GENETIC DIVERGENCE STUDIES IN CARROT (*Daucus carota* L.) UNDER LOW HILL REGION OF HIMACHAL PRADESH

Thesis

by

DEEKSHA RANA

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submitted to

Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY SOLAN (NAUNI) H.P-173230,INDIA

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Dr. B.S Dogra
(Principal Scientist)

Department of Vegetable Science
College of Horticulture and Forestry
Dr. Yashwant Singh Parmar University of Horticulture and Forestry
Solan (Nauni) H.P -173230 India

CERTIFICATE - I

This is to certify that the thesis entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** submitted in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (HORTICULTURE) VEGETABLE SCIENCE** in the discipline of **HORTICULTURAL SCIENCES** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) – 173230 is a bonafide research work carried out by **Ms. DEEKSHA RANA (NH-2019-42-M)** daughter of Shri. Gurbaksh Singh under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Neri, Hamirpur
Dated:

(Dr.B.S. Dogra)
Chairman

Advisory committee

CERTIFICATE - II

This is to certify that the thesis entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh**" submitted by **Ms. DEEKSHA RANA (NH-2019-42-M)** daughter of Shri. Gurbaksh Singh to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP) – 173230 India in partial fulfilment of the requirements for the degree of **MASTER OF SCIENCE (HORTICULTURE)** in the discipline of **VEGETABLE SCIENCE** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an Internal Examiner.

29/09/21

Dr. B.S. Dogra

Principal Scientist
Department of Vegetable Science
Major Advisor

29/09/2021

Internal Examiner

29/09/2021

Dean's Nominee

Members of Advisory Committee

29/09/2021

Dr. Shiv Pratap Singh (Associate Professor) Department of Vegetable Science

29.9.2021

Dr. Santosh Kumari
(Senior Scientist)
Department of Vegetable Science

29/9/21

Dr. Monica Sharma
(AssociateProfessor)
Department of Plant Pathology

Professor and Head
Department of Vegetable Science

Countersigned

Dean
College of Horticulture and Forestry Neri, Hamirpur

CERTIFICATE-111

This is to certify that all the mistakes and errors pointed out by external examiner have been incorporated in the thesis entitled **"Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** submitted by **Ms. DEEKSHA RANA (NH-2019-42-M)** daughter of Shri. Gurbaksh 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) in the discipline of VEGETABLE SCIENCE.**

Dr. B.S Dogra
Chairman
Advisory Committee

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

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Place: **(Deeksha Rana)**

Date:

CONTENTS

ABBREVIATIONS AND SYMBOLS

%	:	Per cent
=	:	Equal to
X	:	Multiplication
°C	:	Degree Celsius
ANOVA	:	Analysis of Variance
C.V.	:	Coefficient of Variation
CD	:	Critical Difference
et al.	:	Co-workers
ha	:	hectare
H.P.	:	Himachal Pradesh
i.e.,	:	That is
m^2	:	Meter square
SE	:	Standard Error
UHF	:	University of Horticulture and Forestry
COHF	:	College of Horticulture and Forestry
viz.	:	Videlicet (namely)
PCV	:	Phenotypic Coefficient of Variation
GCV	:	Genotypic Coefficient of Variation
m	:	Meter
cm	:	Centimeter
g	:	Gram
mg	:	Milligram
/	:	Per
GA	:	Genetic Advance
DAS	:	Days after sowing
°B	:	°Brix
TSS		Total soluble solids
O.D		Optical Density

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Chapter - 1

INTRODUCTION

Carrot (*Daucus carota* L.) is one of the important crops of root vegetables grown for its fleshy edible roots. It is a cool-season crop belongs to family Apiaceae with the diploid chromosome number 2n=2x=18. Carrots are native to Southwestern Asia, especially Afghanistan (Banga,1976). It is extensively cultivated in tropical and temperate countries of the world. In India, carrot is commercially grown in the states of Haryana, Andhra Pradesh, Tamil Nadu, Punjab, Karnataka, Uttar Pradesh, and Assam covering an area of 97 thousand hectares with an annual production of 1648 metric tonnes (Anonymous, 2018).Whereas in Himachal Pradesh it occupies an area of 0.38 thousand hectares with an annual production of 7.67 metric tons (Anonymous, 2018).

Carrot is broadly classified into two distinct groups *viz*., Asiatic and European types. The European types are small in size, low yielding, rich in β-carotene, total soluble solids (TSS), and develop roots both under temperate and tropical climate, but set seeds under temperate conditions, as they need cold stimulus for flowering. The Asiatic types are large-sized, more juicy, high-yielding, comparatively poor in quality parameters, but can produce roots and seeds freely under tropical conditions (Gill and Kataria, 1974). Because of their delicious taste, flavour, and nutritional value, carrots hold a prominent role in the market. The tender roots are used to make gajarhalwa, soups, pickles, sweetmeat, pies, and preserves. The roots of black carrots are often used to make a fermented product called Kanji (an appetizing drink).

Carrot is known for its β-carotene and carotenoids content. It is an excellent source of vitamin A and also contains a considerable quantity of thiamine and riboflavin (Salunkhe and Kadam, 1998). Carrot juice helps in the elimination of uric acid and also beneficial for people suffering from gall stones, constipation, kidney dropsy, and heart troubles (Rai and Yadav, 2007). Carrot roots are used to cure ulcers, burns, scalds and jaundice (Rana, 2008). Wider diversity occurs with respect to pigmentation in wild and cultivated carrot roots. The carrot's white, yellow, orange, or red root colour is determined by the carotenoid composition (Nicolle *et al*. 2004; Surles *et al*. 2004). Xanthophylls, lycopene are found in yellow and red carrots, respectively whereas anthocyanin is present in both purple and black carrots, while white carrots are devoid of these pigments (Rubatzky *et al*. 1999) These pigments have powerful antioxidant properties which exert a variety of health-related benefits (Ross and Kasum, 2002).

Despite its economic and nutritional value, India has done little research on varietal production and improvement. As a result, there is a need to investigate the variability of different horticultural traits in carrot genotypes in order to identify superior varieties through introduction, selection, or hybridization. Before commencement of any breeding or crop improvement programme, it is necessary to study variability present in the base population or the genetic material used. Genotypic and Phenotypic coefficient of variation are useful in estimating the amount of variability present in the germplasm. Most of the important characters including marketable yield are primarily governed by quantitative genes and extremely influenced by environmental factors. This complicates the selection process. Thus, knowledge of heritability is essential for measuring the influence of the environment on the expression of different characters.

Heritability is referred as the portion of phenotypic variation which is transmitted from parent to progeny. Higher heritable variation for a character will provide more chances for the improvement of the trait by selection. Heritability estimates might not provide clear predictability of the breeding value. As a result, heritability estimates combined with genetic advance are usually more useful than heritability estimates alone in predicting genetic gain under selection (Johnson *et al*. 1955). Selection of one character affects a number of associated traits, implying the importance of determining the interrelationship of various yield components, both among themselves and with yield. Therefore, correlation analysis plays an important role in plant breeding programmes as it measures the mutual relationship between yield and its related attributes as well as among the attributes. But the relationship between two traits is not so simple such correlations are often resolved into two direct and indirect effects by the path coefficient technique developed by Wright, 1921. Path coefficient studies are more helpful since it provides better picture of direct and indirect associations and identify the most efficient yield contributing character.

Keeping in view the above discussion, the present investigation entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** was carried out at the Experimental Farm of College of Horticulture and Forestry, Neri with the following objectives:

- To assess the performance and the extent of genetic variability, heritability, and genetic advance in various carrot genotypes.
- To find out the correlation among the various yield and yield contributing characters.
- To estimate direct and indirect effects of different characters on yield using path analysis.
- To identify the promising genotype with desirable horticultural traits.

Chapter - 2

REVIEW OF LITERATURE

The knowledge of genetic variances, the association of characters with yield and path coefficients analysis is essential for finding superior varieties with high yield potential and other desirable characters. The relevant literature available on various aspects included in the present study is briefly reviewed under the following subheads:

2.1 Variability parameters

2.2 Correlation Coefficient Studies

2.3 Path coefficient analysis

2.1.Variability parameters:

Genetic variability is the raw material on which selection starts to evolve elite genotypes. Therefore, its understanding is very important for its efficient utilization in crop improvement. Heritability and genetic advance are important selection parameters because they help determine the impact of environment on character expression and the extent to which improvement is possible after selection (Robinson *et al*. 1951). According to, (Liang and Walter, 1968) high heritability along with high genetic advance might be due to the action of the additive genes whereas, the high heritability coupled with low genetic advance might be due to the non-additive gene actions which include dominance and epistasis.

The nature and extent of variability serve as the basis for selection in crop improvement. Allard (1960) claims that yield is a polygenically controlled quantitative character and is heavily influenced by the environment. Partition of observed variability into heritable and non-heritable components is very much essential to acquire a true estimate of genetic coefficient of variation, which is a useful indicator of the magnitude of genetic variance present in the population. Heritability is a good key for transmission of character from one generation to next. Genetic advance refers to the improvement in the mean genotypic value of the selected plants over parental population. High heritability combined with high genetic advance suggests that phenotypic performance-based selection could be used to improve character and helps for the selection of superior genotypes. The studies conducted in carrot concerning genetic variability, heritability, and genetic advance are reviewed here:

Brar and Sukhija (1980) evaluated fourteen cultivars of carrot and observed wide range of variation for different traits. The highest broad sense heritability and genetic advance were observed for leaf length, leaf weight, and root weight. Days to maturity had the lowest genotypic and phenotypic coefficient of variability, while leaf weight had the highest.

Prasad and Prasad (1980) studied genotypic and phenotypic variability in twenty-one genotypes of carrot and observed wide range of variation for root weight/ plant, leaf length, leaf weight, root length, root diameter and number of leaves per plant. High GCV, heritability and genetic advance was recorded for number of leaves per plant, root length, and root diameter.

Nagaraja (1988) assessed variability, heritability, correlations, and path analysis in carrot (*Daucus carota* L.) in thirty-nine genotypes and observed wide range of variation for all the traits studied. Phenotypic coefficient of variation was found to be higher than genotypic coefficient of variation in respect of all the traits studied. High heritability along with high genetic advance was observed for fresh weight of root per plant, root yield, fresh weight of leaves per plant, dry weight of leaves and specific leaf area indicating the role of additive gene controlling these characters. Ahmed and Tanki (1992) worked out heritability and genetic advance for eight different traits in carrot and reported high heritability in a broad sense for leaf length, leaf weight, root weight and root length, while it was lowest for root yield. All the characters showed high genetic advance except root girth.

Anand (2001) assessed thirty genotypes of European carrot to study genetic evaluation and correlation coefficient and observed higher GCV and PCV for root yield per plot and carotene content whereas, high PCV and moderate GCV for root/top ratio. High heritability recorded for root yield per plot, average root weight, days to marketable maturity and carotene content. Bhatia *et al*. (2002) studied thirty-two genotypes of carrot under high temperature conditions and reported wide variation for root length, leaf length, root diameter, root weight, leaf weight , root to top ratio, unmarketable roots, root yield per hectare and TSS.

Singh *et al*. (2005) worked with thirty- two diverse genotypes of Asiatic carrot for estimating the variability for eleven quantitative and qualitative traits of horticultural importance. High heritability estimates were recorded for carotene content, average fresh root weight with leaves, plant height, TSS, and leaf length. High estimates of genetic advance were observed for root weight with leaves and average fresh root weight. The high heritability was coupled with high genetic advance as percent of the mean for average fresh root weight, root weight with leaves, carotene content, and TSS found to be the most reliable selection parameters.

Kaur *et al*. (2005) assessed genetic variability, heritability, and genetic advance for different quality characters in thirty-eight genotypes of carrot and reported remarkable divergence among the genotypes for different traits. The carotene content showed the highest value for the genotypic and phenotypic coefficient of variation, heritability (broad sense), and genetic advance as percent of the mean. Thereby, showing the importance of selection for improving carotene content. Alves *et al*. (2006) assessed genetic parameters associated with traits important in breeding of carrot and recorded values for heritability ranged from 77.6% (for leaf length) to 22.9 % (for root diameter).

Gupta and Verma (2007) studied the genetic variability for eleven characters in twenty-seven genotypes including the F1 hybrid of carrot. Analysis of variance revealed highly significant differences for all the characters. High heritability along with high genetic advance as percent of mean was recorded for top length, net weight/plant, and net root weight/plant, demonstrating additive gene effects and highlighted the importance of selection for the improvement of these traits.

Hussain and Ahmed (2007) studied thirty- two genotypes of carrot and observed significant differences for yield and other components traits viz., flesh thickness, crown girth, petiole length, leaf width, root: top ratio, root forking, root cracking, total plant weight, dry matter content (%), total soluble solids (%) and total carotene content (mg/100g). Higher PCV and GCV was recorded for all the traits except for root diameter, dry matter content, shoot length, and root length. All the characters showed high heritability except for crown diameter, core diameter and TSS.

Vashisht (2007) evaluated thirty genotypes of temperate carrot for yield and its quality attributes and observed significant differences among all the genotypes for all the characters studied. Days to marketable maturity, average root weight, root length, root diameter, core diameter, crown diameter, leaf length, shoulder thickness, root/top ratio and root yield per plot showed high heritability along with high genetic advance.

Yadav *et al*. (2009) observed divergence for various characters in the carrot and a wide variation for all the characters observed. Maximum root weight and yield were recorded in Badau Local Rampal whereas maximum root length was recorded in Doctor Deshi Red. The PCV and GCV varied from 3.71 to 20.88 percent and 2.46 to 15.75 percent, respectively. The highest heritability was recorded for total soluble solids and the lowest heritability was recorded for root length.

Amin and Singla (2010) studied genetic variability, heritability, and genetic advance in forty-eight lines of carrot (*Daucus carota* var. *sativa* L.). High heritability was noticed for plant weight followed by total yield , root weight, and juice yield. Low heritability estimates were recorded for root girth, root to shoot ratio, and core girth. The high genetic advance was observed for marketable yield followed by total yield and root weight whereas it was low for root girth, root to top ratio, and core girth.

Jain *et al*. (2010) showed highly significant differences among the twenty genotypes of carrot for different characters. The highest genotypic coefficient of variation as well as phenotypic coefficient of variation was observed for root weight. Almost all the characters exhibited high heritability. Wide range of genetic advance was also observed for all the characters.

Kumar *et al*. (2010) studied twenty-nine genotypes of European carrot. Genotypes C-15, C-19, C-20, C-21, C-24, C-26, and C-27 were found promising in the study. Mean sum of squares due to genotypes were found highly significant for all the quantitative traits except for days to marketable root. High heritability accompanied with high genetic gain recorded for the characters *viz*., leaf length, root length, core diameter, gross root weight, net root weight, and yield, is an indication of additive gene effect indicating the importance of selection for improvement.

Thakur (2010) evaluated twenty-three diverse carrot genotypes to study genetic variation and association for some horticultural traits in asiatic carrot (*Daucus carota* L.) . Analysis of variance revealed highly significant differences for all the characters. High to moderate GCV and PCV was recorded for total carotene, root: top ratio, marketable yield per plant, total sugars, root diameter, biological yield per plant, leaf length, number of leaves per plant, core diameter and root yield. High heritability combined with high to moderate genetic advance was reported for root: top ratio, marketable yield per plant, biological yield per plant, leaf weight, carotene content, total sugars, leaf length, crown diameter and root yield per plot indicating the additive gene action for the inheritance of these traits.

Gupta *et al*. (2012) assessed one hundred genotypes including F1 hybrids of temperate carrot to look at the genetic variability, correlation, and path coefficient studies for eight characters. Analysis of variance revealed highly significant differences for all the characters. High heritability in association with high genetic advance as percent of mean was observed for top length, gross weight, and net root weight indicating additive gene effects and emphasized the effectiveness of selection for improvement.

