): Pusa Broccoli KTS-1, Palam Samridhi, BR-NERI-1, BR-NERI-2, BR-NERI-3 and BR-NERI-4

B Row (From Left to Right): BR-NERI-5, BR-NERI-6, BR-NERI-7, BR-NERI-8, BR-NERI-9, BR-NERI-10.

Plate: 5 Leaf shape of various broccoli genotypes



BR-NERI-1



BR-NERI-2



BR-NERI-3



BR-NERI-4



BR-NERI-5



BR-NERI-6

Plate 6(a): Variability in Broccoli Genotypes



BR-NERI-7



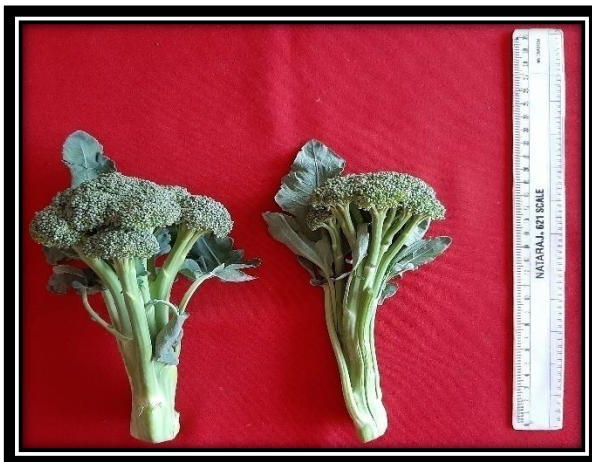
BR-NERI-8



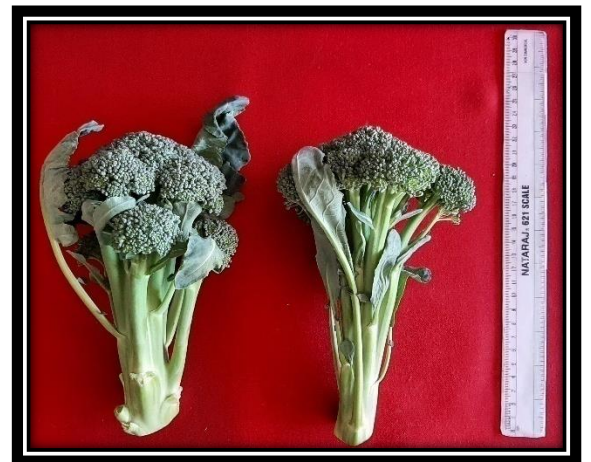
BR-NERI-9



BR-NERI-10



Pusa Broccoli KTS-1



Palam Samridhi

Plate 6(b): Variability in Broccoli Genotypes



Early maturing genotypes

First Row (From Left to Right): Pusa Broccoli KTS-1, Palam Samridhi, BR-NERI-1, BR-NERI-2, BR-NERI-4 and BR-NERI-5.

Second Row (From Left to Right): BR-NERI-6, BR-NERI-9, BR-NERI-10



Late maturing genotypes

(From Left to Right): BR-NERI-3, BR-NERI- 7, BR-NERI-8

Plate: 7 Variability in Broccoli Genotypes according to maturity time

4.2.2 Parameters of variability

For genetic improvement of any crop, genetic variability in the population plays an important role and the germplasm of the crop collected from various sources act as a base population in the plant breeding studies, to increase the variability in the given crop. Genetic variability is the basic requirement for improvement of different horticultural characters in a given crop. Therefore, the knowledge of genetic variability with respect to yield and other important characters is very important for strengthening of any breeding programme.

The present study consisted of 12 genotypes of sprouting broccoli and the variation was observed, for different horticultural traits. The variation exhibited by the various genotypes was the result of interaction of environment and the genotype. As the environmental variation is solely non-fixable and not heritable; therefore only genotypic and phenotypic coefficients of variation were calculated to know the magnitude of genotypic and phenotypic variation in the present study. The results pertaining to genotypic and phenotypic coefficients have been discussed as under:

4.2.2.1 Coefficients of variability

The study of Table 4.3 clearly showed that phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the traits studied which indicated that environment played a greater role in creating variation among the various genotypes. However, there was smaller difference between the PCV and GCV values for all the traits studied.

Out of all 16 quantitative traits studied in the current investigation; high PCV and GCV values (> 20%) were found for 7 traits *viz.* central head size (PCV=39.21% and GCV= 33.89%), central head weight (PCV=58.73% and GCV=50.09%), number of lateral heads per plant (PCV=57.24% and GCV=54.09%), lateral head weight (GCV=44.01% and PCV=47.04%), harvest duration (GCV=43.95 and PCV=44.18%), TSS (GCV=20.23% and PCV=20.54%) and total yield per plant (GCV=29.59% and PCV=40.31%).

However, moderate values (10-20%) of PCV and GCV were exhibited by the traits *viz.* leaf length (PCV=13.20% and GCV=10.76%), leaf area (PCV=16.70% and GCV=11.74%), plant height (PCV=16.19% and GCV=12.97%), plant frame

(PCV=13.29%), dry matter (PCV=14.19% and GCV=14.05%) and ascorbic acid (PCV=17.08% and GCV=15.82%).

While, the low values (< 10%) for PCV and GCV were exhibited by only 4 traits *viz.* leaf width (PCV=7.61% and GCV=4.65%), number of leaves per plant (PCV=9.36% and GCV=7.84%), plant frame (GCV=7.82%) and days to first harvest (GCV=6.47% and PCV=6.59%). Similar results were obtained by Habib *et al.* (2013) and Nandhini *et al.* (2020) in the broccoli.

4.3 Heritability and Genetic Advance

4.3.1. Heritability

Genetic variability alone cannot give us the estimate of the heritable variation, therefore the estimation of heritability is essential. Burton (1953) reported that a genetic coefficient of variability along with heritability estimates would give the best picture of the amount of advance expected from selection in a given population. Heritability can be defined as a measure of genetic variability and determines the tendency of character to pass on to the offspring from, its parents. High, heritability makes it easy to perform direct selection and to improve the desirable trait merely by selecting a suitable parent. Whereas, when a particular trait shows low heritability, than a breeder has to perform progeny tests before any direct selection and if, selection is performed than it, is based on desirable progeny only.

The broad sense heritability with values >90% were considered as high, while those having values between 80-90% were classified as moderate and those which were having values <80% were deemed to show low values. During the present study, heritability in broad sense showed a range of 34.66 to 98.97%. The highest value of heritability was observed by the horticultural character harvest duration (98.97%) followed by dry matter (97.99%), TSS (97.07%) and days to first harvest (96.54%). Whereas, the moderate (80-90%) level of heritability was observed for the traits number of lateral head per plant (89.28%), lateral head weight (87.54%) and ascorbic acid (85.87%). However, the low (< 80%) heritability value was seen in the traits *viz.* leaf length (66.52%), leaf width (37.33%), number of leaves per plant (70.14%), leaf area (49.44%), plant height (64.13%), plant frame (34.66%), central head size (74.71%), central head weight (72.74%) and total yield per plant (53.90). These results were in accordance to those obtained by Nandhini *et al.* (2020) in broccoli.

4.3.2 Genetic Advance (as percentage of mean)

Genetic advance (Table 4.3) was calculated as percentage of mean for all the quantitative traits under study. Genetic advance values < 10% were put under low category, 10-30% were classified as moderate and while, those which exhibited >30% were put in the category of high genetic advance.

In the current investigation, the genetic advance values for all the traits ranged from 5.85 to 105.29%. The high amount of genetic advance was observed for the horticultural traits *viz.* central head size (60.35%) and central head weight (88.01%), number of lateral head per plant (105.29%), lateral head weight (84.83%), harvest duration (90.08%), TSS (41.07%), ascorbic acid (30.21%) and total yield per plant (44.76%). However, moderate level of genetic advance was recorded by the traits *viz.* leaf length (18.09%), leaf area (17.01%), number of leaves per plant (13.53%), plant height (21.39%), days to first harvest (13.10%) and dry matter (28.65%). Whereas, lowest values in terms of genetic advance were found in only two traits *viz.* leaf width (5.85) and plant frame (9.49). These results were in conformity with those reported by Nandhini *et al.* (2020) in the traits *viz.* ascorbic acid, central head weight, days to first harvest and dry matter.

Figure 4.1 Graphical representation of heritability (%) and genetic advance (%) for different traits in broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

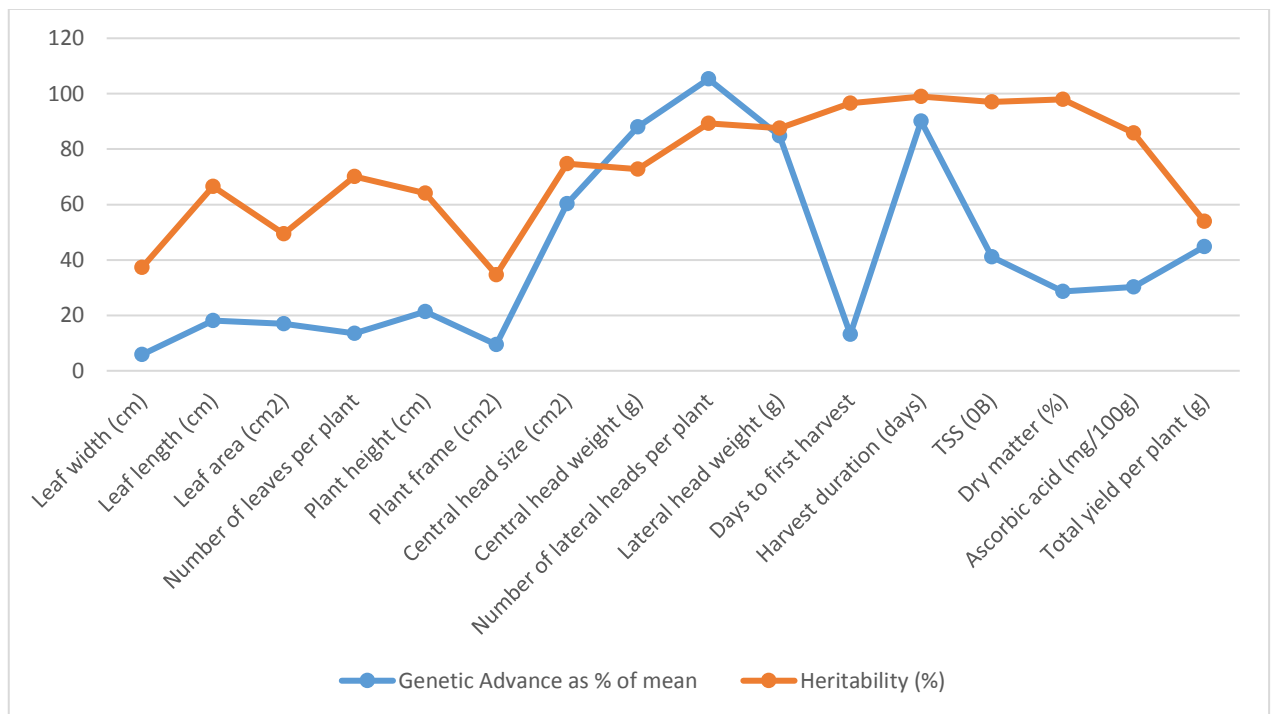


Figure 4.2 Graphical representation of Genotypic and Phenotypic Coefficient of Variation (%)

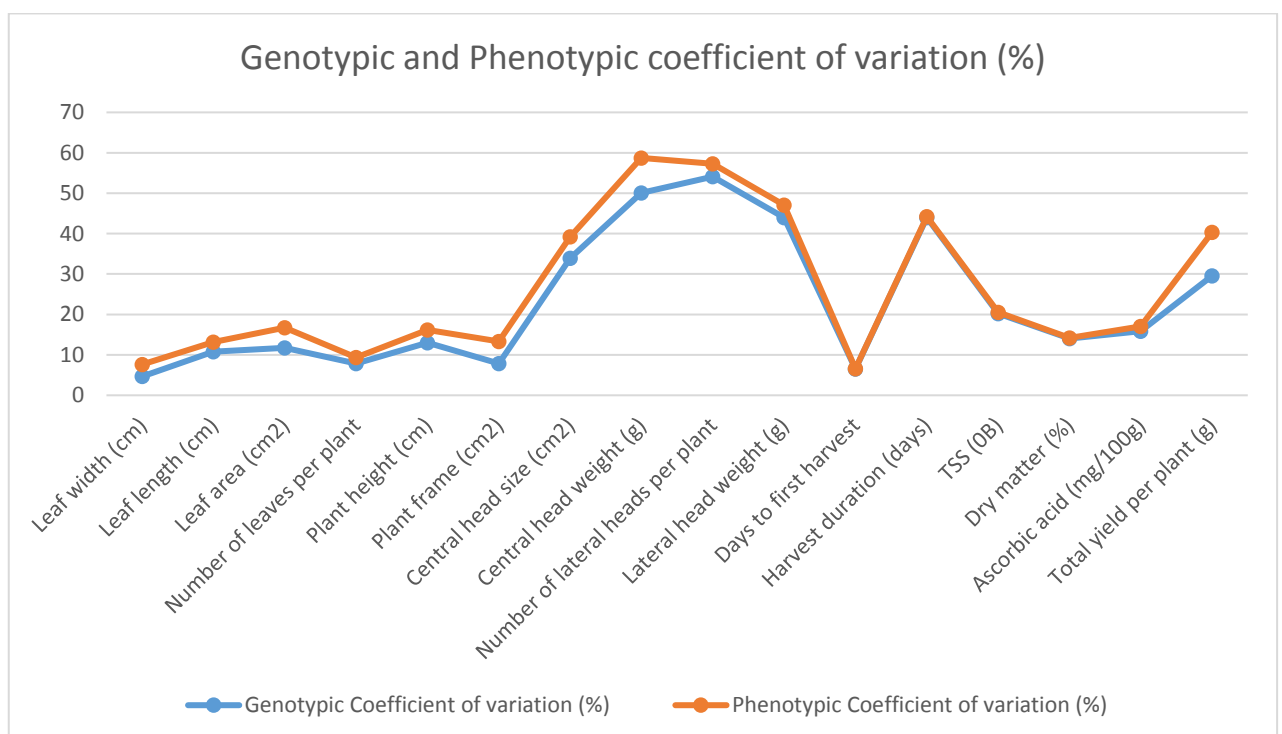


Table: 4.3 Genetic parameters of variation for various horticultural traits in different genotypes of broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

Sr. No.	Characters	Mean	Range		Coefficient of variation (%)		Heritability (%)	Genetic Advance as % of mean
			Minimum	Maximum	Genotypic	Phenotypic		
1	Leaf width (cm)	17.35	16.04	19.15	4.65	7.61	37.33	5.85
2	Leaf length (cm)	47.20	35.26	57.42	10.76	13.20	66.52	18.09
3	Leaf area (cm ²)	829.61	662.06	1003.74	11.74	16.70	49.44	17.01
4	Number of leaves per plant	12.27	10.80	14.26	7.84	9.36	70.14	13.53
5	Plant height (cm)	60.63	40.43	75.06	12.97	16.19	64.13	21.39
6	Plant frame (cm ²)	3419.08	2913.53	3952.66	7.82	13.29	34.66	9.49
7	Central head size (cm ²)	133.14	71.08	186.15	33.89	39.21	74.71	60.35
8	Central head weight (g)	179.29	60.46	334.13	50.09	58.73	72.74	88.01
9	Number of lateral heads per plant	4.25	1.33	7.60	54.09	57.24	89.28	105.29
10	Lateral head weight (g)	27.04	14.66	48.23	44.01	47.04	87.54	84.83
11	Days to first harvest	93.88	86.53	104.66	6.47	6.59	96.54	13.10
12	Harvest duration (days)	16.36	8.00	27.80	43.95	44.18	98.97	90.08
13	TSS (⁰ B)	7.67	5.19	9.58	20.23	20.54	97.07	41.07
14	Dry matter (%)	14.77	12.29	17.83	14.05	14.19	97.99	28.65
15	Ascorbic acid (mg/100g)	62.86	51.20	82.06	15.82	17.08	85.87	30.21
16	Total yield per plant (g)	262.28	132.86	412.06	29.59	40.31	53.90	44.76

4.4 Correlation Studies

Character association plays a major role in any plant breeding programme which aims at improving the quality and yield traits. Correlation determines the relationship among different characters and thus, helps in making selection more effective. Further, the knowledge pertaining to the magnitude of association between different characters of the crop enhances the precision of genetic improvement. In the present investigation, correlation coefficient analysis was carried out both at phenotypic and genotypic levels for all possible combinations of 16 quantitative traits studied. Perusal of Table 4.4 showed that the genotypic correlations were greater in magnitude as compared to the phenotypic correlations for most of the characters; which meant that environment played lesser role in governing the phenotype of the various broccoli genotypes studied. The different significant correlations among 16 quantitative horticultural traits have been discussed below under suitable headings:

4.4.1 Leaf width

Leaf width observed positive and highly significant correlation with the traits leaf length (genotypic=0.919 and phenotypic=0.762), leaf area (genotypic=0.065 and phenotypic=0.848), plant frame (genotypic=0.055 and phenotypic=0.496), central head size (genotypic=0.898), central head weight (genotypic=0.895) and days to first harvest (genotypic=0.037 and phenotypic=0.689), suggesting that the trait leaf width increases with the increase of the characters *viz.* leaf length, leaf area, plant frame, central head size, central head weight, days to first harvest and total yield per plant. However, positive and significant character association was found with the characters central head size (0.383) and the central head weight (0.381) at phenotypic level.