Kumar *et al*. (2011) tested twenty-eight diverse genotypes of carrot and suggested that parameters of genotypic and phenotypic coefficients of variation are useful in detecting the amount of variability present in available genotypes. High coefficients of variability (phenotypic and genotypic) were stated for root length, average root weight, total soluble solids, root/top ratio, fiber content, and total sugar. Except for plant emergence and days to marketable maturity, all characters showed high heritability, moderate to high coefficients of variability, and genetic gain, suggesting the role of additive gene action in their inheritance and the possibility of genetic improvement through selection.

Asima *et al*. (2013) evaluated forty-eight diverse genotypes of Asiatic and European carrots for seventeen quantitative and qualitative traits. High heritability estimates were observed for plant weight, root weight, total yield, marketable yield, and juice content. For total yield and marketable yield, high estimates of genetic advance were reported. The high heritability along with high genetic advance as a percentage of the mean was recorded for total yield, marketable yield, plant weight, root weight, and beta carotene content, showing the importance of selection for improvement of these traits.

Priya and Santhi (2015) reported the genotypic coefficient of variance, heritability, and genetic advance in sixteen genotypes of carrot. High heritability along with high genetic advance as a percentage of the mean was reported for traits like leaf carotene, root carotene, total chlorophyll, and root weight.

Thakur and Jamwal (2015) explained the genetic parameters for different characters of twenty genotypes of European carrot. Significant differences were observed for various traits among the genotypes. The phenotypic and genotypic coefficients of variation (PCV and GCV) ranged from 3.42 to 29.60 percent and 2.11 to 28.12 percent, respectively. High genetic advance (GA) as percentage of mean was exhibited for root to top ratio, leaf length, and total sugar content.

Kaurav (2017) studied genetic studies of yield and yield attributing traits in carrot (*Daucus carota* L.) among twenty genotypes of carrot. Wide range of variation was observed for all the traits. The magnitude of genotypic coefficient of variation and GCV was higher than PCV for all the traits. Highest GCV and PCV were recorded for plant height and root yield per plant. High heritability along with high genetic advance as percentage of mean was recorded in number of leaves per plant, root yield per plant and root length.

Poleshi *et al*. (2017) evaluated forty-eight carrot genotypes to work out genetic variability for root traits in carrot (*Daucus carota* L.) and observed significant differences for all the traits among the genotypes indicating the presence of variability and scope for further crop improvement. Wide range of difference between GCV and PCV was observed indicating the high influence of environment on the character expression. Higher heritability and high genetic advance was reported for shoulder length and shoulder width.

Teli *et al*. (2017) estimated genetic variability, heritability, and genetic advance in thirty genotypes of carrot (*Daucus carota* var. *sativa* L.) for fourteen economic characters. Significant differences were observed for various traits among the genotypes. The magnitude of genotypic coefficient of variation (GCV) was lower than the corresponding phenotypic coefficient of variation (PCV) for all the characters which directed the influence of environment on the character expression. Carotene content, root weight per plant, root shoot ratio, yield per hectare, and fresh weight possessed higher values of GCV, heritability, and genetic gain, which showed that these traits can be improved by bringing effective selection.

Begum (2018) studied genetic variability, heritability, and correlation in twenty-one genotypes of carrot. Analysis of variance showed significant variation for all the quantitative traits. GCV and PCV was higher for all the traits studied. Higher heritability accompanied with high genetic advance was recorded for plot yield, five roots weight, and number of petioles.

Meghashree *et al*. (2018) explored genetic variability for different attributes in twenty-five genotypes of carrot (*Daucus carota* L.). Significant variation was observed for all the observations among the genotypes. Root weight, root to top ratio, total yield/plot, total yield/ha, cortex thickness, TSS, β-carotene content, ascorbic acid content, total phenol, protein, root forking, and root splitting showed high genotypic and phenotypic coefficient of variation. High heritability was observed for all the characters except the number of leaves/plant, petiole length, root diameter, root length and days to first root harvest. High genetic advance over mean was observed for all the characters except the number of leaves/plant, petiole thickness, root diameter, root length and days to first root harvest.

Ahmed *et al*. (2019) analyzed genetic variability and the association among the forty genotypes of European carrot (*Daucus carota* L.) for important horticultural traits which showed a wide range of variability. Narrow difference between the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) for all traits indicating the low influence of environmental factors on the expression of characters. High PCV and GCV was recorded for root diameter, root weight, root yield, and flesh thickness. High heritability and moderate to high genetic advance for flesh thickness, root length, and root diameter indicated additive gene action and the potential for improvement through selection.

Kulkarni *et al*. (2019) assessed ninety-six carrot genotypes under tropical conditions for their genetic variability parameters and observations were recorded on eighteen quantitative traits including root and plant morphological traits. Significant differences were observed for all the traits among the genotypes. Genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) was high for all the traits studied. Yield contributing characters like root weight, vegetative weight, harvest index had higher values of GCV, heritability, and genetic gain.

Singh *et al*. (2020) investigated genetic variability, heritability, and genetic gain for different characters in eighty-one lines of carrot (*Daucus carota* var. *sativa* L.). Significant differences were observed for various traits among the genotypes. The magnitude of the phenotypic coefficient of variation (PCV) was higher than the corresponding genotypic coefficient of variation (GCV) for all the characters indicating the influence of the environment on the expression of these characters. Qualitative traits like anthocyanin content (mg/100g), total sugar content (%), carotene content (mg /100g), and dry matter content (%) have higher values of GCV, heritability, genetic advance, and genetic gain.

Thakur (2020) studied genetic divergence in European carrot (*Daucus carota* L.) for various characters in twenty-six diverse genotypes of carrot and observed moderate genotypic and phenotypic coefficient of variation for root yield per plot, root yield per hectare, average root weight, flesh thickness and root top ratio (weight basis). High heritability was recorded for flesh thickness, β-carotene content, crown diameter, root top ratio (length basis), TSS, root diameter, leaf length, root length, root yield per plot, root yield per ha, average root weight and root top ratio (weight basis).

Kumar *et al*. (2021) carried out the investigation to assess the genetic variability, heritability, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and genetic advance among fifteen genotypes of carrot (*Daucus carota* L.) for 19 characters and observe a significant amount of genetic variability among all the characters. The highest genotypic coefficient of variation was found in flesh thickness, followed by net root weight per five plants , β carotene content, yield (q) per hectare and harvest index . High heritability was recorded for core diameter, followed by vitamin A and β carotene content.

2.2. CORRELATION COEFFICIENT STUDIES:

Correlation coefficient analysis plays an important role in plant breeding programmes as it calculates the mutual relationship between yield and its related attributes and among the attributes too. The association of characters may be due to either genetic linkage or pleiotropy (Harland, 1939).

The association between various characters in carrot has been studied by several investigators and the same is reviewed below:

Bhagchandani and Choudhury (1980) studied six inbred lines of carrot and their thirty F1 hybrids. Positive and highly significant phenotypic correlation coefficients of root weight with leaf length, top weight, root length, and diameter of the root. The diameter of root and root length, in turn, had positive and highly significant correlations with top weight and significant with leaf length. Leaf length was found to have a positive association with top weight.

Nagaraja (1988) assessed variability, heritability, correlations, and path analysis in carrot (*Daucus carota* L.) in thirty-nine genotypes. Correlation coefficient analysis showed positive and significant correlation of root yield with root length, root diameter, core diameter, fresh weight of root per plant, top length, number of leaves per plant, specific leaf area, and carotene content at both genotypic and phenotypic level. Mugniev (1991) estimated correlations involving yield components and quality traits in two hundred carrot varieties and observed negative correlations between most of the traits showing evidence of the difficulty of combining high quality and high yield. Though, they have reported a positive correlation between root length and yield.

Anand (2001) assessed thirty genotypes of European carrot to study genetic evaluation and correlation coefficient and revealed that there was a positive and significant association of root yield per plot with root length, root diameter, average root weight and core diameter. Positive and significant association was observed by root length with average root weight, and core diameter, whereas root diameter showed positive and significant association with crown diameter, core diameter and flesh thickness.

Bhatia *et al*. (2002) studied thirty genotypes of carrot and observed that total root yield showed highly significant and positive correlation with root weight, number of leaves per plant, shoot weight per plant, the weight of unmarketable roots per plot, and forking percent. Root weight was positively and significantly correlated with the number of leaves per plant, shoot weight per plant, the weight of unmarketable roots per plot, and forking percent.

Singh *et al*. (2005) studied thirty-two genotypes of carrot and reported that root weight was positively and significantly correlated with plant height, root length, root diameter, pith thickness, number of leaves per plant, and leaf length. Negative and significant association of root weight was observed with TSS and carotene content at both phenotypic and genotypic levels. Alves *et al*. (2006) assessed genetic parameters and correlation studies among different traits in carrot. The magnitude of genotypic, and phenotypic correlations varied greatly. The highest genotypic correlation (0.85) observed between the root weight and root diameter.

Gupta and Verma (2007) studied twenty-seven genotypes including F-1 hybrids of European carrot to investigate the genotypic, phenotypic, and environmental correlation. For most of the characters, genetic correlations were higher than phenotypic correlations, implying an inherent relationship among them. Net marketable root weight per plot expressed positive and significant genotypic association with top length, root girth, net root weight per plant, gross marketable weight per plot, number of marketable roots per plot, and percentage of unmarketable roots.

Vashisht (2007) analysed correlation coefficient in thirty genotypes of temperate carrot and found that root yield per plot showed positive and significant association with average root weight, root length, root diameter, core diameter, crown diameter, leaf length, shoulder thickness, and core diameter. Jadhav (2009) studied correlation coefficient in ten genotypes of carrot for various traits and observed highly positive and significant correlation of root yield with shoot weight, root weight, root length, root diameter, root girth and weight of marketable roots. Yadav *et al*. (2009) observed the correlation coefficient for various characters in carrot. Highly significant and positive correlation was found in root to shoot ratio, and root weight.

Kumar *et al*. (2010) studied twenty-nine genotypes of European carrot and revealed that yield had a positive and highly significant association with all the characters except for the number of leaves per plant, core diameter, and root/top ratio.

Thakur (2010) evaluated twenty-three diverse carrot genotypes to study genetic variation and association for some horticultural traits in asiatic carrot (*Daucus carota* L.). Positive and significant correlation of marketable root yield per plant was observed with root yield per plant, biological yield per plant, root length, root diameter, root: top ratio, and flesh thickness, implying that selection based on these characteristics may be beneficial for increasing root yield.

Gupta *et al*. (2012) studied one hundred genotypes including F1 hybrids of temperate carrot to explore the genetic variability, correlation, and path coefficient for eight characters. The genetic correlations were higher than the corresponding phenotypic ones for most of the characters suggesting an inherent relationship among them. Net marketable root weight/plot showed positive and significant genotypic association with top length, root girth, gross weight/five plants, net root weight/five plants and gross weight/plot.

Vieira *et al*. (2012) estimated correlation coefficient for processing traits in half-sib progenies of tropical-adapted carrot germplasm and recorded that genotypic and phenotypic correlations among quantitative leaf and root traits were low to intermediate indicating that the traits are either independent or loosely linked and controlled by major genetic factors. Positive and significant association was observed between root length and root weight.

Dod *et al*. (2013) analysed the correlation coefficient in twenty genotypes of carrot (*Daucus carota* L.) and revealed that root yield per plant was closely associated with the number of leaves per plant at harvest, fresh weight of leaves, root length, total plant weight, chlorophyll content of leaves and days to harvest. Hence, these characters may be considered while making selection for the improvement of carrot yield.

Priya and Santhi (2015) reported strong positive association of root yield with root carotene, root weight, root length, root diameter, inner core diameter, root forking percentage, root splitting percentage, and leaf carotene. Poleshi (2016) estimated correlation coefficient in forty-eight genotypes of carrot and revealed that root width, shoulder width, xylem width, shoot length had positive and significant correlation with root yield.

Teli (2016) studied character association and path analysis in thirty genotypes of carrot (*Daucus carota* L.). Correlation study revealed that the genotypic correlation coefficient was slightly higher than the corresponding value of phenotypic correlation for the majority of the characters. Fresh weight per plant, root diameter, root: shoot ratio, flesh thickness, and plant height (60 DAS) showed a significant and positive correlation with total yield per hectare both at phenotypic and genotypic levels, whereas plant height (30 DAS) and the number of leaves per plant showed a negative correlation with yield.

Kaurav (2017) studied genetic studies of yield and yield attributing traits in carrot (*Daucus carota* L.) among twenty genotypes of carrot. Correlation coefficient revealed that there was a significant and positive correlation of yield with root length, root diameter, core diameter and pith diameter

Begum (2018) studied genetic variability, heritability, and correlation in twenty-one genotypes of carrot. Positive and significant correlation was recorded for root yield with phloem width, and root weight. While negative correlation was reported for TSS with β-carotene.

Meghashree (2018) analysed correlation coefficient in twenty-five genotypes of carrot (*Daucus carota* L.) and reported high positive and significant association of total root yield/ha with plant height, leaf length, petiole length, root weight, core diameter, core thickness and cortex thickness.

Ahmed *et al*. (2019) studied genetic variability and association among the forty genotypes of European carrot (*Daucus carota* L.) for important horticultural traits. Discovered a wide range of variability for the traits. Higher genotypic correlation revealed an inherent association among the traits. Root yield has a strong character association with root weight, root length, and crown diameter, implying an important role of selection for higher yield.

Kulkarni *et al*. (2019) analysed the correlation coefficient in ninety-six germplasm lines of carrot. Genotypic correlation coefficient study revealed that root weight, root length, leaf width, petiole length, leaf length, and root diameter had a significant positive correlation with yield indicating their effectiveness in selection for higher productivity.

Thakur (2020) studied character association in twenty-six genotypes of European carrot and revealed that yield was positively and significantly associated with average root weight, root length, root diameter, root top ratio (length basis), leaf length, crown diameter and beta carotene content. Kumar *et al*. (2021) analysed correlation coefficient for various characters in fifteen genotypes of carrot and revealed that most of the traits were positively associated with each other. TSS showed positive and significant correlation with root girth.

2.3. PATH COEFFICIENT ANALYSIS:

Path coefficient analysis allows the partitioning of correlation coefficients into direct and indirect effects, and more useful in achieving effective selection of superior genotypes. It is useful in determining whether the association of characters with yield is due to direct effects on yield or is the result of indirect effects through other component characters. Wright (1921) introduced path analysis, which was used for the first time in plant breeding by Dewey and Lu (1959).

Bhagchandani and Choudhury (1980) observed that the diameter of the root had the highest direct effects on yield followed by top weight and root length whereas core diameter had negative direct effects. Nagaraja (1988) assessed variability, heritability, correlations, and path analysis in carrot (*Daucus carota* L.) in thirty-nine genotypes. Path analysis showed that root diameter had maximum positive direct effect on root yield.

Singh *et al*. (1989) evaluated forty genotypes of carrot and observed that root weight had highest positive direct effects on root yield followed by leaf length and root diameter. While maximum negative direct effect on root yield showed by total soluble solids.

Tewatia *et al*. (2000) studied twenty-four lines of tropical carrot along with two check varieties to record observations on root length, shoot length, root diameter, root weight, shoot weight, leaf number, and root: shoot ratio and observed that positive indirect effects of root length via root weight, root weight via root length and root diameter on root yield. Anand (2001) reported that the root diameter and root length showed highest positive direct effects towards root yield per plot.

Bhatia *et al*. (2002) revealed that path analysis can be helpful in selection for the improvement of root quality in early sown carrot based on marketable roots per plot, the weight of marketable roots per plot, root weight, number of leaves per plant, root weight per plant and percentage marketable roots would be more efficient for better quality and root yield.