Whereas, the character expressed negative highly significant character association with the traits number of lateral heads per plant (genotypic= -0.818 and phenotypic= -0.462), harvest duration (genotypic= -0.529), TSS (genotypic= -0.813 and phenotypic= -0.504), dry matter (genotypic= -0.431), suggesting inverse association of these traits with the horticultural character leaf width. However, negative and significant character association was found with the character lateral head weight (-0.356) at genotypic level only. Similar findings have also been reported by Nandhini *et al.* (2019).

4.4.2. Leaf length

The trait leaf length showed positive and highly significant correlation with the horticultural characters leaf area (genotypic=0.954 and phenotypic=0.806), plant height (genotypic= 0.717 and phenotypic= 0.654), plant frame (genotypic= 0.696 and phenotypic= 0.528) and days to first harvest (genotypic= 0.731 and phenotypic= 0.651) which means that with the increase of one trait, other trait also increases and vice versa. This indicates that the above traits can be selected simultaneously.

However, the trait expressed negative and highly significant correlation with the trait lateral head weight (genotypic= -0.434); while, negative and significant type of character association was shown by the horticultural trait i.e. leaf length with the trait harvest duration (genotypic= -0.335).

4.4.3. Leaf area

The horticultural trait leaf area showed positive and highly significant correlation with the characters *viz.* plant height (phenotypic= 0.479), plant frame (genotypic= 0.050 and phenotypic= 0.542), central head size (genotypic= 0.690), central head weight (genotypic= 0.718), days to first harvest (genotypic= 0.907 and phenotypic= 0.700) suggesting that the genotypes with greater leaf area had larger plant height, plant frame, central head size, central head weight and days to first harvest. However, leaf area showed positive and significant correlation with the traits number of leaves per plant (genotypic= 0.340 and phenotypic= 0.391), central head size (phenotypic= 0.410) and central head weight (phenotypic= 0.415).

Whereas, the character under study i.e. leaf area expressed negative and highly significant correlation with the traits number of lateral heads per plant (genotypic= -0.651) and TSS (genotypic= -0.674 and phenotypic= -0.466); on the other hand it showed negative and significant correlation with the traits *viz.* number of lateral heads per plant (phenotypic= -0.409) and dry matter (genotypic= -0.332). Suggesting, inverse association of these traits with the trait leaf area. These findings were in close conformity with those obtained by Habib *et al.* (2013).

4.4.4. Number of leaves per plant

Number of leaves per plant expressed positive and significant correlation with the characters plant frame (genotypic= 0.418 and phenotypic= 0.375) and total yield per plant (genotypic= 0.423 and phenotypic= 0.418); suggesting that the broccoli genotypes with greater number of leaves had larger plant frame and more yield. These findings were in accordance with the findings obtained by Habib *et al.* (2013); Nandhini *et al.* (2019).

4.4.5. Plant height

Highly significant and positive correlation was exhibited by the trait plant height with the character number of lateral heads per plant (genotypic level= 0.519; phenotypic level= 0.449). The studies thus, indicated that the genotypes of sprouting broccoli with greater plant height had more number of lateral heads per plant and vice versa. However, plant height was positively and significantly associated with the trait dry matter (0.418) at genotypic level.

On the other hand, the character plant height exhibited negative and highly significant correlation with the characters *viz.* central head weight (genotypic level= -0.485), lateral head weight (genotypic= -0.769 and phenotypic= -0.534). Whereas, it showed negative and significant correlation with the traits *viz.* central head size (phenotypic= -0.386) and harvest duration (genotypic level= -0.354). These results were in confirmation to those reported by Habib *et al.* (2013).

4.4.6. Plant frame

Plant frame exhibited positive and highly significant correlation with the traits central head size (genotypic level= 0.644 and phenotypic level= 0.428), central head weight (genotypic level= 0.621), days to first harvest (genotypic level= 0.726 and phenotypic level= 0.459); thus indicating that plant frame increases with increase in all of the above discussed characters. However, the character plant frame showed positive and significant correlation with the trait central head weight (0.379) at phenotypic level only.

Plant frame exhibited negative and highly significant correlation with the traits *viz.* number of lateral heads per plant (-0.579) and TSS (-0.489) at genotypic levels only. Similar results have also been reported by Habib *et al.* (2013).

4.4.7. Central head size

Central head size showed positive and highly significant correlation with the traits *viz.* central head weight (0.954 and 0.921) and days to first harvest (0.658 and 0.548) at both genotypic and phenotypic levels respectively. Whereas, positive and significant correlation was found between the traits central head size and the characters *viz.* lateral head weight (0.377) and ascorbic acid (0.338) at genotypic level only. Thus, it indicated that increase in the central head size led to increase in the characters central head weight, days to first harvest, lateral head weight and ascorbic acid.

Whereas, negative and highly significant relationship was found between the character central head size and the traits *viz.* number of lateral heads per plant (genotypic= -0.021 and phenotypic= -0.791), TSS (genotypic= -0.939 and phenotypic= -0.786), dry matter (genotypic= -0.751 and phenotypic= -0.645); thus, suggesting that central head size had inverse relationship with these traits. The present findings were in line with the findings of those obtained by Nandhini *et al.* (2019).

4.4.8. Central head weight

Positive and highly significant correlation was found for the trait central head weight with the character days to first harvest (genotypic= 0.750 and phenotypic= 0.622) indicating that simultaneous selection can be done for this trait.

However, the trait central head weight exhibited negatively highly significant correlation with the trait number of lateral heads per plant (genotypic= -0.041 and phenotypic= -0.789), TSS (genotypic=-0.981 and phenotypic= -0.826) and dry matter (genotypic=-0.891 and phenotypic= -0.760), which suggested inverse relationship of central head weight with all these characters. These findings were in close accordance with the findings of Nandhini *et al.* (2019).

4.4.9. Number of lateral heads per plant

Positive and highly significant association was found between the trait number of lateral heads per plant and the characters *viz.* TSS (genotypic=0.945 and phenotypic= 0.890) and dry matter (genotypic=0.770 and phenotypic= 0.712). Hence, it suggested that TSS and dry matter both increased in the given genotypes of broccoli with increase in number of lateral heads; therefore this paved the way for simultaneous improvement of the above traits.

Negative and highly significant correlation was observed between the trait number of lateral heads per plant and the character days to first harvest (genotypic=-0.724 and phenotypic= -0.674) thus it could be inferred that the genotypes of the broccoli with lesser number of lateral heads per plant recorded more number of days to first harvest.

4.4.10. Lateral head weight

Positive and highly significant correlation for the trait lateral head weight was observed with the traits *viz.* harvest duration (0.838 and 0.774) at genotypic and phenotypic levels respectively. Thus, it could be inferred that the broccoli genotypes with greater lateral head weight also recorded longer harvest duration. Moreover, it also indicated that the association among the traits was heritable and these two traits could be selected simultaneously.

Negatively significant correlation was found between the traits lateral head weight and the days to first harvest (-0.351) at genotypic level indicating that the plants having larger lateral head weight took lesser days to first harvest in the given genotypes of broccoli during the present investigation.

4.4.11. Days to first harvest

Days to first harvest is an important trait in any breeding programme; the trait registered negative and highly significant correlation with the horticultural characters *viz.* harvest duration (genotypic=-0.474 and phenotypic= -0.466), TSS (genotypic=-0.790 and phenotypic= -0.765) and dry matter (genotypic=-0.577 and phenotypic= -0.566) indicating inverse relationship of this trait with the characters harvest duration, TSS and dry matter. Thus it indicated that simultaneous improvement of the traits harvest duration, TSS and dry matter with lesser number of days to first harvest was a difficult proposition.

4.4.12. Harvest duration

Longer harvest duration is a desirable character in broccoli. It showed positive significant association with the trait total yield per plant (0.366) at genotypic level only which suggested that the genotypes with longer harvest duration also recorded higher total yield per plant and vice versa.

4.4.13. TSS

The horticultural trait i.e. TSS reported positive and highly significant correlation with the trait dry matter (genotypic=0.883 and phenotypic= 0.869) suggesting that high TSS values were observed for the heads with greater dry matter. This indicated that both these traits can thus be improved simultaneously.

4.4.14. Dry matter

Dry matter showed negative and highly significant correlation with the character total yield per plant (-0.817 and 0.604) at genotypic and phenotypic levels respectively indicating that increase in dry matter led to decrease in total yield per plant. Similar results were also recorded by Habib *et al.* (2013).

4.4.15. Ascorbic acid content

Ascorbic acid content exhibited a positive significant correlation with the character plant frame (0.366 and 0.357) at both genotypic and phenotypic levels suggesting that the genotypes of broccoli which had higher content of ascorbic acid had more plant spread. Which suggested that both these characters were either being controlled by the same gene or the genes controlling the traits were closely linked with each other.

4.4.16. Total yield per plant

Total yield per plant reported positive and highly significant correlation with the traits *viz.* leaf width (genotypic=0.621), leaf area (genotypic=0.584), plant frame (genotypic=0.571), central head size (genotypic= 0.867 and phenotypic= 0.819), central head weight (genotypic= 0.870 and phenotypic= 0.879), lateral head weight (genotypic= 0.699 and phenotypic= 0.444) and days to first harvest (genotype= 0.466) suggesting that the total

yield per plant increased with the increase in the traits *viz.* leaf width, leaf area, plant frame, central head size, central head weight, lateral head weight and days to first harvest. This suggested that all these traits can be easily increased by selecting the genotypes with higher yield per plant. Whereas, the trait total yield per plant reported positive and significant correlation with the traits *viz.* number of leaves per plant (genotypic= 0.423 and phenotypic= 0.418), plant frame (phenotypic= 0.337) and days to first harvest (phenotypic= 0.333).

However, negative and highly significant correlations were observed by the trait total yield per plant with the horticultural traits *viz.* plant height (-0.613) at genotypic level, number of lateral heads per plant (genotypic= -0.894 and phenotypic= -0.512), TSS (genotypic= -0.790 and phenotypic= -0.566) and dry matter (genotypic= -0.819 and phenotypic= -0.604) indicating that the broccoli genotypes where total yield per plant was on higher side exhibited lesser plant height along with lesser number of lateral heads per plant and TSS. These findings were in close accordance with the findings of Habib *et al.* (2013) and Nandhini *et al.* (2019).

Table-4.4 Genotypic and Phenotypic correlation coefficients between total yield per plant and its component characters in broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
C1	G	1.000															
	P	1.000															
C2	G	0.919**	1.000														
	P	0.762**	1.000														
C3	G	0.065**	0.954**	1.000													
	P	0.848**	0.806**	1.000													
C4	G	0.307	0.291	0.340*	1.000												
	P	0.228	0.293	0.391*	1.000												
C5	G	0.235	0.717**	0.227	0.145	1.000											
	P	0.308	0.654**	0.479**	0.311	1.000											
C6	G	0.055**	0.696**	0.050**	0.418*	0.037	1.000										
	P	0.496**	0.528**	0.542**	0.375*	0.128	1.000										
C7	G	0.898**	0.240	0.690**	0.114	-0.598**	0.644**	1.000									
	P	0.383*	0.240	0.410*	0.209	-0.386*	0.428**	1.000									
C8	G	0.895**	0.329	0.718**	0.146	-0.485**	0.621**	0.954**	1.000								
	P	0.381*	0.272	0.415*	0.228	-0.288	0.379*	0.921**	1.000								
C9	G	-0.818**	-0.241	-0.651**	0.014	0.519**	-0.579**	-0.021**	-0.041**	1.000							
	P	-0.462**	-0.164	-0.409*	0.032	0.449**	-0.315	-0.791**	-0.789**	1.000							
C10	G	-0.356*	-0.434**	-0.215	0.204	-0.769**	0.157	0.377*	0.265	-0.155	1.000						
	P	-0.181	-0.323	-0.079	0.251	-0.534**	0.118	0.283	0.203	-0.154	1.000						
C11	G	0.037**	0.731**	0.907**	-0.016	0.142	0.726**	0.658**	0.750**	-0.724**	-0.351*	1.000					
	P	0.689**	0.651**	0.700**	0.009	0.179	0.459**	0.548**	0.622**	-0.674**	-0.312	1.000					
C12	G	-0.529**	-0.335*	-0.214	0.307	-0.354*	-0.027	-0.036	-0.069	0.163	0.838**	-0.474**	1.000				
	P	-0.308	-0.284	-0.137	0.246	-0.286	-0.028	-0.042	-0.064	0.157	0.774**	-0.466**	1.000				
C13	G	-0.813**	-0.326	-0.674**	-0.081	0.357	-0.489**	-0.939**	-0.981**	0.945**	0.007	-0.790**	0.233	1.000			
	P	-0.504**	-0.249	-0.466**	-0.099	0.288	-0.268	-0.786**	-0.826**	0.890**	-0.025	-0.765**	0.228	1.000			
C14	G	-0.431**	-0.074	-0.332*	-0.229	0.418*	-0.180	-0.751**	-0.891**	0.770**	-0.107	-0.577**	0.066	0.883**	1.000		
	P	-0.272	-0.074	-0.261	-0.216	0.307	-0.150	-0.645**	-0.760**	0.712**	-0.112	-0.566**	0.063	0.869**	1.000		
C15	G	0.263	0.037	0.297	0.040	-0.273	0.366*	0.338*	0.125	-0.204	0.322	-0.074	0.188	-0.089	0.234	1.000	
	P	0.078	-0.010	0.167	0.098	-0.210	0.357*	0.301	0.096	-0.188	0.309	-0.077	0.174	-0.078	0.213	1.000	
C16	G	0.621**	0.180	0.584**	0.423*	-0.613**	0.571**	0.867**	0.870**	-0.894**	0.699**	0.466**	0.366*	-0.790**	-0.817**	0.206	1.000
	P	0.222	0.200	0.307	0.418*	-0.269	0.337*	0.819**	0.879**	-0.512**	0.444**	0.333*	0.260	-0.566**	-0.604**	0.142	1.000

C1 Leaf width (cm) C3 Leaf area (cm²) C5 Plant height (cm) C7 Central head size (cm²) C9 Number of lateral heads / plant C11 Days to first harvest C13 TSS (°B) C15 Ascorbic acid (mg/100g)
 C2 Leaf length (cm) C4 Number of leaves/ plant C6 Plant frame (cm²) C8 Central head weight (g) C10 Lateral head weight (g) C12 Harvest duration C14 Dry matter (%) C16 Total yield per plant (g)

Where, * Significant at 5% level, ** Significant at 1% level

4.5 Path coefficient analysis studies

Path coefficient analysis study was conducted in 12 genotypes of sprouting broccoli and the direct and indirect effects of different independent characters on the dependent character i.e. total yield per plant have been tabulated in Table 4.5; the genotypic correlation coefficients with the character total yield per plant were partitioned into direct and indirect effects taking the economically important trait i.e. total yield per plant as dependent variable.

The path analysis concept was first given by Wright (1921) and this technique was used for the first time by Dewey and Lu (1959); this, technique proved very helpful in order to determine/identify various yield contributing horticultural characters. Path coefficient analysis together with correlation studies give very effective results and show their utility in further improvement of the crops by either direct or indirect selection through the components of the dependent trait. Path analysis measures the cause of association between two variables. If a particular character shows greater direct effect on the correlation with the yield than this character is very important and the improvement in yield can be directly done by selection of this trait. Whereas, if the correlation between yield and a character is mainly due to the indirect effects of a particular character through some other independent trait, then the indirect selection through that trait is effective in bringing improvement of dependent trait like yield. However If, the direct effect is positive and high, but the correlation is negative, in such situations direct selection for such trait should be practiced for improving the dependent trait like yield and to reduce the undesirable indirect effects through other independent component traits.