Gupta and Verma (2007) analysed the path coefficient among twenty-seven carrot genotypes for eleven characters and reported that gross marketable weight/plot had highest positive direct effect on net marketable root weight/plot followed by net root weight/plot, top length, root girth, root to shoot ratio and percentage of unmarketable root. Hence these traits should be given more emphasis while selecting the genotypes for higher yield. Yadav *et al*. (2009) observed the direct effects of root weight on root yield.

Thakur (2010) evaluated twenty-three diverse carrot genotypes to study genetic variation and association for some horticultural traits in asiatic carrot (*Daucus carota* L.) and observed that root yield per plot and biological yield per plant had highest positive direct effects on marketable root yield per plant.

Kumar *et al*. (2011) examined the path analysis in Asiatic carrot and found that plant height had a very high positive direct genotypic and phenotypic effect on root weight followed by leaf weight and root diameter, whereas TSS had negative direct effects on root weight.

Gupta *et al*. (2012) evaluated one hundred genotypes including F1 hybrids of temperate carrot to work out the genetic variability, correlation, and path coefficient for eight characters. Path analysis studies for net marketable root weight/plot revealed that gross weight/plot is the most important yield contributing traits followed by net root weight/five plants and the number of marketable roots/plot . Hence, emphasis should be given to these traits while selecting the genotypes for higher yield. Vieira *et al*. (2012) revealed that there was positive and significant association between root length and root weight which was confirmed by the high direct effect in path analysis.

Priya and Santhi (2015) observed the path analysis in sixteen genotypes of carrot. Path analysis showed a high positive direct effect of plant height, root length, root weight, root forking percentage, root splitting percentage, and total chlorophyll content on root yield.

Thakur and Jamwal (2015) explained the genetic parameters, correlation and path analysis of different characters of 20 genotypes of European carrot. Path analysis revealed that root diameter, root to top ratio, leaf length, TSS, and total sugar content had a high positive direct effect on yield.

Teli (2016) studied character association and path analysis in thirty genotypes of carrot (*Daucus carota* L.) and revealed that root weight, fresh weight per plant, root: shoot ratio, leaf length, flesh thickness, and the number of leaves per plant had a positive direct effect on total yield per hectare. Kaurav (2017) studied genetic studies of yield and yield attributing traits in carrot (*Daucus carota* L.) among twenty genotypes of carrot. Path analysis revealed that root diameter had highest positive direct effects on root yield followed by pith diameter, days to germination, flesh: pith ratio, and leaf: root ratio.

Poleshi (2017) evaluated forty-eight genotypes of carrot under tropical region and revealed that root width, shoulder width, xylem width, shoot length had positive direct effects on root yield by using path analysis. Meghashree (2018) examined path analysis in twenty-five genotypes of carrot (*Daucus carota* L.) and revealed that root weight had high direct effect on total yield/ha. Therefore, selection of these characters would be more useful in the improvement of total yield/ha.

Thakur (2020) studied character association and path analysis in twenty-six genotypes of European carrot and observed that average root weight, root diameter, root top ratio (length basis) and β-carotene had high positive direct effects towards root yield.

Chapter - 3

MATERIALS AND METHODS

The present investigation entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** was conducted from September 2020 to January 2021 at the Experimental Farm of the Department of Vegetable Science at College of Horticulture & Forestry, Neri, Hamirpur, HP. The procedures and materials used during the investigation are listed in detail in this chapter under suitable headings.

3.1 Experimental site

3.1.1. Location

The experiment was conducted at Experimental Farm of Department of Vegetable Science, College of Horticulture and Forestry, Neri, Hamirpur, HP. low hill zone of Himachal Pradesh. The site is located at an altitude of 650 meters above mean sea level, lying between latitude and longitude of **31°41'47.6" North** and **72°28'6.3" East,** respectively under low hill zone of Himachal Pradesh.

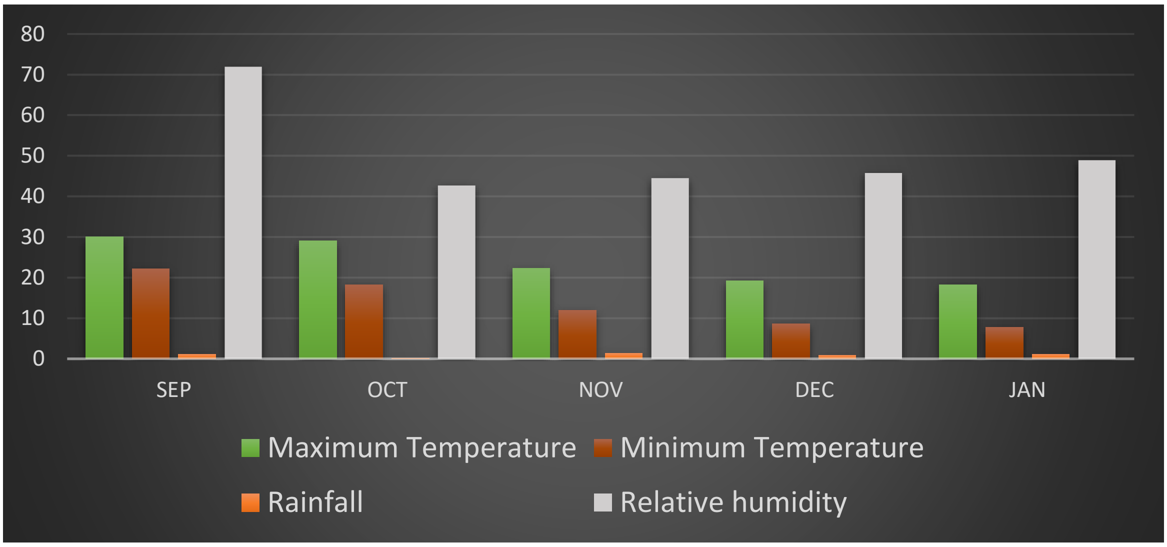
3.1.2 Soil

The experimental field soil was sandy loam that was well-drained, uniformly textured, and had a medium NPK status.

3.1.3. Climate and weather conditions

The place experiences hot summers and mild winters with moderate rainfall of 1200mm of which 80 per cent is received during June to September. The meteorological data pertaining to the different parameters during the crop season such as maximum and minimum temperatures, relative humidity and rainfall were taken at Meteorological observatory, College of Horticulture and Forestry, Neri, Hamirpur (H.P) are presented in (Appendix -I) and Fig 3.1.

Fig. 3.1 Agro-meteorological data during cropping period



Source : Department of soil science and water management, COHF, Neri, Hamirpur, H.P. (177001)

3.2 Experimental materials

Experimental material used in for the present investigation comprises of twenty-three (including the check variety) diverse genotypes of carrot (*Daucus carota* L.) In Table 3.2, the genotypes under study are listed along with their sources.

Table 3.2: List of Genotypes of Carrot along with their source

Sr. no.	Genotype	Source
1.	Kashi Krishna	IIVR, Varanasi
2.	Pusa Yamdagini (check variety)	IARI Regional Station, Katrain
3.	PC-161	PAU, Ludhiana
4.	Nantes	IARI Regional Station, Katrain

5.	**Kashi Arun**	**IIVR, Varanasi**
6.	**Hisar Gairic**	**HAU, Hissar**
7.	**Pusa Nayanjyoti**	**IARI Regional Station, Katrain**
8.	**Pusa Rudhira**	**IARI, New Delhi**
9.	**Laxmangarh Selection**	**National Innovation Foundation**
10.	**Durgapur-4-Red**	**National Innovation Foundation**
11.	**CA-COHFNERI-2**	**Department of Vegetable Science, COH&F Neri, Hamirpur**
12.	**Punjab Black Beauty**	**PAU, Ludhiana**
13.	**CA-COHFNERI-3**	**Department of Vegetable Science, COH&F Neri, Hamirpur**
14.	**CA-COHFNERI-1**	**Department of Vegetable Science, COH&F Neri, Hamirpur**
15.	**Madhuban**	**National Innovation Foundation**

16.	VRCAR-198	IIVR, Varanasi
17.	VRCAR-96	IIVR, Varanasi
18.	VRCAR-160	IIVR, Varanasi
19.	VRCAR 171-1	IIVR, Varanasi
20.	VRCAR-85	IIVR, Varanasi
21.	VRCAR-109	IIVR, Varanasi
22.	VRCAR-184	IIVR, Varanasi
23.	Pusa Vrishti	IARI, New Delhi

3.3 Experimental Layout

The details of experimental layout are given below:

Crop	**Carrot (*Daucus carota* L.)**
Number of treatments	23 (including check)
Design	RCBD
Replications	3
Plot size	1.2 m x 1.0 m
Spacing	30 cm x 10 cm
Date of sowing	26^{th} September 2020
Season	Rabi (2020-21)

3.4 Field Operations:

The experimental field was ploughed and prepared extensively with the help of a tractor and planked before few days of sowing. Blocks, pebbles, and previous crop residues were manually extracted. The field was levelled and brought to a fine tilth for proper water drainage. At the time of field preparation, well-rotten farmyard manure was applied. Plant nutrients *viz*., N, P, K were applied as basal dose as per the package of practices. Plots were laid out according to the layout plan after levelling. Seeds of different genotypes of carrot were directly sown in the field. To ensure healthy crop cultural operations like thinning, hoeing, weeding, earthing up, timely irrigations and plant protection measures were carried out as per package of practices and when required during the entire course of experiment.

Seed sowing

Thinning

Hoeing

Earthing up

Plate :1. Field Operations

3.5 Observations To Be Recorded:

The observations were made on five randomly selected plants in each plot for each replication, and the mean was calculated for statistical analysis. Observations were recorded for the following characters :

3.5.1 Days to 50% germination

From the date of sowing to germination, the days needed for 50% seed germination were calculated.

3.5.2 Plant height at harvest (cm)

At the time of harvest, the length of the plant was measured in centimetres using a meter scale from the distal end of the root to the tip of the main stem.

3.5.3 Leaf length (cm)

Leaf length of each plant was measured from the crown to the tip of the largest leaf (top height). After that, the average was calculated and expressed in centimetres.

3.5.4 Number of leaves per plant

Total numbers of leaves were counted from each randomly selected plants and then the average was calculated.

3.5.5 Root weight (g)

After harvesting, the fresh root weight was weighed on a digital weighing balance, and the average value was measured and expressed in (g).

3.5.6 Root length (cm)

The root length of five plants was measured by metric scale from the base of the shoot to the tip of the root at harvesting time and the average value was calculated and expressed in centimetres.

3.5.7 Root diameter (cm)

At the end of the experiment, the root diameter was measured just below the crown using a vernier calliper, and the average was estimated and expressed in centimetres.

3.5.8 Flesh thickness (cm)

Flesh thickness (Root diameter – Core diameter) of the five selected roots from each treatment and replication was computed with the help of Vernier calliper at the time of harvesting. The mean was recorded for statistical analysis.

3.5.9 Crown diameter (cm)

Five randomly selected plants used for measuring root length were also used to measure crown diameter. Crown diameter was measured from the crown or shoulder portion of the root with the help of digital vernier calliper at harvest time.

3.5.10 Core diameter (cm)

Root core diameter was measured in cm by cutting the root just below the crown end at harvest time.

3.5.11 Root: shoot ratio (on weight basis)

The root : shoot ratio was determined by dividing the average weight of roots by the average weight of shoots for randomly selected plants.

3.5.12 Total yield per plot (kg)

Total yield per plot was computed by weighing the roots obtained from each treatment and its replication.

3.5.13 Total soluble solids [TSS (°B)]

Total soluble solid was calculated using a hand refractometer. The juice from a composite sample of randomly selected roots was squeezed through a double layer of fine mesh muslin cloth, and a drop of clear juice was dropped in the glass of a hand refractometer to calculate total soluble solids (AOAC 1970).

3.5.14 Self core (Yes/No)

The five roots from which the core diameter was taken were also used to observe the self and distinct nature.

3.5.15 Root shape

Root shape has been noted as conical, cylindrical, and tapering based on visual observations at harvesting.

3.5.16 Root colour

The colour of each individual root was visually analysed for recording the root colour of the genotypes at the end of harvest.

3.5.17 Dry matter content (%)

Dry matter content of roots was estimated by drying 50g of the root sample of each genotype. After drying for 2-3 days in sun, and thereafter, in the oven at 50-60 °C and dried until the weight of the sample become constant and expressed in percentage.

$$\text{Dry matter content (\%)} = \frac{\text{Absolute dry weight of sample}}{\text{Initial fresh weight of the sample}} \times 100$$

3.5.18 Days to harvest

Five randomly selected plants in each replication were counted for the total number of days from sowing to last root harvest.

3.5.19 Carotene content (mg/100g)

Total carotenoid was estimated by following the method suggested by AOAC (1990).

Reagents used

(a) Acetone

(b) Na_2SO_4 (Sodium Sulphate)

(c) Petroleum ether

Procedure

2g dry sample of carrot root was taken, and yellow pigment was extracted with 10ml of 3% acetone in petroleum ether with a pinch of Na_2SO_4. The process was repeated 4-6 times to ensure complete extraction of the pigment. The extract was poured in a separating funnel and washed with distilled water 3-4 times to remove the acetone. The lower layer of acetone-water was removed, and the petroleum ether layer was separated out. The volume of the upper yellow layer was made to 50 or 100 ml by adding petroleum ether. The optical density of the yellow pigment was read at 452 nm in a spectrophotometer using petroleum ether as blank.

$$\text{Carotene content (mg/100g)} = \frac{3.857 \times \text{O.D. of sample} \times \text{volume made up} \times \text{dilution} \times 100}{\text{Weight of sample} \times 1000}$$

3.5.20 Incidence of disease (if any)

Throughout the cropping period typical symptoms of diseases of carrot was regularly monitored.

3.6 Statistical Analysis:

The analysis of variance will be carried out as per the procedure given by Gomez and Gomez (1984).

3.6.1 ANOVA for RCBD

Sources of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	F_{cal}
Genotypes (g)	(g-1)	S_g	$\frac{S_g}{(g-1)} = M_g$	$\frac{M_g}{M_e}$
Replication (r)	(r-1)	S_r	$\frac{S_r}{(r-1)} = M_r$	$\frac{M_r}{M_e}$
Error (e)	(r-1)(g-1)	S_e	$\frac{S_e}{(r-1)(g-1)} = M$	
Total	(rg-1)	S_T		

Where,

r = Number of replications,

g = Number of genotypes,

S_r = Sum of squares due to replications,

S_g = Sum of squares due to genotypes,

S_e = Sum of squares due to errors,

S_T = Total sum of squares,

M_r = Mean sum of squares due to replications,

M_t = Mean sum of squares due to treatments,

M_e = Mean sum of squares due to error.

The replication and treatment mean sum of squares was tested against the mean sum of squares due to error by 'F-test' for (r-1), (r-1) (g-1) and (g-1), (r-1) (g-1) degree of freedom for RCBD at 0.05 level of significance.

The calculated F-values were compared with the tabulated F-value. When F-test will be found significant, the critical difference were calculated to find out the superiority of one genotype over the others.

The standard error and citical differences was calculated as follows:

$$SE(m) \pm = \sqrt{M_e / r}$$

$$SE(d) \pm = \sqrt{2\, M_e / r}$$

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

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference

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

3.6.2. Parameters of Variability

The genotypic, and phenotypic, coefficients of variation were estimated as suggested by Burton and De Vane (1953) as follows:

3.6.2.1. Genotypic coefficient of variation (%) = $\frac{\sqrt{Vg}}{\bar{X}}$ X 100

3.6.2.2. Phenotypic coefficient of variation (%) = $\frac{\sqrt{Vp}}{\bar{X}}$ X 100

Where,

V_e = M_e

V_g = Genotypic variance (M_g - M_e)/ r

V_p = Phenotypic variance (V_g + V_e)

$\bar{X}$ = General mean of population

3.6.2.3. Heritability

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

$$\mathbf{H\ (\%) = \frac{Vg}{V_P} \times 100}$$

Where,

H = Heritability (%)

Vg = Genotypic variance [Vg = (Mg- M_e) / r]

V_p = Phenotypic variance (Vg + V_e)

3.6.2.4. Genetic Advance

The expected genetic advance resulting from the selection of five percent superior individuals was conducted as per Allard (1960):

GA = H × $\sigma\rho$ × K

Where,

H = Heritability (%)

σ_ρ = Penotypic standard deviation

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

3.6.2.5. Genetic gain

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

$$GG = \frac{G_A}{G_M} \text{ X } 100$$

Where,

GG = Genetic gain

GA= Genetic advance

GM = Population mean

For categorization of magnitude of different parameters, following limits were used (Warshamana, 2005).