The genotypic correlation coefficients of the trait total yield per plant and its components were divided into two effects *viz.* direct effect and indirect effect. Total yield per plant was taken as dependent variable however, rest all of the characters were taken as independent variables.

4.5.1 Leaf width (cm)

The character leaf width showed positive direct effect (0.11393) and positive genotypic correlation (0.621) with the dependent trait total yield per plant which suggested that the selection directly through the trait leaf width is effective in increasing the values of the dependent trait.

Highest, positive indirect effects were exhibited by the characters central head weight (1.30365) followed by the trait TSS (0.37005), plant frame (0.30312), leaf length (0.10026), dry matter (0.04258), plant height (0.02620) and harvest duration (0.00667). However, the negative indirect effects were shown by the characters *viz.* number of lateral heads per plant (-0.76641), days to first harvest (-0.48278), leaf area (-0.19150), lateral head weight (-0.14922), number of leaves per plant (-0.02690), central head size (-0.02597) and ascorbic acid (-0.0054). Similar findings have been obtained, as per the studies conducted by Nandhini *et al.* (2019).

4.5.2 Leaf length (cm)

Positive direct effect (0.10913) along with positive genotypic correlation (0.180) was exhibited by the character leaf length with the dependent trait total yield per plant; which indicated that yield can be increased by direct selection of the genotypes which have higher leaf length.

Maximum positive indirect effect was seen in the character central head weight (0.47880) followed by the independent traits *viz.* plant frame (0.20001), TSS (0.14844), leaf width (0.10467), plant frame (0.07977), dry matter (0.00734) and harvest duration (0.00423).

Whereas, negative indirect effects were exerted through the characters days to first harvest (-0.34042), number of lateral heads per plant (-0.22592), lateral head weight (-0.18192), leaf area (-0.17143), number of leaves per plant (-0.02549), central head size (-0.00695) and ascorbic acid (-0.00041) on the dependent trait i.e. total yield per plant.

4.5.3 Leaf area (cm²)

Negative direct effect was exerted by the character leaf area (-0.17977) on the dependent character total yield per plant. However, positive genotypic correlation (0.584) was found for leaf area with the dependent trait total yield per plant; which suggested that negative direct effect tend to reduce the positive correlation between the leaf area and yield and hence in this case the selection through positive indirect effects could help in increasing yield in the present genotypes of broccoli under study.

Maximum positive indirect effect was shown by the independent trait central head weight (1.04508) followed by the traits TSS (0.30690), plant frame (0.30159), leaf width (0.12136), leaf length (0.10407), dry matter (0.03279), plant height (0.02523) and harvest duration (0.00270) on the dependent trait i.e. total yield per plant. On the other hand, the negative indirect effects were exerted through the independent traits *viz.* number of lateral heads per plant (-0.61060), days to first harvest (-0.42239), lateral head weight (-0.08993), number of leaves per plant (-0.02985), central head size (-0.01995) and ascorbic acid (-0.00332) respectively. These findings were in close conformity with that of Singh *et al.* (2014) in cauliflower crop.

4.5.4 Number of leaves per plant

Negative direct effect was exerted by the character number of leaves per plant (-0.08775) on the dependent trait total yield per plant. Whereas positive association (0.423) at genotypic level was observed between number of leaves per plant and the dependent trait; which is desirable as the increase in number of leaves per plant helps to increase the yield. Hence, in-order to increase the yield component i.e. total yield per plant we have to select the broccoli genotypes on the basis of independent traits showing positive indirect effects.

Highest indirect effect with positive sign was reported through the character central head weight (0.21219) followed by plant frame (0.12007), lateral head weight (0.08545), TSS (0.03682), leaf width (0.03493), leaf length (0.03171), dry matter (0.02261), lateral head weight (0.08545), number of lateral heads per plant (0.01269), plant height (0.01616) and days to first harvest (0.00736). Whereas, negative indirect effects were seen through the traits *viz.* leaf area (-0.06116), harvest duration (-0.00387), central head size (-0.00330), ascorbic acid (-0.00045) on the dependent trait total yield per plant. Similar findings have been obtained by Nandhini *et al.* (2019) in broccoli and in cauliflower crop by Shruthy and Celine (2018).

4.5.5 Plant height (cm)

The trait plant height (0.11129) showed positive direct effect on dependent trait total yield per plant. However, it showed negative genotypic correlation with the total yield per plant. Therefore selection should be done through the other traits showing negative indirect effects.

The highest negative indirect effects were shown by the traits central head weight (-0.70560) followed by lateral head weight (-0.32238), TSS (-0.16259), days to first harvest (-0.06616), dry matter (-0.04136), leaf area (-0.04076) and number of leaves per plant (-0.01274) thus showing that maximum improvement in the yield can be brought if selection is done through the trait central head weight. Whereas, highest positive indirect effect was observed through the independent trait number of lateral heads per plant (0.48667) followed by the traits *viz.* leaf length (0.07822), leaf width (0.02682), central head size (0.01731), plant frame (0.01061), harvest duration (0.00446) and ascorbic acid (0.00305). Similar, findings have also been reported by Nandhini *et al.* (2019).

4.5.6 Plant frame (cm²)

Plant frame (0.28736) exhibited positive direct effect on the dependent trait i.e. total yield per plant. Similarly, positive association at genotypic level (0.571) was observed between the characters plant frame and total yield per plant which is desirable. Thus selection in this case through the direct effect could be effective, as positive direct effect will make the correlation more positive and hence will help in increasing the yield in the given broccoli genotypes.

Maximum positive indirect effect was shown by the trait central head weight (0.90446) followed by TSS (0.22281), leaf width (0.12018), leaf length (0.07596), lateral head weight (0.06594), dry matter (0.01780), plant height (0.00411) and harvest duration (0.00034). However, negative indirect effects were shown by the characters *viz.* number of lateral heads per plant (-0.54228), days to first harvest (-0.33778), leaf area (-0.18868), number of leaves per plant (-0.03667), central head size (-0.01864) and ascorbic acid (-0.00409). Similar trends in terms of the direct effects were obtained by Pramila *et al.* (2020) in cauliflower crop.

4.5.7 Central head size

The trait central head size (-0.02892) exhibited negative direct effect on the dependent trait total yield per plant in broccoli with respect to the various genotypes studied; which showed that it tends to decrease the genotypic correlation (0.867) with the character total yield per plant i.e. a yield character. Hence, in this case the selection through indirect effect with positive value will lead to increase in the dependent trait.

Positive indirect effect was observed through the characters *viz.* central head weight (1.38919), TSS (0.42756), lateral head weight (0.15794), leaf width (0.10230), plant frame (0.18518), dry matter (0.07427), leaf length (0.02622) and harvest duration (0.00045). Whereas, negative indirect effects on the dependent trait was shown by the independent characters *viz.* number of lateral heads per plant (-0.95690), days to first harvest (-0.30619), leaf area (-0.12403), plant height (-0.06660), number of leaves per plant (-0.01001) and ascorbic acid (-0.00378).

4.5.8 Central head weight (g)

Positive direct effect was shown by the character central head weight (1.45617). Further the positive genotypic correlation (0.870) was observed with the dependent trait total yield per plant by this character; therefore in-order to improve the dependent yield trait the selection through the trait central head weight can be effective.

Positive indirect effects were recorded through the traits *viz.* TSS (0.44643), plant frame (0.17848), lateral head weight (0.11126), leaf width (0.10199), dry matter (0.08815), leaf length (0.03588) and harvest duration (0.00087) on the dependent trait. However, highest negative indirect effect in terms of magnitude was shown by the trait number of lateral heads per plant (-0.97539) followed by days to first harvest (-0.34905), leaf area (-0.12902), plant height (-0.05393), number of leaves per plant (-0.01279), central head size (-0.02759) and ascorbic acid (-0.00139). Similar direct and indirect effects over the dependent trait i.e. total yield per plant were obtained by Nandhini *et al.* (2019) in path analysis studies conducted in broccoli.

4.5.9 Number of lateral heads per plant

Number of lateral heads per plant (0.93736) showed positive direct effect on the dependent trait total yield per plant. Whereas, the character showed negative genotypic correlation (-0.894) with the dependent trait total yield per plant at genotypic level; therefore, in this case increase in the dependent character total yield per plant could be brought directly through the independent trait i.e. number of lateral heads per plant; as the positive direct effect tend to reduce the negative association between the number of lateral heads and the economic character i.e. total yield per plant.

Positive indirect effects on total yield per plant was recorded by the traits *viz.* days to first harvest (0.33699), leaf area (0.11711), plant height (0.05778), central head size (0.02952) and ascorbic acid (0.00228). Whereas, negative indirect effects were observed through the traits like central head weight (-1.51526), TSS (-0.43021), plant frame (-0.16624), leaf width (-0.09315), dry matter (-0.07613), lateral head weight (-0.06483), leaf length (-0.02630), harvest duration (-0.00206) and number of leaves per plant (-0.00119).

4.5.10 Lateral head weight

Lateral head weight (0.41906) reported positive direct effect on the dependent trait total yield per plant. Similarly, positive association at genotypic level (0.699) was observed between the characters lateral head weight and total yield per plant which is desirable. Thus selection in this case through the direct effect will be effective as positive direct effect will make the correlation more positive and hence will help in increasing the yield in the broccoli genotypes.

Maximum positive indirect effect was shown by the trait central head weight (0.38661) followed by days to first harvest (0.16326), leaf area (0.03858), plant frame (0.04522) and dry matter (0.01058). However, negative indirect effects were shown by the characters *viz.* number of lateral heads per plant (-0.14501), plant height (-0.08562), leaf length (-0.04738), leaf width (-0.04057), number of leaves per plant (-0.01789), central head size (-0.01090), harvest duration (-0.01057), ascorbic acid (-0.00360) and TSS (-0.00322).

4.5.11 Days to first harvest

The character days to first harvest showed negative direct effect (-0.46554) on the dependent character total yield per plant. But the trait days to first harvest showed positive association with the trait total yield per plant; which is undesirable as the genotypes with higher yield took longer for the first harvest. Negative direct effect with the economic character total yield per plant tends to make the positive correlation less positive and hence the selection through the trait days to first harvest is effective to develop high yielding genotypes.

Positive indirect effects were reported through the independent traits like central head weight (1.09180), TSS (0.35941), plant frame (0.20850), leaf width (0.11814), leaf length (0.07980), dry matter (0.05710), plant height (0.01582), harvest duration (0.00598), number of leaves per plant (0.00139) and ascorbic acid (0.00083) on the dependent trait total yield per plant. Whereas, negative indirect effects were observed through the independent traits *viz.* number of lateral heads per plant (-0.67853), leaf area (-0.16311), lateral head weight (-0.14696) and central head size (-0.01902). The results obtained were in line to those obtained by Nandhini *et al.* (2019) in broccoli.

4.5.12 Harvest duration

Negative direct effect was observed by the trait harvest duration (-0.01261) on the dependent trait total yield per plant which is not desirable as it tends to make genotypic correlation (0.366) with total yield per plant less positive and thus decreasing the positive association with yield. Therefore, in this scenario selection through positive indirect effects is favorable for improving the dependent trait.

Highest positive indirect effects were observed through characters *viz.* lateral head weight (0.35130), days to first harvest (0.22080), number of lateral heads per plant (0.15285), leaf area (0.03845) and central head size (0.00103). Whereas, negative indirect effects were exhibited through the traits *viz.* TSS (-0.10592), central head weight (-0.10077), leaf width (-0.06029), plant height (-0.03935), leaf length (-0.03660), number of leaves per plant (-0.02691), plant frame (-0.00777), dry matter (-0.00651) and ascorbic acid (-0.00210). Similar results in terms of the direct effects were obtained by Pramila *et al.* (2020) in cauliflower crop.

4.5.13 TSS (°Brix)

Negative direct effect (-0.45521) and negative association (-0.790) was observed by the character TSS with the dependent trait i.e. total yield per plant. Therefore, to improve yield in various broccoli genotypes the selection through the independent trait TSS directly could be effective.

Negative indirect effects were observed through the traits *viz.* central head weight (-1.42809), plant frame (-0.14065), leaf width (-0.09261), dry matter (-0.08729), leaf length (-0.03559) and harvest duration (-0.00293). Whereas, the maximum positive indirect effect was exerted through the trait number of lateral heads per plant (0.88587)

followed by days to first harvest (0.36757), leaf area (0.12120), plant height (0.03975), central head size (0.02716), number of leaves per plant (0.00710), lateral head weight (0.00297) and ascorbic acid (0.00100).

4.5.14 Dry matter (%)

Negative direct effect (-0.09891) and negative association (-0.817) was observed by the character dry matter with the dependent trait total yield per plant. Therefore to improve yield in various broccoli genotypes the selection through the independent traits showing positive direct effect could be effective.

Maximum positive indirect effect on the independent trait total yield per plant was recorded through the trait number of lateral heads per plant (0.72152) followed by days to first harvest (0.26876), leaf area (0.05960), plant height (0.04654), central head size (0.02172) and number of leaves per plant (0.02006). However, negative indirect effects were observed through the traits *viz.* central head weight (-1.29777), TSS (-0.40174), plant frame (-0.05171), leaf width (-0.04905), lateral head weight (-0.04483), leaf length (-0.00810), ascorbic acid (-0.00261) and harvest duration (-0.00083).

4.5.15 Ascorbic acid content (mg/100g)

Ascorbic acid content (-0.01118) observed negative direct effect over the dependent trait i.e. total yield per plant; whereas, it recorded positive genotypic correlation (0.206) with the economic character total yield per plant. Therefore, in-order to increase the dependent character i.e. total yield per plant in various broccoli genotypes the selection through the independent traits showing positive indirect effects could be effective.

Positive indirect effect on the dependent trait total yield per plant was recorded through the independent traits *viz.* central head weight (0.18131), lateral head weight (0.13511), plant frame (0.10521), TSS (0.04073), days to first harvest (0.03443), leaf width (0.02991) and leaf length (0.00400). Whereas, negative indirect effect was exerted by the independent traits *viz.* number of lateral heads per plant (-0.19109), leaf area (-0.05338), plant height (-0.03039), dry matter (-0.02313), central head size (-0.00978), number of leaves per plant (-0.00352) and harvest duration (-0.00236).

Table 4.5 Genotypic path coefficient analysis for direct and indirect effects of component characters on yield in broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

	C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13	C 14	C 15	C 16
C1	0.11393	0.10026	-0.19150	-0.02690	0.02620	0.30312	-0.02597	1.30365	-0.76641	-0.14922	-0.48278	0.00667	0.37005	0.04258	-0.00294	0.621**
C2	0.10467	0.10913	-0.17143	-0.02549	0.07977	0.20001	-0.00695	0.47880	-0.22592	-0.18192	-0.34042	0.00423	0.14844	0.00734	-0.00041	0.180
C3	0.12136	0.10407	-0.17977	-0.02985	0.02523	0.30159	-0.01995	1.04508	-0.61068	-0.08993	-0.42239	0.00270	0.30690	0.03279	-0.00332	0.584**
C4	0.03493	0.03171	-0.06116	-0.08775	0.01616	0.12007	-0.00330	0.21219	0.01269	0.08545	0.00736	-0.00387	0.03682	0.02261	-0.00045	0.423*
C5	0.02682	0.07822	-0.04076	-0.01274	0.11129	0.01061	0.01731	-0.70560	0.48667	-0.32238	-0.06616	0.00446	-0.16259	-0.04136	0.00305	-0.613**
C6	0.12018	0.07596	-0.18868	-0.03667	0.00411	0.28736	-0.01864	0.90446	-0.54228	0.06594	-0.33778	0.00034	0.22281	0.01780	-0.00409	0.571**
C7	0.10230	0.02622	-0.12403	-0.01001	-0.06660	0.18518	-0.02892	1.38919	-0.95690	0.15794	-0.30619	0.00045	0.42756	0.07427	-0.00378	0.867**
C8	0.10199	0.03588	-0.12902	-0.01279	-0.05393	0.17848	-0.02759	1.45617	-0.97539	0.11126	-0.34905	0.00087	0.44643	0.08815	-0.00139	0.870**
C9	-0.09315	-0.02630	0.11711	-0.00119	0.05778	-0.16624	0.02952	-1.51526	0.93736	-0.06483	0.33699	-0.00206	-0.43021	-0.07613	0.00228	-0.894**
C10	-0.04057	-0.04738	0.03858	-0.01789	-0.08562	0.04522	-0.01090	0.38661	-0.14501	0.41906	0.16326	-0.01057	-0.00322	0.01058	-0.00360	0.699**
C11	0.11814	0.07980	-0.16311	0.00139	0.01582	0.20850	-0.01902	1.09180	-0.67853	-0.14696	-0.46554	0.00598	0.35941	0.05710	0.00083	0.466**
C12	-0.06029	-0.03660	0.03845	-0.02691	-0.03935	-0.00777	0.00103	-0.10077	0.15285	0.35130	0.22080	-0.01261	-0.10592	-0.00651	-0.00210	0.366*
C13	-0.09261	-0.03559	0.12120	0.00710	0.03975	-0.14065	0.02716	-1.42809	0.88587	0.00297	0.36757	-0.00293	-0.45521	-0.08729	0.00100	-0.790**
C14	-0.04905	-0.00810	0.05960	0.02006	0.04654	-0.05171	0.02172	-1.29777	0.72152	-0.04483	0.26876	-0.00083	-0.40174	-0.09891	-0.00261	-0.817**
C15	0.02991	0.00400	-0.05338	-0.00352	-0.03039	0.10521	-0.00978	0.18131	-0.19109	0.13511	0.03443	-0.00236	0.04073	-0.02313	-0.01118	0.206