PCV and GCV	>30%	-	High
	15 – 30%	-	Moderate
	<15%	-	Low
Heritability	>80%	-	High
	50 – 80%	-	Moderate
	< 50%	-	Low

Genetic gain >50% - High

25 – 50 % - Moderate

<25% - Low

3.7. Correlation Analysis

The genotypic and phenotypic correlations was calculated as per Al-Jibouri *et al.* (1958) which is as follows:

Source of variati	D.F	Mean sum of squa		Mean sum o square	Variation rat (F - value)
		X	Y		
Replication (r)	(r-1)				
Genotypes (t)	(g-1)	M_g X	M_g Y	M_g XY= MP	MP_1/ MP_2
Error (r)	(r-1)(g-1)	M_e X	M_e Y	M_e XY = MP	

Genotypic, Phenotypic, and environmental co-variance between X and Y characters worked out as under :

Environmental covariance (V_e XY) = MP_2

Genotypic covariance (V_g XY) = ($MP_1 – MP_2$)/ r

Phenotypic covariance (V_p XY) = V_g XY + V_e XY

Where,

V_e XY = Environmental covariance between X and Y

V_g XY = Genotypic covariance between X and Y

$V_p XY$ = Phenotypic covariance between X and Y

Coefficients of correlation :

3.7.1. Phenotypic correlation between characters X and Y:

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

3.7.2. Genotypic correlation between characters X and Y:

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

3.7.3. Environment correlation between characters X and Y:

$$r_e = \frac{Ve\ XY}{\sqrt{Ve\ X \times Ve\ Y}}$$

Where,

V_pXY, $V_g\ XY$, $V_e\ XY$ denotes phenotypic, genotypic, and environmental covariances between characters X and Y, respectively.

V_pX, $V_g\ X$, $V_e\ X$ denotes phenotypic, genotypic, and environmental variances between characters X, whereas,V_pY, $V_g\ Y$, $V_e\ Y$ denotes phenotypic, genotypic, and environmental variances between characters Y.

3.8. Path Coefficient Analysis

The following formula was used for calculating path coefficient analysis suggested by Dewy and Lu (1959). The path coefficient will be obtained by the simultaneous selection of the following equations, which express the basic relationship between genotypic correlation (r) and path coefficient (P)

$r_{14} = P_{14} + r_{12}P_{24} + r_{13}P_{34}$ $r_{24} = r_{21}P_{14} + P_{24} + r_{23}P_{34}$ $r_{34} = r_{31}P_{14} + P_{32} + r_{24}P_{34}$

where r_{14}, r_{24} and r_{34} are the genotypic correlation of component characters with yield (dependant variable) and r_{13}, r_{23}, and r_{24} are genotypic correlations among the component characters (independent variables) and $r_{12}P_{34}$, $r_{13}P_{34}$, $r_{21}P_{14}$, $r_{23}P_{34}$, $r_{31}P_{14}$ and $r_{24}P_{34}$ are indirect effects.

The direct effects will be calculated by the following set of equations:

$$P_{14} = C_{11}r_{14} + C_{12}r_{24} + C_{13}r_{34}$$

$$P_{24} = C_{21}r_{14} + C_{22}r_{24} + C_{23}r_{34}$$

$$P_{34} = C_{31}r_{14} + C_{32}r_{32} + C_{24}r_{34}$$

Where C_{11}, C_{12}, C_{23}, and C_{33} are constants and P_{14}, P_{24} and P_{34} are the estimates of direct effects.

3.8.1. Residual effect

It measures the role of other possible independent variables which were not included in the study on dependent variable. The residual effect was estimated with the help of direct effect and simple correlation coefficients as given below:

$$I = P^2x_4 + P^2{}_{14} + P^2{}_{24} + P^2{}_{34} + 2P_{14}r_{12}P_{24} + 2P_{14}r_{13}P_{34} + 2P_{24}r_{22}P_{34}$$

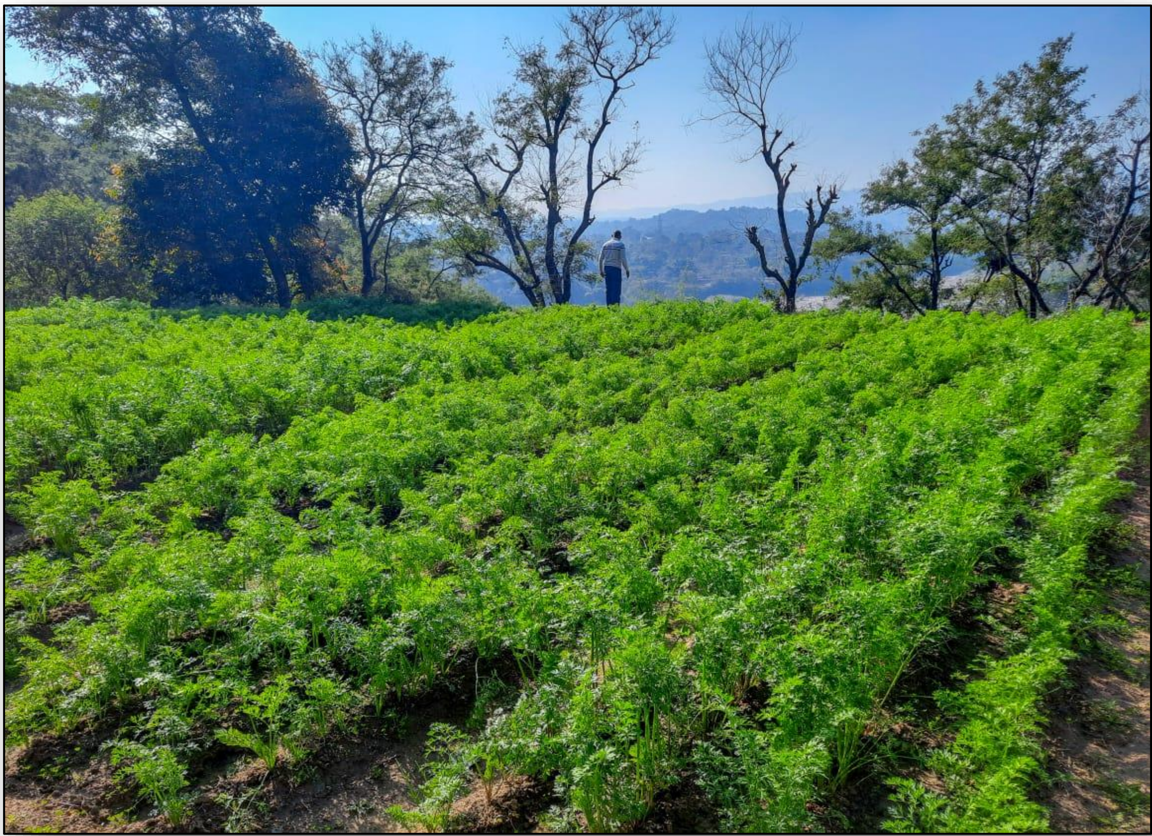


Plate :2. General view of the experimental layout

Chapter – 4

RESULTS AND DISCUSSION

The present investigation entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** was carried out to get information on nature and extent of genetic variability , heritability, genetic advance as percent of mean, correlation coefficients and path analysis among twenty-three genotypes of carrot for root yield and its contributing characters including quality traits so as to select suitable genotypes either for direct introduction or for the further use in breeding programme. The results obtained in the present investigation are presented under the following heads:

4.1 Range and mean Performance of genotypes

4.2 Variability Parameters

4.2.1 Coefficient of variation

4.2.2 Heritability

4.2.3 Genetic advance (as % of mean)

4.3 Correlation Coefficient analysis

4.4 Path coefficient analysis

4.1 Range and Mean Performance of genotypes:

The analysis of variance revealed highly significant differences among the genotypes for all the characters which reflects good deal of variability in the genetical material used as shown in (Appendix -II). Mean performance of the twenty-three genotypes for various characters are depicted and discussed below:

4.1.1 Days to 50% Germination:

Days to 50% germination reflected highly significant differences among the genotypes ranging from 7.00-14.00 days. The genotype Madhuban took 7.00 days to 50% germination which was found statistically at par with eight genotypes including standard check viz, CA-COHFNERI-1 (7.67), Pusa Rudhira (7.67), Hisar Gairic (7.67), Nantes

(7.67), Pusa Yamdagini (7.67), Pusa Nayanjyoti (8.00), CA-COHFNERI-3 (8.33) and Laxmangarh Selection (8.33). While the genotype VRCAR-184 recorded maximum 14.00 days followed by genotype VRCAR-96 (13.67), VRCAR-109 (13.33), and VRCAR-198 (12.67).

4.1.2 Plant height at harvest (cm):

Plant height reflects the growth habit of the plant as well as growing season of the crop. The observations pertaining to plant height revealed significant differences among different genotypes, as shown in (Table 4.1), in which plant height varied from 40.50 to 111.47 cm. Genotype Madhuban revealed the maximum plant height of 111.47 cm which was statistically different from other genotypes. The standard check Pusa Yamdagini recorded a root length of (53.00 cm) which was found statistically at par with Pusa Nayanjyoti (50.57 cm). These results are in agreement with the earlier findings of Meghashree *et al*. (2018), Ahmed *et al*. (2019) and Singh *et al*. (2020).

4.1.3 Leaf Length (cm):

The data presented in table 4.1 reflected significant differences among genotypes for leaf length. The variation for leaf length ranged from 24.73 to 84.03 cm. Leaf length was maximum in Madhuban (84.03 cm) which was found statistically at par with Durgapur-4-Red (73.53 cm). While the minimum leaf length was recorded in Nantes (24.73 cm) which was found statistically at par with two other genotypes including check *viz*., Pusa Nayanjyoti (34.63 cm) and Pusa Yamdagini (32.67cm). The results are in line with those of Poleshi *et al*. (2017), Meghashree *et al*. (2018), and Ahmed *et al*. (2019) who have also reported significant variation for leaf length.

4.1.4 Number of Leaves per plant:

The analysis of variance revealed significant differences for number of leaves per plant which ranged from 5.03 to 12.67. Maximum number of leaves were observed in Pusa Vrishti (12.67), which was statistically found to be differ from other genotypes. While the minimum number of leaves per plant were recorded in standard check Pusa Yamdagini

(5.03) and in Madhuban (5.03) and they were found to be statistically at par with VRCAR-96 (5.50), Pusa Nayanjyoti (5.67) and CA-COHFNERI-2 (6.20). A wide range of variation for number of leaves per plant has also been observed by Teli *et al*. (2017), Meghashree *et al*. (2018), Ahmed *et al*. (2019) and Singh *et al*. (2020) in carrot.

4.1.5 Root diameter (cm):

Root diameter is also an important yield contributing character. Analysis of variance showed divergence for root diameter among the genotypes, ranging from 2.32 to 4.42 cm (Table-4.2). Maximum root diameter (4.42 cm) was observed in Kashi Arun, which was observed statistically at par with four genotypes *viz*., Hisar Gairic (4.02 cm), VRCAR-96 (4.00 cm), CA-COHFNERI-3 (3.98 cm), and Madhuban (3.97 cm).While, the minimum root diameter was observed in Nantes (2.32 cm). Root diameter of 2.87 cm was recorded in Pusa Yamdagini (standard check) which was found to be statistically at par with seven genotypes *viz*., Pusa Rudhira (3.25 cm), CA-COHFNERI-1 (3.21cm), PC-161 (3.09 cm), Pusa Vrishti (2.79 cm), Pusa Nayanjyoti (2.76 cm), VRCAR-184 (2.71 cm) and VRCAR-109 (2.53 cm).The variation for root diameter has also been reported by Thakur and Jamwal (2015), Teli *et al*. (2017), Meghashree *et al*. (2018), Ahmed *et al*. (2019), and Singh *et al*. (2020).

4.1.6 Crown diameter (cm):

Carrots with less crown diameter are preferred in the market. Wide range of variability was observed for crown diameter as shown in the analysis of variance (Table 4.2), which ranged from 2.08 cm (Nantes) to 4.30 cm (Kashi Arun). Minimum crown diameter of 2.08 cm was observed in Nantes which was statistically at par with standard check Pusa Yamdagini 2.09 cm. While the maximum crown diameter of 4.30 cm has been recorded in Kashi Arun. Similar findings are also observed by Poleshi *et al*. (2017), Ahmed *et al*. (2019) and Kulkarni *et al*. (2019).

4.1.7 Core diameter (cm):

Core diameter is an important attribute which reflects the quality of carrot roots. Lesser core or self-cored varieties are much preferred by the consumers. The analysis of variance showed wide differences among the genotypes for core diameter. Nantes recorded the minimum core diameter of 1.02 cm which was statistically at par with eight genotypes including standard check *viz*., Pusa Nayanjyoti (1.09 cm), Pusa Rudhira (1.24 cm), VRCAR-109 (1.25 cm), Pusa Yamadagini (1.39 cm), CA-COHFNERI-2 (1.47 cm), CA-COHFNERI-1 (1.50 cm), VRCAR-184 (1.50 cm), and PC-161 (1.51 cm). Maximum core diameter of 2.11cm was reflected by VRCAR-198 followed by Punjab Black Beauty (2.09 cm), Kashi Arun (2.08 cm) and VRCAR-96 (2.01 cm). Wide range of variability for core diameter had also been reported by Poleshi *et al*. (2017), Meghashree *et al*. (2018), Kulkarni *et al*. (2019), and Singh *et al*. (2020) in carrot.

4.1.8 Flesh thickness (cm):

More phloem to xylem ratio is an important breeding objective in breeding programme of carrots. A wide amount of variation was found among the genotypes for flesh thickness (Table 4.2) ranging from 0.97 to 2.68 cm. Maximum flesh thickness was found in genotype Kashi Arun (2.68 cm) which was observed statistically at par with Madhuban (2.27 cm), CA-COHFNERI-3 (2.25 cm), and Laxmangarh Selection (2.23 cm). while minimum (0.97 cm) value observed in Pusa Vrishti. Pusa Yamdagini (standard check) recorded flesh thickness of 1.48 cm which was found statistically at par with nine genotypes *viz*., VRCAR-184 (1.21 cm), VRCAR-109 (1.29 cm), Nantes (1.3 cm), Punjab Black Beauty (1.35 cm), VRACAR-198 (1.42 cm), PC-161(1.58 cm), Pusa Nayanjyoti (1.66 cm), CA-COHFNERI-1 (1.71 cm), and Kashi Krishna (1.79 cm). Similar findings were also reported by Poleshi *et al*. (2017), Teli et al. (2017), Ahmed *et al*. (2019), and Singh *et al*. (2020).

4.1.9 Root length (cm):

Root length is also an important character affecting the marketable root yield and generally it is directly proportional to the yield. The genotypes under study revealed substantial variability as indicated by significant analysis of variance. The mean value for root length ranged from 15.77 cm to 27.43 cm.