Residual effect: 0.04294

Diagonal figures represent the direct effect.

Where,

C1 Leaf width (cm)

C4 Number of leaves per plant

C7 Central head size (cm²)

C10 Lateral head weight (g)

C13 TSS (°B)

C2 Leaf length (cm)

C5 Plant height (cm)

C8 Central head weight (g)

C11 Days to first harvest

C14 Dry matter (%)

C3 Leaf area (cm²)

C6 Plant frame (cm²)

C9 Number of lateral heads per plant

C12 Harvest duration (days)

C15 Ascorbic acid (mg/100g)

C16 Genotypic correlation coefficient with total yield per plant (g)

Chapter-5

SUMMARY AND CONCLUSION

The present investigation entitled “Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh” was conducted during rabi season of 2021 at the Experimental Research Farm of Department of Vegetable Science, College of Horticulture and Forestry, Neri, District Hamirpur of Himachal Pradesh in order to adjudge the amount of variability present in the various genotypes of broccoli under study.

In all 12 different genotypes of sprouting broccoli including one check variety (Palam Samridhi) were evaluated to carry the present study. The experiment was laid out using Randomized Complete Block Design (RCBD) with three replications of each genotype. The nursey was raised by sowing the seeds on 12th October, 2021 and after four weeks of seed sowing, transplanting was accomplished, 20 plants were planted in each plot of size 1.8 × 2.25 m. The seedlings were transplanted in the field on 11th November, 2021 at a spacing of 45 × 45cm. Proper cultural operations were followed to maintain the healthy plant population. The observations were recorded on traits *viz.* leaf width (cm), leaf length (cm), leaf area (cm²), number of leaves per plant, plant height (cm), plant frame (cm²), central head size (cm²), central head weight (g), number of lateral heads per plant, lateral head weight (g), days to first harvest, harvest duration (days), TSS (⁰B), dry matter (%), ascorbic acid (mg/100g) and total yield per plant (g) in 12 genotypes of broccoli (*Brassica oleracea* L. var. *italica* Plenck.). The observations with respect to 3 qualitative traits leaf shape, color of head and central head compactness were also recorded in the above genotypes of broccoli. During the course of investigation no disease was observed; therefore, no observation was recorded for the character prevalence of diseases (if any). Estimation of the parameters of variability (PCV and GCV), heritability and genetic advance was done for all the quantitative traits under study. Besides this the correlation studies and path analysis studies were conducted to know the association of the various characters and the

contribution of these characters in terms of direct and indirect effects on the genotypic correlation of the character with the dependent trait total yield per plant.

Analysis of Variance (ANOVA) for 12 genotypes depicted that the mean sum of squares due to the genotypes were significant for all the characters indicating presence of considerable variability among the various sprouting broccoli genotypes. No disease incidence was recorded in any of the 12 genotypes of broccoli under natural epiphytotic conditions. Overall mean performance of all the genotypes indicated that the broccoli genotype BR-NERI-9 (412.06 g) recorded highest total yield per plant followed by BR-NERI-8 (360.86), BR-NERI-5 (306.66), BR-NERI-7 (306.6) and BR-NERI-3 (296.46) which was higher than the check variety Palam Samridhi (294.8 g). However, BR-NERI-9 was found to be statistically at par with the genotypes BR-NERI-3, BR-NERI-5, BR-NERI-7, BR-NERI-8, Palam Samridhi; which indicated that all these genotypes were comparable to the check variety Palam Samridhi. The best genotype BR-NERI-9 in terms of total yield per plant was found superior for other horticultural traits *viz.*, number of leaves per plant, central head weight (g), lateral head weight (g), days to first harvest and harvest duration (days).

High magnitude of Genotypic Coefficient of Variation (GCV) and Phenotypic Coefficient of Variation (PCV) were recorded by the traits number of lateral heads per plant (PCV=57.24 and GCV=54.09), central head weight (PCV=58.73 and GCV= 50.09), lateral head weight (PCV=47.04 and GCV= 44.01), harvest duration (PCV=44.18 and GCV= 43.95) and central head size (PCV=39.21 and GCV= 33.89). It was clearly observed that phenotypic coefficient of variation was higher than the genotypic coefficient of variation and the difference among the two coefficients was quite less in magnitude. High level of heritability was exhibited by the traits *viz.*, harvest duration (98.97), dry matter (97.99), TSS (97.07), days to first harvest (96.54) and number of lateral heads per plant (89.28); Whereas the highest genetic advance as *percent* of mean was observed in the traits number of lateral head per plant (105.29), harvest duration (90.08), central head weight (88.01) and the trait lateral head weight (84.83).

TABLE: 5.1 Top five promising genotypes for different characters studied in broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

Sr. No.	Characters	Genotypes
1.	Leaf width (cm)	BR-NERI-8 (19.15), BR-NERI-7 (18.69), BR-NERI-3 (18.32), Pusa Broccoli KTS-1 (17.97) and BR-NERI-10 (17.66)
2.	Leaf length (cm)	BR-NERI-8 (57.42), BR-NERI-7 (51.96), BR-NERI-10 (51.33), BR-NERI-3 (49.92) and Pusa Broccoli KTS-1 (48.47),
3.	Leaf area (cm ²)	BR-NERI-8 (1003.74), BR-NERI-7 (992.56), BR-NERI-3 (896.87), Pusa Broccoli KTS-1(896.86) and Palam Samridhi (878.78)
4.	Number of leaves per plant	BR-NERI-10 (14.26), BR-NERI-9 (13.6), Pusa Broccoli KTS-1 (12.86), BR-NERI-8 (12.8) and BR-NERI-7 (12.4)
5.	Plant height (cm)	BR-NERI-10 (75.06), BR-NERI-8 (68.46), BR-NERI-4 (65.9), BR-NERI-1 (65.28) and BR-NERI-2 (64.33)
6.	Plant frame (cm ²)	Palam Samridhi (3952.66), BR-NERI-10 (3766.73), BR-NERI-7 (3733.66), BR-NERI-3 (3699.73) and BR-NERI-8 (3677.6)
7.	Central head size (cm ²)	BR-NERI-7 (186.15), BR-NERI-8 (183.98), BR-NERI-3 (182.27), BR-NERI-5 (173.5) and Pusa Broccoli KTS-1 (160.45)
8.	Central head weight (g)	BR-NERI-8 (334.13), BR-NERI-7 (282.4), BR-NERI-3 (266.26), BR-NERI-5 (241.66) and BR-NERI-9 (222.8)

TABLE: 5.1 (Continued...) Top five promising genotypes for different characters studied in broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