Madhuban exhibited maximum root length (27.43 cm) which was found statistically similar to four genotypes *viz*., Kashi Krishna (26.50 cm), Punjab Black Beauty (26.33 cm), Kashi Arun (25.47 cm) and PC-161 (25.00 cm). While minimum value (15.77 cm) was recorded for Nantes. The check variety Pusa Yamdagini recorded a root length of 20.33 cm which was statistically at par with CA-COHFNERI-1 (22.50 cm), Durgapur-4-Red (22.30 cm), VRCAR-198 (22.07 cm), and VRCAR-85 (21.60 cm), Pusa Rudhira (20.2 cm), VRCAR 171-1 (19.67 cm), CA-COHFNERI-3 (19.60 cm), Pusa Vrishti (19.08 cm), CA-COHFNERI-2 (18.87 cm), VRCAR-96 (18.30 cm) and Pusa Nayanjyoti (15.93 cm) genotypes. Poleshi *et al*. (2017), Teli *et al*. (2017), Meghashree *et al*. (2018), Ahmed *et al*. (2019), Kulkarni *et al*. (2019), and Singh *et al*. (2020) had also reported wide range of variability for root length in carrot.

4.1.10 Root weight (g):

Root weight is an important character as it is directly associated with yield of a genotype. Hence the genotypes bearing maximum root weight is considered to be desirable. Root weight ranged from 50.43 g to 125.20 g with grand mean 85.74 g. Kashi Arun produced maximum root weight (125.20 g) which was found to be statistically at par with five genotypes *viz*., VRCAR-198 (109.93 g), VRCAR-96 (109.2 g), VRCAR-85 (105.2 g), Madhuban (101.3 g) and Durgapur-4-Red (100.43 g). Minimum root weight of 50.43 g was recorded for Nantes (50.43 g) followed by standard check variety Pusa Yamdagini (57.63 g), VRCAR-109 (62.00 g), VRCAR-184 (66.37 g), Pusa Nayanjyoti (68.83 g), Pusa Rudhira (69.30 g) and CA-COHFNERI-2 (72.63 g). These findings are in agreement with results obtained by Poleshi *et al*. (2017), Teli *et al*. (2017), Meghashree *et al*. (2018), Ahmed *et al*. (2019), Kulkarni *et al*. (2019), and Singh *et al*. (2020) who had also reported the variability for root weight in carrot.

Table: 4.1 Mean performances of carrot genotypes for days to 50% germination, plant height (cm), leaf length (cm), and number of leaves per plant traits.

Genotypes	Days to 50% Germination	Plant Height (cm)	Leaf Length (cm)	Number of leaves per Plant
Kashi Krishna	8.67	76.90	50.40	7.27
Pusa Yamdagini	7.67	53.00	32.67	5.03
PC-161	8.67	82.33	57.33	6.70
Nantes	7.67	40.50	24.73	6.27
Kashi Arun	9.00	89.91	64.44	7.30
Hisar Gairic	7.67	88.77	65.10	8.53
Pusa Nayanjyoti	8.00	50.57	34.63	5.67
Pusa Rudhira	7.67	74.90	54.70	6.70
Laxmangarh Selection	8.33	89.10	65.47	7.27
Durgapur-4-Red	9.00	95.83	73.53	8.43
CA-COHFNERI-2	9.00	80.87	62.00	6.27
Punjab Black Beauty	11.00	76.07	49.73	8.53
CA-COHFNERI-3	8.33	87.17	67.57	6.2
CA-COHFNERI-1	7.67	82.67	60.17	6.87
Madhuban	7.00	111.47	84.03	5.03
VRCAR-198	12.67	93.17	71.10	7.03
VRCAR-96	13.67	72.77	54.47	9.67
VRCAR-160	9.33	84.77	61.67	5.50
VRCAR 171-1	11.33	83.97	64.30	7.30
VRCAR-85	12.00	72.10	50.50	9.53
VRCAR-109	13.33	88.33	64.43	7.47
VRCAR-184	14.00	82.43	58.63	7.87
Pusa Vrishti	9.00	72.30	53.22	12.67
Mean	**9.59**	**79.56**	**57.60**	**7.35**
Range	**7.00-14.00**	**40.5-111.47**	**24.73-84.03**	**5.03-12.67**
SE(m)	**0.53**	**4.21**	**4.00**	**0.43**
C.V%	**9.50**	**9.15**	**12.02**	**10.06**
C.D.(0.05)	**1.50**	**12.02**	**11.44**	**1.22**

Table: 4.2 Mean performances of carrot genotypes for root diameter (cm), crown diameter (cm), core diameter (cm), and flesh thickness (cm) traits:

Genotypes	Root Diameter (cm)	Crown Diameter (cm)	Core Diameter (cm)	Flesh thickness (cm)
Kashi Krishna	3.87	3.45	2.08	1.79
Pusa Yamdagini	2.87	2.09	1.39	1.48
PC-161	3.09	2.83	1.51	1.58
Nantes	2.32	2.08	1.02	1.3
Kashi Arun	4.42	4.30	1.74	2.68
Hisar Gairic	4.02	3.47	1.86	2.16
Pusa Nayanjyoti	2.76	3.04	1.09	1.66
Pusa Rudhira	3.25	3.14	1.24	2.01
Laxmangarh Selection	3.82	3.49	1.59	2.23
Durgapur-4-Red	3.54	3.10	1.57	1.98
CA-COHFNERI-2	3.57	3.34	1.47	2.11
Punjab Black Beauty	3.44	3.81	2.09	1.35
CA-COHFNERI-3	3.98	2.91	1.73	2.25
CA-COHFNERI-1	3.21	3.14	1.50	1.71
Madhuban	3.97	3.91	1.70	2.27
VRCAR-198	3.53	3.63	2.11	1.42
VRCAR-96	4.00	3.95	2.01	1.99
VRCAR-160	3.58	3.80	1.58	2.00
VRCAR 171-1	3.78	3.76	1.58	2.20
VRCAR-85	3.87	3.51	1.72	2.15
VRCAR-109	2.53	2.32	1.25	1.29
VRCAR-184	2.71	2.41	1.50	1.21
Pusa Vrishti	2.79	2.61	1.82	0.97
Mean	**3.43**	**3.22**	**1.61**	**1.82**
Range	**2.32-4.42**	**2.08-4.30**	**1.02-2.11**	**0.97-2.68**
SE(m)	**0.19**	**0.03**	**0.17**	**0.16**
C.V%	**9.38**	**1.55**	**18.44**	**15.65**
C.D.(0.05)	**0.53**	**0.08**	**0.49**	**0.47**

4.1.11 Root : shoot ratio:

Root: shoot ratio is an important character because it is associated with the yield. Hence the genotypes bearing maximum root: shoot ratio are considered ideal. Considerable amount of variation was present among the genotypes with respect to root : shoot ratio as shown in (table 4.3) ranging from 0.92 to 4.14. The maximum root: top ratio was recorded in Pusa Nayanjyoti (4.14), and it was found statistically at par with standard check Pusa Yamdagini (3.86), Nantes (3.77) and VRCAR -160 (2.72). The minimum root: shoot ratio was observed in Hisar Gairic (0.92). Significant variation in carrot for root: shoot ratio had also been observed by Thakur and Jamwal (2015), Poleshi *et al*. (2017), Teli *et al*. (2017), Meghashree *et al*. (2018), and Singh *et al*. (2020) in carrot.

4.1.12 Total Yield per plot (kg):

Total yield is one of the utmost important characters in any research programme in which the producers are interested. The observations recorded for this character showed significant variations among various genotypes (Table 4.3), which was ranged from 0.40 kg to 6.00 kg. The highest total yield per plot was found in Madhuban (6.00 kg) followed by Durgapur-4-Red (5.97 kg), Kashi Arun (4.63 kg) and Hisar Gairic (4.87 kg). While the minimum total yield per plot was observed in VRCAR-109 (0.40 kg). The standard check Pusa Yamdagini recorded total yield of 2.57 kg per plot which was statistically similar to nine genotypes *viz*.,VRCAR-160 (3.87 kg), Kashi Krishna (3.60 kg), Pusa Rudhira (3.00 kg), Pusa Nayanjyoti (2.77 kg), CA-COHFNERI-2 (2.15 kg), VRCAR171-1 (2.07 kg), and VRCAR-85 (1.40 kg). These results are similar to the findings of Thakur and Jamwal (2015), Meghashree *et al*. (2018) and Singh *et al*. (2020).

4.1.13 Total soluble solids (°Brix):

The observations recorded on total soluble solids showed significant differences among the genotypes as depicted in the analysis of variance (Table 4.4). It ranged from 4.03-7.00°B. The comparison of mean values for different genotypes revealed that highest total soluble solids was found in Pusa Nayanjyoti (7.00 °B) which was statistically at par with standard check Pusa Yamdagini (6.97 °B). The minimum total soluble solids were recorded in Laxmangarh Selection (4.03 °B) which was statistically at par with VRCAR-

85 (4.13 °B). These findings are in line with those of results obtained by Thakur and Jamwal (2015), Dhillon *et al*. (2016), Teli *et al*. (2017), Meghashree *et al*. (2018), Kulkarni *et al*. (2019), and Singh *et al*. (2020) who had also reported wide range of variability for total soluble solids among the genotypes.

4.1.14 Carotene content (mg/100 g):

Carotene content is also an important quality parameter in carrot as β- carotene is the precursor of vitamin A, and the consumer would prefer the carrot roots rich in carotene. Wide range of variations were observed for carotene content as indicated by the significant analysis of variance. The difference among the genotypes for this character ranged from 2.69- 26.61 mg/100g. Pusa Nayanjyoti recorded maximum carotene content (26.61 mg/100g) which was statistically different from other genotypes. Minimum carotene content was observed in genotype VRCAR-85 (2.69 mg/100g). The standard cultivar Pusa Yamadagini recorded carotene content (19.94 mg/100g) which was at par with Laxmagarh Selection (19.99 mg/100g). These results are in agreement with the earlier findings of Kaur *et al*. (2005), Thakur and Jamwal (2015), Dhillon *et al*. (2016), Teli *et al*. (2017), Meghashree *et al*. (2018), and Singh *et al*. (2020).

4.1.15 Dry matter content (%):

Dry matter content exhibited significant variations among the genotypes under study which ranged from 9.23 to 14.23 per cent. The genotype PC-161 recorded highest dry matter content (14.23 %) while the standard cultivar Pusa Yamdagini exhibited dry matter of 10.46 per cent. The minimum value for dry matter content was recorded for Pusa Nayanjyoti (9.23 %) which was statistically at par with CA-COHFNERI-1 (9.25 %). Results of the present study were in accordance with the findings of Kaur *et al*. (2005), Thakur and Jamwal (2015), Dhillon *et al*. (2016), Teli *et al*. (2017), and Singh *et al*. (2020).

Table: 4.3 Mean performances of carrot genotypes for root length (cm) , root weight (g), root : shoot ratio, and total yield per plot (kg) traits.

Genotypes	Root length (cm)	Root weight (g)	Root : Shoot ratio	Total yield per plot (kg)
Kashi Krishna	26.5	89.10	1.33	3.60
Pusa Yamdagini	20.33	57.63	3.86	2.57
PC-161	25.00	78.63	1.41	4.43
Nantes	15.77	50.43	3.77	1.17
Kashi Arun	25.47	125.2	1.64	4.63
Hisar Gairic	23.67	89.10	0.92	4.87
Pusa Nayanjyoti	15.93	68.83	4.14	2.77
Pusa Rudhira	20.20	69.30	1.68	3.00
Laxmangarh Selection	23.63	94.19	1.53	4.50
Durgapur-4-Red	22.30	100.43	1.19	5.97
CA-COHFNERI-2	18.87	72.63	0.96	2.15
Punjab Black Beauty	26.33	95.75	0.98	4.43
CA-COHFNERI-3	19.60	79.97	1.83	3.97
CA-COHFNERI-1	22.50	81.53	1.78	4.15
Madhuban	27.43	101.30	1.39	6.00
VRCAR-198	22.07	109.93	1.17	0.63
VRCAR-96	18.30	109.20	1.48	0.53
VRCAR-160	23.10	86.00	2.72	3.87
VRCAR 171-1	19.67	94.33	1.22	2.07
VRCAR-85	21.60	105.20	1.77	1.40
VRCAR-109	23.90	62.00	1.18	0.40
VRCAR-184	23.80	66.37	1.10	4.03
Pusa Vrishti	19.08	84.87	1.25	1.07
Mean	**21.96**	**85.74**	**1.75**	**3.14**
Range	**15.77-27.43**	**50.43-125.20**	**0.92-4.14**	**0.40-6.00**
SE(m)	**0.89**	**9.60**	**0.53**	**0.49**
C.V%	**7.02**	**19.39**	**52.59**	**26.89**
C.D.(0.05)	**2.55**	**27.44**	**1.52**	**1.40**

4.1.16 Days to harvest:

The data pertaining to days to root harvest showed significant differences among the genotypes under study which ranged from 85.00-101.67 days. The minimum days to root harvest was taken by Madhuban (85.00) which was statistically different from other genotypes while the maximum days to root harvest recorded for Nantes (101.67). Pusa Yamdagini (standard check) had taken 96.00 days to root harvest. Similar findings were also reported by Thakur and Jamwal (2015), Meghashree *et al*. (2018), and Singh *et al*. (2020).

4.1.17 Root colour:

Carotenoid content in carrot is associated with the colour of the roots. The perusal of data based on visual observations presented in (Table 4.5) revealed different colour intensities and were categorised as Dark Red, Light Red, Red, Light Purple, Black, Orange, and yellow. Twelve genotypes had Red coloured roots, whereas one genotype had Dark Red coloured roots. While three genotypes had Orange coloured roots, and two genotypes had black coloured roots. Yellow colour roots observed in one genotype and Light Purple coloured roots was also observed in one genotype.

4.1.18 Root shape:

Data based on visual observation are presented in (Table 4.5) showed variation w.r.t root shape which were mostly categorized as tapering, conical and cylindrical. Seventeen genotypes had tapering, and four genotypes had conical shape whereas the shape of the roots of two genotypes were cylindrical.

4.1.19 Self-core (Yes/No)

Most of the genotypes was self-core except six genotypes which had distinct core. The observations recorded for this trait are presented in Table 4.5.

4.1.20 Incidence of disease (if any)

The crop was not infected with any disease during crop production.

Table: 4.4 Mean performances of carrot genotypes for TSS (°B), carotene content (mg/100g), dry matter content (%), and days to root harvest traits.

Genotypes	TSS (°B)	Carotene content (mg/100g)	Dry matter content (%)	Days to root harvest
Kashi Krishna	5.60	11.39	10.85	91.67
Pusa Yamdagini	6.97	19.94	10.46	96.00
PC-161	5.83	25.00	14.23	91.67
Nantes	5.93	5.21	10.63	101.67
Kashi Arun	5.90	25.84	10.2	91.33
Hisar Gairic	5.63	3.91	10.26	90.00
Pusa Nayanjyoti	7.00	26.61	9.23	90.00
Pusa Rudhira	5.07	13.94	13.83	90.33
Laxmangarh Selection	4.03	19.99	12.44	91.67
Durgapur-4-Red	5.13	17.00	10.81	91.67
CA-COHFNERI-2	5.00	25.83	10.04	86.33
Punjab Black Beauty	5.43	3.44	10.08	92.67
CA-COHFNERI-3	4.93	23.54	10.20	86.33
CA-COHFNERI-1	4.50	11.28	9.25	90.67
Madhuban	6.03	23.53	10.94	85.00
VRCAR-198	6.03	10.81	11.15	91.67
VRCAR-96	4.97	18.04	13.45	89.67
VRCAR-160	4.97	8.62	10.02	89.67
VRCAR 171-1	5.87	16.72	11.54	88.00
VRCAR-85	4.13	2.69	10.85	87.67
VRCAR-109	5.93	6.49	10.32	90.00
VRCAR-184	6.00	13.44	11.86	88.00
Pusa Vrishti	6.07	17.23	12.05	91.33
Mean	**5.52**	**15.24**	**11.07**	**90.56**
Range	**4.03-7.00**	**2.69-26.61**	**9.23-14.23**	**85-101.67**
SE(m)	**0.05**	**0.11**	**0.04**	**0.42**
C.V%	**1.68**	**1.29**	**0.59**	**0.81**
C.D.(0.05)	**0.15**	**0.32**	**0.11**	**1.20**

Table: 4.5 Mean performances of carrot genotypes for different morphological traits.