Sr. No.	Characters	Genotypes
9.	Number of lateral heads per plant	BR-NERI-1 (7.6), BR-NERI-10 (7.4), BR-NERI-4 (7.2), BR-NERI-2 (5.73) and Palam Samridhi (4.53)
10.	Lateral head weight (g)	Palam Samridhi (48.23), BR-NERI-9 (46.26), BR-NERI-5 (39.66), BR-NERI-6 (32.26) and Pusa Broccoli KTS-1 (30.33)
11.	Days to first harvest	BR-NERI-4 (86.53), BR-NERI-5 (88.4), BR-NERI-9 (90.4), BR-NERI-2 (91.26) and BR-NERI-10 (91.4)
12.	Harvest duration (days)	BR-NERI-6 (27.8), BR-NERI-9 (26.66), Palam Samridhi (25.86), Pusa Broccoli KTS-1 (21.06) and BR-NERI-5 (15.066)
13.	TSS (⁰ B)	BR-NERI-10 (9.58), BR-NERI-4 (9.4), BR-NERI-2 (9.36), Palam Samridhi (9.06), BR-NERI-1 (8.84)
14.	Dry matter (%)	Palam Samridhi (17.83), BR-NERI-2 (17.66), BR-NERI-10 (16.80), BR-NERI-4 (16.71) and BR-NERI-1 (15.45)
15.	Ascorbic acid (mg/100g)	BR-NERI-7 (82.06), Palam Samridhi (79.37), Pusa Broccoli KTS-1(71.82), BR-NERI-5 (64.87) and BR-NERI-4 (63.09)
16.	Total yield per plant	BR-NERI-9 (412.06), BR-NERI-8 (360.86), BR-NERI-5 (306.66), BR-NERI-7 (306.6) and BR-NERI-3 (296.46)

Correlation studies revealed that generally the genotypic correlations were higher in magnitude as compared to the phenotypic correlations indicating that apparent association is due to genetic reasons. The most important economic character i.e. total yield per plant showed positive and significant correlations with the traits leaf width (genotypic=0.62), leaf area (genotypic=0.58) number of leaves per plant (genotypic=0.42 and phenotypic= 0.41), plant frame (genotypic=0.57 and phenotypic= 0.33), central head size (genotypic=0.86 and phenotypic= 0.81), central head weight (genotypic=0.87 and phenotypic= 0.87), lateral head weight (genotypic=0.69 and phenotypic= 0.44), days to first harvest (genotypic=0.46 and phenotypic= 0.33) and harvest duration (genotypic=0.36). Whereas, the path analysis studies suggested that the character central head weight (g) showed maximum direct positive effect on the dependent trait total yield per plant followed by number of lateral heads per plant, lateral head weight (g), plant frame (cm²), leaf width (cm), plant height (cm) and leaf length (cm).

CONCLUSION

- On the basis of investigations carried out during the present study, it can be concluded that the genotype BR-NERI-9 (412.06 g) was the best genotype in terms of total yield per plant followed by the genotypes BR-NERI-8 (360.86 g), BR-NERI-5 (306.66 g), BR-NERI-7 (306.6 g) and BR-NERI-3 (296.46 g). These genotypes were also found significantly superior to other genotypes for the traits such as total yield per plant and few other traits like number of leaves per plant, central head weight (g), lateral head weight (g), days to first harvest and harvest duration (days). Therefore, these superior genotypes can be recommended for cultivation or can be used for future breeding programmes after conducting thorough multi-location trials.
- High amount of coefficient of variation was observed for the characters *viz.*, central head size, central head weight, number of lateral heads per plant, lateral head weight, harvest duration, TSS and total yield per plant. However high genetic advance was exhibited by the traits *viz.*, central head size, central head weight, number of lateral heads per plant, central head weight, harvest duration, TSS, ascorbic acid and total yield per plant, high heritability coupled with high genetic advance was observed for

the horticultural traits *viz.* harvest duration, TSS thus the selection was found to be effective for these traits.

- Correlation studies suggested that the most important trait was central head weight as it highly affected the economic trait total yield per plant in the positive direction.
- High significant and positive correlation at genotypic and phenotypic levels of total yield per plant was recorded with number of leaves per plant, plant frame, central head size, central head weight, lateral head weight and days to first harvest.
- Path analysis studies showed that the character central head weight exhibited the maximum direct effect on the economic yield character and hence selection through this trait can help in evolving genotypes with high total yield per plant.

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APPENDIX- 1

Analysis of Variance for various horticultural traits in Broccoli (*Brassica oleracea* L. var. *italica* Plenck.)

Sr. No.	Characters	Mean Sum of squares		
		Replication	Genotype	Error
		2 (Degree of freedom)	11 (Degree of freedom)	22 (Degree of freedom)
1	Leaf width (cm)	0.12	3.05*	1.09
2	Leaf length (cm)	2.61	90.55*	13.00
3	Leaf area (cm ²)	26374.72	38185.44*	9705.11
4	Number of leaves per plant	0.59	3.17*	0.39
5	Plant height (cm)	0.01	220.13*	34.58
6	Plant frame (cm ²)	200789.10	349658.40*	134909.30
7	Central head size (cm ²)	1315.42	6799.59*	689.36
8	Central head weight (g)	543.23	27222.32*	3021.72
9	Number of lateral heads per plant	1.22	16.53*	0.63
10	Lateral head weight (g)	5.29	445.15*	20.14
11	Days to first harvest	3.05	112.21*	1.32
12	Harvest duration (days)	0.13	155.81*	0.53
13	TSS (⁰ B)	0.02	7.31*	0.07
14	Dry matter (%)	0.03	13.01*	0.08
15	Ascorbic acid (mg/100g)	23.17	313.32*	16.28
16	Total yield per plant (g)	1278.90	23230.04*	5152.75

*significant at 5% level of significance

Department of Vegetable Science
College of Horticulture and Forestry, Neri
Dr. Yashwant Singh Parmar University of Horticulture and Forestry
Nauni, Solan (HP) - 173 230 India

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Name of the Student : Shivalika Rani

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Major Advisor : Dr. Shiv Pratap Singh

ABSTRACT

The present study entitled “Genetic variability and character association studies in sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) under low hill conditions of Himachal Pradesh” was conducted during rabi season of 2021 at the Experimental Research Farm, Department of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur (HP). Twelve genotypes of broccoli including check “Palam Samridhi” were evaluated in Randomized Complete Block Design to check the extent of genetic variability, heritability, genetic advance, character association and path coefficient analysis for various horticultural traits including yield. Analysis of Variance indicated significant difference among all the genotypes of broccoli for all the traits studied. Best genotype in terms of total yield per plant was BR-NERI-9 (412.06 g) which was statistically at par with the genotypes BR-NERI-8 (360.86g), BR-NERI-5 (306.66g), BR-NERI-7 (306.6g), BR-NERI-3 (296.46g) and Palam Samridhi (294.80g). The traits *viz.* central head size, central head weight, number of lateral heads per plant, lateral head weight, harvest duration, TSS, and total yield per plant expressed high GCV and PCV values. High heritability was exhibited by the trait harvest duration followed by dry matter, TSS and days to first harvest. However high genetic advance as percentage of mean was observed for the traits central head size, and central head weight, number of lateral head per plant, lateral head weight, harvest duration, TSS, ascorbic acid and total yield per plant. The trait total yield per plant reported positive and highly significant correlation with the traits *viz.*, leaf width, leaf area, plant frame, central head size, central head weight, lateral head weight and days to first harvest. Path coefficient analysis showed positive direct effect on total yield per plant through the traits leaf length, leaf width, plant height, plant frame, central head weight, number of lateral heads per plant and lateral head weight.

Signature of the Student
Name: Shivalika Rani
Date:

Signature of Major advisor
Name: Dr. Shiv Pratap Singh
Date:

Countersigned

Professor and Head
Department of Vegetable Science,
College of Horticulture and Forestry, Neri, Hamirpur

BRIEF BIO-DATA

Name : Shivalika Rani
Father's Name : Mr. Kuldeep Singh
Date of Birth : 11-09-1999
Gender : Female
Marital Status : Unmarried
Nationality : Indian
Educational Qualification :

Certificate/ Degree	Year of Passing	Board/ University	Marks (%)	Class/ Grade
10 th	2014	H.P.B.O.S.E	92.85	First
12 th	2016	H.P.B.O.S.E	80	First
B. Sc. (Hons.) Horticulture	2020	Dr. YS Parmar University of Horticulture and Forestry, Nauni	76.20	First

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(Shivalika Rani)