Genotypes	Root Shape	Root Colour	Self-core Yes/No
Kashi Krishna	Tapering	Black	YES
Pusa Yamdagini	Slightly tapering	Orange	YES
PC-161	Tapering	Red	YES
Nantes	Cylindrical	Orange	YES
Kashi Arun	Tapering	Red	YES
Hisar Gairic	Tapering	Red	YES
Pusa Nayanjyoti	Cylindrical	Orange	YES
Pusa Rudhira	Tapering	Dark Red	YES
Laxmangarh Selecti	Tapering	Red	YES
Durgapur-4-Red	Tapering	Red	NO
CA-COHFNERI-3	Tapering	Red	NO
Punjab Black Beau	Conical	Black	NO
CA-COHFNERI-2	Tapering	Red	YES
CA-COHFNERI-1	Tapering	Red	YES
Madhuban	Conical	Light Purple	NO
VRCAR-198	Tapering	Light Red	NO
VRCAR-96	Conical	Red	YES
VRCAR-160	Tapering	Yellow	YES
VRCAR 171-1	Conical	Light Red	NO
VRCAR-85	Tapering	Orange	YES
VRCAR-109	Tapering	Red	YES
VRCAR-184	Tapering	Red	YES
Pusa Vrishti	Conical	Red	YES

4.2 Variability Parameters :

The success of any breeding programme for population improvement is determined by variability in the base population and the effectiveness of selection (Kumari *et al*. 2008). The knowledge of various variability parameters i.e phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), general mean, variation range, heritability (in broad sense) , and genetic advance (GA) as per cent of mean are very much useful in predicting the amount of variation present in the given set of genetic material. Therefore, in order to determine the importance and response of selection for various traits in the present studies, the estimates of phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (in broad sense) , and genetic advance (GA) as per cent of mean were worked out and have been presented in Table 4.6.

4.2.1 Coefficient of variation :

Estimation of genetic parameters of variation for yield and its attributes revealed a wide range of variation for the studied characters (Table 4.6). The results showed that the phenotypic coefficient of variation was greater in magnitude than the genotypic coefficient of variation for all of the characters, indicating that there was noticeable variability in the genetic material used, which was not simply due to genotypic effect but also due to the effect of environment. The wide difference in phenotypic and genotypic coefficients of variation indicated their sensitivity to environmental fluctuations, whereas the narrow difference indicated less environmental interference on the expression of these characters. Characters with high phenotypic and genotypic coefficients of variation have ample scope for improvement through selection. Narrow difference between PCV and GCV for a trait means the trait is less affected by the environment. The PCV and GCV for the characters under study are categorized on the scale as low (<15 %) , moderate (15- 30 %), and high (> 30 %) as worked out by Warshamana, 2005.

High magnitude of GCV and PCV were observed for root : shoot ratio (87.02 and 93.87), plant height at harvest (61.99 and 64.49), total yield per plot (52.17 and 58.69), and carotene content (51.39 and 51.40 respectively). These characters with high GCV and PCV can be improved effectively through selection. High GCV and PCV for plant height was observed by Kaurav (2017). Priya and Santhi (2015) observed high GCV and PCV for carotene content in carrot.

High PCV and GCV for carotene content has been reported by Dhillon *et al*. (2016) and Singh *et al*. (2020). Meghashree *et al*. (2018) observed high GCV and PCV for total yield per plot. High PCV and GCV for root : shoot ratio has also reported by Yadav *et al*. (2009).

Moderate magnitude of GCV and PCV were observed for the traits flesh thickness (22.00 and 27.00), number of leaves per plant (22.56 and 24.7), leaf length (22.25 and 25.29),), days to 50% germination (22.04 and 24.00), crown diameter (19.06 and 19.12), root weight (18.57 and 26.85), core diameter (15.39 and 24.02), root diameter (15.38 and 18.02 respectively). Meghashree *et al*. (2018) reported moderate GCV for core diameter, and leaf length. Moderate PCV and GCV for number of leaves per plant had been reported by Kaurav (2017). Kumar *et al*. (2010) observed moderate GCV for root diameter in carrot. Thakur (2010) reported moderate PCV and GCV for root diameter in carrot and for leaf length. Moderate GCV for flesh thickness was similar to the findings of Teli *et al*. (2017). Thakur (2010) observed moderate GCV and PCV for core diameter.

The low magnitude of GCV and PCV was observed for root length (14.10 and 15.76), total soluble solids (13.80 and 13.90), dry matter content (12.22 and 12.23), and days to harvest (3.73 and 3.82 respectively). Dhillon *et al*. (2016) reported low PCV for total soluble solids. Low GCV for days to root harvest and for root length has also been reported by Meghashree *et al*. (2018). Thakur (2010) reported low GCV and PCV for dry matter content.

4.2.2 Heritability:

Studies on genetic coefficient of variation aid in determining the range of genetic variability for a given character and comparing the variability found in different characters. Although, genetic variability alone cannot be used to determine heritable variation. Burton and De Vane (1953) suggested that GCV along with heritability gives a better idea about the efficiency of selection. Heritability is referred as the portion of phenotypic variation which is transmitted from parent to progeny. Selection is more effective for improvement of a trait with high heritability.

Heritability for the characters under study are categorized as high (>80%), moderate (50- 80%) and low (<50%) . In the present investigation, the range of heritability for various characters under study was observed from 41.06 to 99.94 % (Table 4.6). High heritability was recorded for the characters viz., carotene content (99.94%), dry matter content (99.77%), crown diameter (99.35%), total soluble solids (98.55%), days to harvest (95.56), plant height at harvest (92.38%), root : shoot ratio (85.94%), days to 50% germination (84.34%), number of leaves per plant (83.4%), and root length (80.13%). Moderate heritability recorded for total yield per plot (79.01%), leaf length (77.4%), root diameter (72.9%), and flesh thickness (66.4%). Low heritability was reported for root weight (47.85%), and core diameter (41.06%). Characters having high heritability are less influenced by the prevailing environment whereas traits with moderate and low heritability have pronounced effect of environment for their expression. Selection is more effective for improvement of a trait with high heritability.

High heritability for carotene content, dry matter content and for days to harvest was also reported by Singh *et al.* (2020). Ahmed *et al*. (2019) reported high heritability for root length. Teli *et al*. (2017) observed high heritability for TSS, root : shoot ratio and for days to 50% germination. Further, Kulkarni *et al*. (2019) reported high heritability for root length and low heritability for core diameter. High heritability for crown diameter, moderate heritability for flesh thickness and low heritability for root weight also reported by Poleshi *et al*. (2017). Meghashree *et al*. (2018) observed high heritability for plant height and moderate heritability for root diameter. High heritability for number of leaves per plant and moderate heritability for leaf length was also recorded by Teli *et al*. (2017).

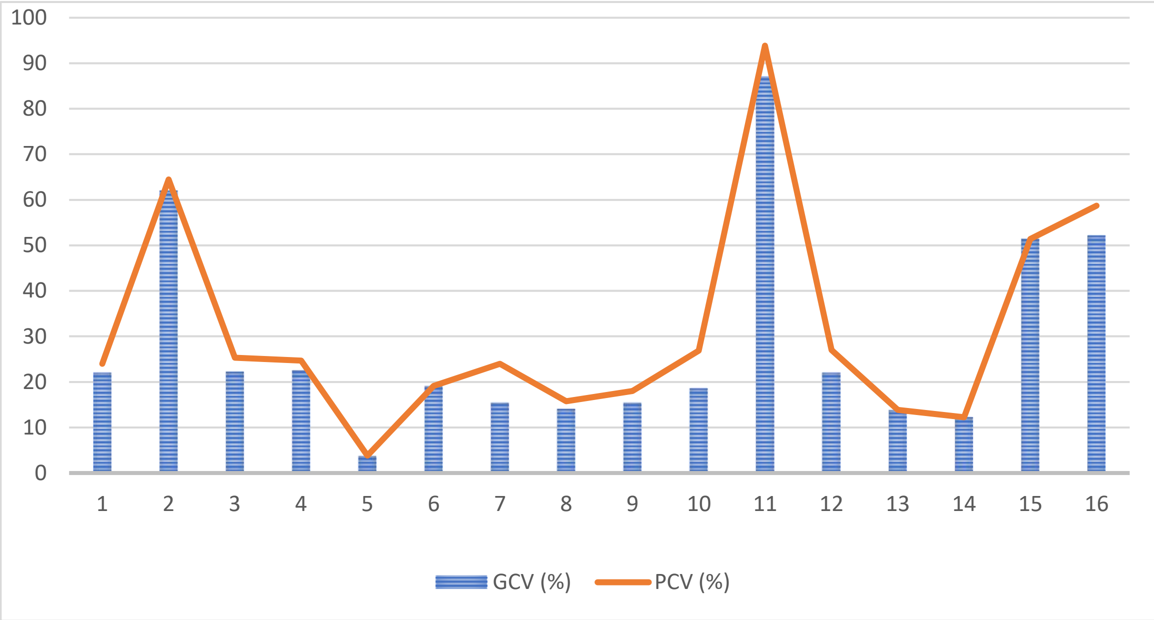
4.2.3 Genetic advance (as % of mean):

The phenotypic superiority of selected plants over the original population is not solely due to their genotype superiority. It may be due to favourable environmental factors. So, heritability estimates alone are not reliable. Genetic advance in some cases gives good idea for the actual position. Improvement in the mean genotypic value of the selected plants over base population is known as genetic advance. Genetic advance depends upon heritability of the character under selection, genetic variability of genotypes and intensity of selection. Johnson *et al*. (1955) suggested that characters with high heritability coupled with high genetic advance would response to selection better than those with high heritability and low genetic advance. High heritability along with high genetic advance shows that characters were governed mainly due to additive gene effect and therefore selection might be effective for these traits.

Genetic advance was calculated as per cent mean for yield and its components which is presented in Table 4.6 and shown in Fig.3, and it was recorded in a range of 7.52% to 166.18%. The highest genetic advance as per cent of mean (genetic gain) was recorded for the traits root : shoot ratio (166.18%), followed by plant height at harvest (122.73%), carotene content (105.82%), and total yield per plot (95.53%). Similar findings have also been reported by Meghashree *et al*. (2018) who observed high genetic advance for plant height, total yield per plot, and for carotene content. Teli *et al*. (2017) reported high genetic gain for root : shoot ratio.

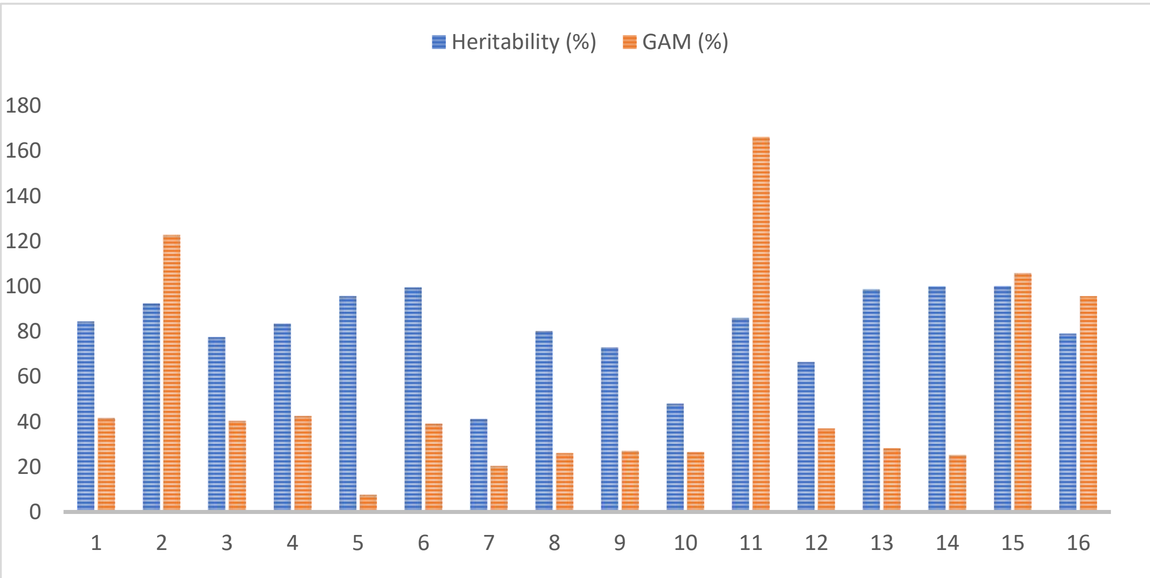
Moderate genetic gain calculated for number of leaves per plant (42.43%), days to 50% germination (41.69%), leaf length (40.32%), crown diameter(39.13%), flesh thickness(36.93%), total soluble solids (28.22%), root diameter (27.06%), root weight (26.46%), root length (26.01%), and dry matter content (25.13%). Teli *et al*. (2017) reported moderate genetic advance for number of leaves per plant, days to 50% germination, flesh thickness, total soluble solids, and root diameter. Moderate genetic gain for dry matter content has also been observed by Kaur *et al*. (2005). Meghashree *et al*. (2018) reported moderate genetic advance for root length. Kaurav (2017) reported moderate genetic advance for root weight. Low genetic advance as per cent of mean was reported for core diameter (20.31%) and days to harvest (7.52%) which indicates the preponderance of non- additive gene action and selection based on these parameters found not effective. Meghashree *et al*. (2018) reported low genetic advance for days to harvest.

Fig. 3.2 Genotypic and Phenotypic coefficient of variability for different traits in carrot.



Where , 1 = Days to 50% germination, 2 = Plant height at harvest (cm), 3 = Leaf length (cm), 4= Number of leaves per plant, 5 = Days to harvest, 6 = Crown diameter (cm), 7 = Core diameter (cm), 8 = Root length (cm), 9 = Root diameter (cm), 10 = Root weight (g), 11 = Root : shoot ratio, 12 = Flesh thickness (cm), 13 = Total soluble solids (°B), 14 = Dry matter content (%), 15 = Carotene content (mg/100g), 16 = Total yield per plot (kg).

Fig. 3.3 Estimates of heritability and genetic advance as percent of mean for different traits in carrot



Where , 1 = Days to 50% germination, 2 = Plant height at harvest (cm), 3 = Leaf length (cm), 4= Number of leaves per plant, 5 = Days to harvest, 6 = Crown diameter (cm), 7 = Core diameter (cm), 8 = Root length (cm), 9 = Root diameter (cm), 10 = Root weight (g), 11 = Root : shoot ratio, 12 = Flesh thickness (cm), 13 = Total soluble solids (°B), 14 = Dry matter content (%), 15 = Carotene content (mg/100g), 16 = Total yield per plot (kg).

Table 4.6 Estimation of range, phenotypic and genotypic coefficients of variation, heritability, and genetic advance as % of mean.

Sr. No.	Characters	Mean	Range		Coefficient of variation (%)		Heritability (%)	Genetic Advance as % of mean (%)
			Minimum	Maximum	Genotypic	Phenotypic		
1	Days to 50% germination	9.59	7.00	14.00	22.04	24.00	84.34	41.69
2	Plant height at harvest (cm)	79.56	40.50	111.47	61.99	64.49	92.38	122.73
3	Leaf length (cm)	57.60	24.73	84.03	22.25	25.29	77.40	40.32
4	Number of leaves per plant	7.35	5.03	12.67	22.56	24.70	83.40	42.43
5	Days to root harvest	90.56	85.00	101.67	3.73	3.82	95.56	7.52
6	Crown diameter(cm)	3.22	2.08	4.30	19.06	19.12	99.35	39.13
7	Core diameter(cm)	1.61	1.02	2.11	15.39	24.02	41.06	20.31
8	Root length(cm)	21.96	15.77	27.43	14.10	15.76	80.13	26.01
9	Root diameter(cm)	3.43	2.32	4.42	15.38	18.02	72.90	27.06
10	Root weight (g)	85.74	50.43	125.20	18.57	26.85	47.85	26.46
11	Root : shoot ratio	1.75	0.92	4.14	87.02	93.87	85.94	166.18
12	Flesh thickness (cm)	1.82	0.97	2.68	22.00	27.00	66.40	36.93
13	TSS (ºB)	5.52	4.03	7.00	13.80	13.90	98.55	28.22
14	Dry matter content (%)	11.07	9.23	14.23	12.22	12.23	99.77	25.13
15	Carotene content (mg/100g)	15.24	2.69	26.61	51.39	51.40	99.94	105.82
16	Total yield per plot	3.12	0.40	6.00	52.17	58.69	79.01	95.53

4.3 Correlation Coefficient analysis :

Yield is a complex quantitative character, being controlled by a number of characters, hence, yield can be improved by rigorous selection. The effect of the component characters on yield can be studied by correlation analysis programme for bringing genetic improvement in the crop. It gives an idea about the linear association among characters and help us to identify the most important characters to be considered for effective selection for increasing yield and its quality. A few of the component traits may be directly and positively associated with yield and often provide chances of improvement through selection. Knowledge of association between traits serve important purpose for the breeder because all the phenotypic traits are the result of interplay of several genetic factors among themselves and their individual and combined interaction with the environmental factors.

In the present study, in general, trend revealed that genotypic correlation coefficients were higher in magnitude than phenotypic correlation coefficients for all the characters, which meant that environment played lesser role in governing the phenotype of the carrot genotypes studied. Yield improvement could be achieved through the characters which have significant and positive correlation with yield. The correlation coefficients between the characters at both genotypic and phenotypic levels were estimated and are presented in Table 4.7 and 4.8, respectively.

4.3.1 Phenotypic correlations:

Perusal of data from Table 4.8 expressed that total yield per plot showed positive and significant correlation with the traits *viz*., plant height at harvest (0.685), root length (0.535), leaf length (0.338), root diameter (0.308), flesh thickness (0.289) and crown diameter (0.258) while it had negative and significant association with days to 50% germination (-0.424), number of leaves per plant (-0.261), and root : shoot ratio (-0.559). Carotene content showed positive and significant association with plant height (0.382), and flesh thickness (0.293) whereas it showed negative significant association with days to 50% germination (-0.302), number of leaves per plant (-0.280), days to harvest (-0.290), and root : shoot ratio (-0.311). Dry matter content had positive and significant association with number of leaves per plant (0.265). Total soluble solids exhibited positive and significant association with days to harvest (0.268) while negative and significant correlation was obtained for leaf length (-0.291), crown diameter (-0.353), root diameter (-0.398), root weight (-0.254) and flesh thickness (-0.383).

Positive and highly significant association of flesh thickness was observed with root diameter (0.779), crown diameter (0.601), root weight (0.398), leaf length (0.522), and plant height at harvest (0.350) while with days to 50 % germination (-0.298), days to harvest (-0.406) and root : shoot ratio (-0.267) it showed negative and significant association. . Root : shoot ratio had positive and significant association with days to 50 % germination (0.705) while it expressed negatively significant association with plant height (-0.917). Root weight was correlated significantly positive with crown diameter (0.701), root diameter (0.740), core diameter (0.676), leaf length (0.455), and root length (0.386) while it had negative and significant association with days to harvest (-0.264). Positive and significant correlation of root diameter was reflected with crown diameter (0.776), core diameter (0.609), leaf length (0.544), root length (0.387) and plant height at harvest (0.327) while it had negative and significant association with days to harvest (-0.439). Root length revealed positive and significant association with leaf length (0.484), core diameter (0.420), crown diameter (0.356), and plant height at harvest (0.344) and had negative and significant correlation with days to harvest (-0.239).

Positive and significant correlation was exhibited by core diameter with crown diameter (0.477), leaf length (0.400), number of leaves per plant (0.279), and days to 50 % germination (0.245). Crown diameter had positive and significant association with leaf length (0.468) and negatively significant association with days to harvest (-0.441). Days to harvest showed negative and significant association with leaf length (-0.621). Positive and significant association of number of leaves per plant was observed with days to 50% germination (0.384) while it showed negative and significant correlation with plant height at harvest (-0.267). Significant positive association of leaf length was observed with plant height (0.298). Plant height had negative and significant association with days to 50% germination (-0.698).

4.3.2 Genotypic correlations:

Genotypic correlations provide measures of genetic association between characters and is more reliable than phenotypic correlation and thus helps to identify the characters to be utilized in breeding programme.

The data represented in Table 4.7 revealed that total yield per plot was positively and significantly correlated with plant height at harvest (0.813), root length (0.626), flesh thickness (0.513), leaf length (0.463) and root diameter (0.421) while days to 50% germination (-0.550), number of leaves per plant (-0.303) and root : shoot ratio (0.714) showed negative significant correlation with total yield per plot. Carotene content exhibited positive and significant association with plant height (0.397), flesh thickness (0.358) and total soluble solids (0.237) whereas it showed negative significant association with days to 50% germination (-0.327), number of leaves per plant (-0.308), days to harvest (-0.296), and root : shoot ratio (-0.334). Positive and significant association of dry matter content was observed with number of leaves per plant (0.293). Total soluble solids had positive and significant association only with days to harvest (0.272) while negative and significant correlation was obtained for leaf length (-0.353), crown diameter (-0.357), core diameter (-0.281), root diameter (-0.483), root weight (-0.379) and flesh thickness (-0.463).

Positive and highly significant association of flesh thickness was observed with root diameter (0.893), crown diameter (0.737), root weight (0.673), leaf length (0.522), plant height at harvest (0.472), and core diameter (0.288) whereas, with days to 50 % germination (-0.255), number of leaves per plant (-0.306), days to harvest (-0.492) and root : shoot ratio (-0.354) it showed negative and significant association. Root : shoot ratio had positive and significant association with days to 50 % germination (0.819) and number of leaves per plant (0.308) while it expressed negatively significant association with plant height at harvest (-0.975). Root weight was correlated significantly positive with crown diameter (0.998), root diameter (0.888), core diameter (0.805), leaf length (0.652), root length (0.440), number of leaves per plant (0.422) and days to 50 % germination (0.238). Positive and significant correlation of root diameter was obtained with crown diameter (0.902), core diameter (0.689), leaf length (0.592), root length (0.386) and plant height at harvest (0.377) while it had negative and significant association with days to harvest (-0.527). Root length revealed positive and significant association leaf length (0.580), core diameter (0.536), crown diameter (0.392), and plant height at harvest (0.377) and had negative and significant correlation with days to harvest (-0.243). Positive and significant correlation was exhibited by core diameter with crown diameter (0.731), number of leaves per plant (0.600), leaf length (0.418), and days to 50 % germination (0.349) while it was negatively significant correlated with days to harvest (-0.327). Crown diameter showed positive and significant association with leaf length (0.527) and negatively significant association with days to harvest (-0.451). Days to harvest showed negative and significant association with leaf length (-0.716). Positive and significant association of number of leaves per plant was observed with days to 50% germination (0.408) while it had negative and significant correlation with plant height at harvest (-0.284). Leaf length had positive association with plant height (0.254). Negative and significant association of plant height at harvest was observed with days to 50% germination (-0.771).

Corresponding to the results of present study, positive and significant correlation of root yield with root length, crown diameter, and flesh thickness at both genotypic and phenotypic level had been reported by Ahmed *et al*. (2019). Teli (2016) revealed positive and significant association of total yield with root length, root diameter, leaf length, plant height, and flesh thickness. Similar results exhibiting significant positive association of root yield with plant height had been reported by Singh *et al*. (2005). Leaf length, root length, and root diameter expressed positive and highly significant association with total yield per plot in carrot as reported by Thakur and Jamwal (2015) and Kulkarni *et al*. (2019). Root yield showed positive and significant association with root length and root diameter which was reported by Priya and Santhi (2015). Yadav *et al*. (2009) recorded significant positive association of leaf length and root length with root yield. Root yield per plot showed positively and significant correlation with root length, root diameter, crown diameter and flesh thickness which was observed by Thakur (2010) in her findings. Singh *et al*. (2005) and Teli (2016) recorded positive and significant correlation of root length with plant height. Root weight showed positive and significant association with root diameter and flesh thickness which was similar to the findings of Teli (2016). Singh *et al*. (2005) recorded positive and significant correlation of root diameter with flesh thickness also by Kumar *et al*. (2010) and Kumar *et al*. (2011) who observed similar results in carrot. Total soluble solids showed positive and significant correlation with days to harvest which was similar to the results obtained by Kulkarni *et al*. (2019). Among the yield contributing characters root diameter with core diameter, root length with leaf length showed significant and positive correlation which was similar to the findings of Bhatia *et al*. (2002).

4.4 Path coefficient analysis:

Path coefficient analysis is simply a standard partial regression coefficient which splits the genotypic correlation coefficient into direct and indirect effects on yield. It is useful in finding out whether the association of characters with yield is due to their direct effects on yield or is consequences of their indirect effects via other component characters. In the present investigation, total yield per plot has been used as dependable variables with other traits. Since the values of genotypic path correlation coefficient are more reliable in predicting the correct idea about the direct and indirect effect of the component traits, only this has been discussed below in Table 4.9.

4.4.1 Days to 50% germination:

Negative direct effect was observed on total yield per plot through days to 50% germination (-0.1162). High indirect effect on days to 50% germination was seen through root : shoot ratio (0.9252) followed by root weight (0.1266), core diameter (0.1226), carotene content (0.0769), days to harvest (0.0652), number of leaves per plant (0.0632), root diameter (0.0550), root length (0.0271) and dry matter content (0.0045). Whereas, negative indirect effects were observed through total soluble solids (-0.0092), crown diameter (-0.0317), leaf length (-0.0869), flesh thickness (-0.4847) and plant height at harvest (-1.2889).

4.4.2 Plant height at harvest (cm):

Plant height showed positive direct effect on total yield per plot (1.6710). Positive indirect effects were seen via flesh thickness (0.8976), root length (0.2458), days to 50 % germination (0.0896), root weight (0.0611), days to harvest (0.0155) and negative indirect effects were observed through core diameter (-0.0015), dry matter content (-0.0023), total soluble solids (-0.0530), number of leaves per plant (-0.0441), crown diameter (-0.0722), carotene content (-0.0933), leaf length (-0.1497), root diameter (-0.6801) and root : shoot ratio (-1.1023) as similar to those of Singh *et al*. (2005), Kumar *et al*. (2011), and Priya and Santhi (2015).

4.4.3 Leaf length (cm):

Negative direct effect of leaf length (-0.5884) was observed on yield per plot. High indirect effects were seen through flesh thickness (0.9923), plant height at harvest (0.4252), root length (0.3783), root weight (0.3477), days to harvest (0.2130), core diameter (0.1469), number of leaves per plant (0.0095), root : shoot ratio (0.0036), dry matter content (0.0019) and negative effect was observed through days to 50 % germination (-0.0172), carotene content (-0.0425), total soluble solids (-0.0530), crown diameter (-0.219) and root diameter (-1.1329). Similar results were also reported by Gupta and Verma (2007), Thakur and Jamwal (2015), and Teli (2016).

4.4.4 Number of leaves per plant:

Number of leaves per plant showed positive direct effect (0.1550) on yield per plot. Root : shoot ratio (0.3481), core diameter (0.2110), root weight (0.2251), carotene content (0.0723), dry matter content (0.0068), days to harvest (0.0055) had indirect effect on number of leaves per plant. Negative indirect effect was observed through crown diameter (-0.2110), leaf length (-0.0359), total soluble solids (-0.0332), root length (-0.0345), days to 50 % germination (-0.0474), root diameter (-0.0980), plant height at harvest (-0.475), and flesh thickness (-0.5816) as reported by Bhatia *et al*. (2002), Singh *et al*. (2005) and Ahmed *et al*. (2019).

4.4.5 Days to harvest:

Days to harvest showed negative direct effect on yield per plot (-0.2976). High indirect effects were observed by root diameter (1.0080), leaf length (0.4212), crown diameter (0.1873), carotene content (0.0697), total soluble solids (0.0409), days to 50 % germination (0.0255), and negative effect was observed through number of leaves per plant (-0.0029), plant height at harvest (-0.087), core diameter (-0.1148), root : shoot ratio (-0.1526), root length (-0.1585), root weight (-0.2188) and flesh thickness (-0.9364) as similar to those of Thakur (2010).

4.4.6 Crown diameter (cm):

Negative direct effect of crown diameter was recorded for yield per plot (-0.4156). Positive indirect effect was seen through flesh thickness (1.4010), root weight (0.532), plant height at harvest (0.2901), root length (0.2553), core diameter (0.2567), days to harvest (0.1341), number of leaves per plant (0.0082) and negative indirect effect was observed through dry matter content (-0.0004), days to 50 % germination (-0.0089), carotene content (-0.0192), root : shoot ratio (-0.0549), total soluble solids (-0.0536), leaf length (-0.3100) and root diameter (-1.726). Similar results were reported by Thakur (2010), and Ahmed *et al*. (2019).

4.4.7 Core diameter (cm):

Core diameter showed positive direct effect on yield per plot (0.3514). Positive indirect effect was seen via flesh thickness (0.5471), root weight (0.4289), root length (0.3492), root : shoot ratio (0.1126), days to harvest (0.0972), number of leaves per plant (0.0931), carotene content (0.0465), dry matter content (0.0024) and negative indirect effect was observed through plant height at harvest (-0.0073), total soluble solids (-0.0423), days to 50 % germination (-0.0405), leaf length (-0.2460), crown diameter (-0.3036), and root diameter (-1.3182) as similar to those of Kaurav (2016) and Ahmed *et al*. (2019).

4.4.8 Root length (cm):

Root length reflected positive direct effect on yield per plot (0.6519). Positive indirect effect was observed through plant height at harvest (0.6301), flesh thickness (0.3372), root weight (0.2348), core diameter (0.1882), days to harvest (0.0723), carotene content (0.0337), dry matter content (0.0005) and negative effect was observed through days to 50% germination (-0.0048), number of leaves per plant (-0.0082), total soluble solids (-0.0194), crown diameter (-0.1627), root : shoot ratio (-0.2458), leaf length (-0.3414) and root diameter (-0.7396). These results are in line with Tewatia *et al*. (2000), Yadav *et al*. (2009), Thakur (2010) and Priya and Santhi (2015).

4.4.9 Root diameter (cm):

Root diameter showed negative direct effect on yield per plot (-1.9144). High indirect effect was shown by flesh thickness (1.6978), plant height at harvest (0.5936), root weight (0.4736), root length (0.2519), core diameter (0.2420), days to harvest (0.1567), number of leaves per plant (0.0079), days to 50% germination (0.0033), and negative effect was observed through carotene content (-0.0419), total soluble solids (-0.0725), root : shoot ratio (-0.2503), leaf length (-0.3482) and crown diameter (-0.3747). Singh *et al*. (2005), Priya and Santhi (2015) and Teli (2016) also studied the direct effects of root diameter on yield.

4.4.10 Root weight (g):

Positive direct effect was observed through root weight on yield per plot (0.5331). Flesh thickness (1.2801), root length (0.2871), core diameter (0.2888), plant height at harvest (0.1915), days to harvest (0.1222), root : shoot ratio (0.0781), number of leaves per plant (0.0655), dry matter content (0.0020) showed high indirect effects on root weight. While negative indirect effect was recorded for carotene content (-0.0187), days to 50 % germination (-0.0276), total soluble solids (-0.0569), leaf length (-0.3839), crown diameter (-0.4148), and root diameter (-1.7008). These results are in line with Bhatia *et al*. (2002), Yadav *et al*. (2009), Thakur (2010), Priya and Santhi (2015), Teli (2016) and Ahmed *et al*. (2019).

4.4.11 Root : shoot ratio:

Root : shoot ratio had positive direct effect on yield per plot (1.1302). Positive indirect effect was seen through root diameter (0.4239), carotene content (0.0784), days to harvest (0.0402), number of leaves per plant (0.0477), core diameter (0.0350), root weight (0.0368), crown diameter (0.0202), total soluble solids (0.0123), dry matter content (0.0026) and negative effect was showed through leaf length (-0.0019), days to 50 % germination (-0.951), root length (-0.1418), flesh thickness (-0.6741), and plant height at harvest (-1.6297). Similar findings reported by Thakur and Jamwal (2015), Teli (2016) and Kaurav (2017).

4.4.12 Flesh thickness (cm):

Positive direct effect of flesh thickness was recorded for root yield per plot (1.9021). Plant height at harvest (0.7885), root weight (0.3588), days to harvest (0.1465), root length (0.1156), core diameter (0.1011), and days to 50% germination (0.0296) showed positive indirect effects on flesh thickness. While negative indirect effect was observed through leaf length (-0.3070), number of leaves per plant (-0.0474), crown diameter (-0.3061), root diameter (-1.7088), root : shoot ratio (-0.4005), total soluble solids (-0.0695), dry matter content (-0.0014) and carotene content (-0.0843) as the findings of Teli *et al*. (2016).

4.4.13 Total soluble solids TSS (° Brix):

Total soluble solids had positive direct on root yield per plot (0.1502). Positive indirect effect was seen through root diameter (0.9241), leaf length (0.2076), crown diameter (0.1483), root : shoot ratio (0.0922), days to 50 % germination (0.0071) and negative effect was recorded for dry matter content (-0.0032), number of leaves per plant (-0.0343), carotene content (-0.0558), days to harvest (-0.0810), core diameter (-0.0989), root weight (-0.2020), plant height at harvest (-0.2214), flesh thickness (-0.8799), and root length (-0.0843) as similar to the results obtained by Yadav *et al*. (2009), Thakur (2010), and Thakur and Jamwal (2015) in carrot.

4.4.15 Dry matter content (%) :

Dry matter content showed positive direct effect on root yield per plot (0.0232). Positive indirect effect was seen via root shoot ratio (0.1267), root weight (0.0458), core diameter (0.0363), number of leaves per plant (0.0454), root length (0.0133), crown diameter (0.0077) and negative effect through days to harvest (-0.0014), root diameter (-0.0063), total soluble solids (-0.0208), days to 50 % germination (-0.0225), leaf length (-0.037), carotene content (-0.0386), flesh thickness (-0.1139), and plant height at harvest (-0.1674).

4.4.16 Carotene content (mg/100g) :

Negative direct effect of carotene content was recorded for root yield per plot (-0.2351). High indirect effect was seen through plant height at harvest (0.6632), flesh thickness (0.6817), days to harvest (0.0882), days to 50 % germination (0.0380), root weight (0.0423), total soluble solids (0.0356), and dry matter content (0.0038).While negative effect was observed through crown diameter (-0.0340), number of leaves per plant (-0.0477), core diameter (-0.0695), leaf length (-0.1062), root length (-0.0934), root diameter (-0.3412), and root shoot ratio (-0.3771). Similar results were reported by Yadav *et al*. (2009), Thakur (2010), Priya and Santhi (2015), Thakur and Jamwal (2015) and Teli (2016).

Table 4.7 Estimates of genotypic correlation coefficients of correlation among different characters in Carrot.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16
Y1	**1**															
Y2	-0.771**	**1**														
Y3	0.148	0.254*	**1**													
Y4	0.408**	-0.284*	0.061	**1**												
Y5	-0.219	-0.052	-0.716**	-0.018	**1**											
Y6	0.076	0.174	0.527**	0.053	-0.451**	**1**										
Y7	0.349**	-0.004	0.418**	0.600**	-0.327**	0.731**	**1**									
Y8	0.042	0.377**	0.580**	-0.053	-0.243*	0.392**	0.536**	**1**								
Y9	-0.029	0.355**	0.592**	0.051	-0.527**	0.902**	0.689**	0.386**	**1**							
Y10	0.238*	0.115	0.652**	0.422**	-0.411**	0.998**	0.805**	0.440**	0.888**	**1**						
Y11	0.819**	-0.975**	0.003	0.308*	-0.135	-0.049	0.100	-0.218	-0.221	0.069	**1**					
Y12	-0.255*	0.472**	0.522**	-0.306*	-0.492**	0.737**	0.288*	0.177	0.893**	0.673**	-0.354**	**1**				
Y13	-0.061	-0.133	-0.353**	-0.221	0.272*	-0.357**	-0.281*	-0.129	-0.483**	-0.379**	0.082	-0.463**	**1**			
Y14	0.194	-0.100	0.082	0.293*	0.005	-0.019	0.103	0.020	0.003	0.086	0.112	-0.060	-0.138	**1**		
Y15	-0.327**	0.397**	0.181	-0.308*	-0.296*	0.082	-0.198	-0.143	0.178	0.079	-0.334**	0.358**	0.237*	0.164	**1**	
Y16	-0.550**	0.813**	0.463**	-0.303*	-0.214	0.285*	0.069	0.626**	0.421**	0.236	-0.714**	0.513 **	-0.129	-0.120	0.247	**1**

*Significance at 5% level **Significance at 1% level

where Y1 = Days to 50% germination, Y2 = Plant height at harvest (cm), Y3 = Leaf length (cm), Y4= Number of leaves per plant, Y5 = Days to harvest, Y6 = Crown diameter (cm), Y7 = Core diameter (cm), Y8 = Root length (cm), Y9 = Root diameter (cm), Y10 = Root weight (g), Y11 = Root : shoot ratio, Y12 = Flesh thickness (cm), Y13 = Total soluble solids (°B), Y14 = Dry matter content (%), Y15 = Carotene content (mg/100g), Y16 = Total yield per plot (kg).

Table 4.8 Estimates of phenotypic correlation coefficients of correlation among different characters in Carrot.

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16
Y1	**1**															
Y2	-0.698**	**1**														
Y3	0.078	0.298*	**1**													
Y4	0.384**	-0.267*	-0.021	**1**												
Y5	-0.193	-0.062	-0.621**	-0.042	**1**											
Y6	0.075	0.170	0.468**	0.053	-0.441**	**1**										
Y7	0.245*	0.078	0.400**	0.279*	-0.186	0.477**	**1**									
Y8	0.042	0.344**	0.484**	-0.036	-0.239*	0.356**	0.420**	**1**								
Y9	-0.083	0.327**	0.544**	0.023	-0.439**	0.776**	0.609**	0.387**	**1**							
Y10	0.187	0.105	0.455**	0.229	-0.264*	0.701**	0.676**	0.386**	0.740**	**1**						
Y11	0.705**	-0.917**	-0.005	0.226	-0.108	-0.047	0.042	-0.188	-0.186	0.032	**1**					
Y12	-0.298*	0.350**	0.369**	-0.191	-0.406**	0.601**	-0.023	0.156	0.779**	0.398**	-0.267*	**1**				
Y13	-0.054	-0.120	-0.291*	-0.207	0.268*	-0.353**	-0.151	-0.113	-0.398**	-0.254*	0.071	-0.383**	**1**			
Y14	0.176	-0.096	0.071	0.265*	0.004	-0.018	0.058	0.017	-0.002	0.051	0.104	-0.049	-0.137	**1**		
Y15	-0.302*	0.382**	0.157	-0.280*	-0.290*	0.081	-0.125	-0.131	0.154	0.058	-0.311**	0.293*	0.235	0.164	**1**	
Y16	-0.424**	0.685**	0.338**	-0.261*	-0.187	0.258*	0.126	0.535**	0.308**	0.194	-0.559**	0.289*	-0.133	-0.103	0.221	**1**

*Significance at 5% level **Significance at 1% level , where Y1 = Days to 50% germination, Y2 = Plant height at harvest (cm), Y3 = Leaf length (cm), Y4= Number of leaves per plant, Y5 = Days to harvest, Y6 = Crown diameter (cm), Y7 = Core diameter (cm), Y8 = Root length (cm), Y9 = Root diameter (cm), Y10 = Root weight (g), Y11 = Root : shoot ratio, Y12 = Flesh thickness (cm), Y13 = Total soluble solids (°B), Y14 = Dry matter content (%), Y15 = Carotene content (mg/100g), Y16 = Total yield per plot (kg).

Table 4.9 Genotypic path coefficient analysis for direct and Indirect effects of component characters on yield in Carrot (*Daucus carota* L.)

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	GCCTYP
Y1	**-0.1162**	-1.2889	-0.0869	0.0632	0.0652	-0.0317	0.1226	0.0271	0.055	0.1266	0.9252	-0.4847	-0.0092	0.0045	0.0769	-0.550
Y2	0.0896	**1.671**	-0.1497	-0.0441	0.0155	-0.0722	-0.0015	0.2458	-0.6801	0.0611	-1.1023	0.8976	-0.0199	-0.0023	-0.0933	0.813
Y3	-0.0172	0.4252	**-0.5884**	0.0095	0.213	-0.219	0.1469	0.3783	-1.1329	0.3477	0.0036	0.9923	-0.053	0.0019	-0.0425	0.463
Y4	-0.0474	-0.475	-0.0359	**0.155**	0.0055	-0.0219	0.211	-0.0345	-0.098	0.2251	0.3481	-0.5816	-0.0332	0.0068	0.0723	-0.303
Y5	0.0255	-0.087	0.4212	-0.0029	**-0.2976**	0.1873	-0.1148	-0.1585	1.008	-0.2188	-0.1526	-0.9364	0.0409	0.0001	0.0697	-0.214
Y6	-0.0089	0.2901	-0.31	0.0082	0.1341	**-0.4156**	0.2567	0.2553	-1.726	0.532	-0.0549	1.401	-0.0536	-0.0004	-0.0192	0.285
Y7	-0.0405	-0.0073	-0.246	0.0931	0.0972	-0.3036	**0.3514**	0.3492	-1.3182	0.4289	0.1126	0.5471	-0.0423	0.0024	0.0465	0.069
Y8	-0.0048	0.6301	-0.3414	-0.0082	0.0723	-0.1627	0.1882	**0.6519**	-0.7396	0.2348	-0.2458	0.3372	-0.0194	0.0005	0.0337	0.626
Y9	0.0033	0.5936	-0.3482	0.0079	0.1567	-0.3747	0.242	0.2519	**-1.9144**	0.4736	-0.2503	1.6978	-0.0725	0.0001	-0.0419	0.421
Y10	-0.0276	0.1915	-0.3839	0.0655	0.1222	-0.4148	0.2828	0.2871	-1.7008	**0.5331**	0.0781	1.2801	-0.0569	0.002	-0.0187	0.236
Y11	-0.0951	-1.6297	-0.0019	0.0477	0.0402	0.0202	0.035	-0.1418	0.4239	0.0368	**1.1302**	-0.6741	0.0123	0.0026	0.0784	-0.714
Y12	0.0296	0.7885	-0.307	-0.0474	0.1465	-0.3061	0.1011	0.1156	-1.7088	0.3588	-0.4005	**1.9021**	-0.0695	-0.0014	-0.0843	0.513
Y13	0.0071	-0.2214	0.2076	-0.0343	-0.081	0.1483	-0.0989	-0.0843	0.9241	-0.202	0.0922	-0.8799	**0.1502**	-0.0032	-0.0558	-0.129
Y14	-0.0225	-0.1674	-0.048	0.0454	-0.0014	0.0077	0.0363	0.0133	-0.0063	0.0458	0.1267	-0.1139	-0.0208	**0.0232**	-0.0386	-0.120
Y15	0.038	0.6632	-0.1062	-0.0477	0.0882	-0.034	-0.0695	-0.0934	-0.3412	0.0423	-0.3771	0.6817	0.0356	0.0038	**-0.2351**	0.247

Where Y1 = Days to 50% germination, Y2 = Plant height at harvest (cm), Y3 = Leaf length (cm), Y4= Number of leaves per plant, Y5 = Days to harvest, Y6 = Crown diameter (cm), Y7 = Core diameter (cm), Y8 = Root length (cm), Y9 = Root diameter (cm), Y10 = Root weight (g), Y11 = Root : shoot ratio, Y12 = Flesh thickness (cm), Y13 = Total soluble solids (°B), Y14 = Dry matter content (%), Y15 = Carotene content (mg/100g), Y16 = Total yield per plot (kg), GCCTYP= Genotypic coefficient of variation total yield per plot.

Residual effect 0.10815

Diagonal figures represent the direct effect.

Plate : 3. High yielding genotypes of carrot

Madhuban

Durgapur- 4 - Red

Kashi Arun

Hisar Gairic

Plate : 4. Genotypes rich in carotene content with high TSS

Pusa Nayanjyoti

Pusa Yamdagini

Plate : 5. Genetic variability in carrot genotypes

Chapter – 5

SUMMARY AND CONCLUSIONS

The present investigation entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** was conducted from September 2020 to January 2021 at the Experimental Farm of Department of Vegetable Science at College of Horticulture & Forestry, Neri, Hamirpur, HP. The experimental material consists of twenty-three genotypes of carrot and was laid out in randomized complete block design with three replications. Observations were recorded on various characters viz. , days to 50% germination, plant height (cm), leaf length (cm), number of leaves per plant, days to harvest, crown diameter (cm), core diameter (cm), root length (cm), root diameter (cm), root weight (g), root : shoot ratio, flesh thickness (cm), total soluble solids (°B), carotene content (mg/100g) and total yield per plot (kg). Morphological characterization of genotypes was done on visual observations. The data was subjected to statistical analysis for variability parameters like mean, genotypic and phenotypic coefficient of variation, heritability, genetic advance as percentage of mean, correlation coefficient and path coefficient analysis.

The major findings of this study are as follows:

- Analysis of variance revealed highly significant differences among the genotypes for all the characters indicating the presence of variability.
- Based on the mean values with respect to characters, the genotype Madhubhan gave the highest total yield per plot (kg) followed by Durgapur-4-Red, Hisar Gairic, and Kashi Arun . Genotype Kashi Arun found promising for root length, root diameter, root weight, and flesh thickness which was statistically at par with Madhuban with respect to these traits. Madhuban was also found promising for showing maximum plant height and leaf length, earliest in germination and took minimum days to harvest. Nantes recorded minimum crown diameter and core diameter and was statistically at par with Pusa Yamdagini (standard check). Pusa Nayanjyoti had found promising for carotene content, root : shoot ratio, total soluble solids, and dry matter content and found

statistically at par with Pusa Yamdagini (standard check). Therefore, these genotypes can be used effectively for further breeding strategies after seeing their performance in other statistical genetic tools such as parameters of variability, correlation, and path coefficient analysis.

- Phenotypic coefficient of variation was greater in magnitude than the genotypic coefficient of variation for all of the characters, indicating the influence of environment in their expression. High magnitude of GCV and PCV were observed for root shoot ratio followed by plant height , total yield per plot, and carotene content. Moderate magnitude of GCV and PCV was observed for the traits like flesh thickness, root weight, leaf length, core diameter, days to 50% germination, crown diameter, root diameter and root length.
- High heritability accompanied with high or moderate genetic advance as per cent of mean was recorded for the characters *viz*., carotene content, dry matter content, crown diameter, total soluble solids, days to harvest, plant height, root : shoot ratio, days to 50% germination, number of leaves per plant, root length, total yield per plot, leaf length, flesh thickness, root diameter, and root weight. This indicates that additive gene action plays an important role in governing these characters and can be improved by effective selection.
- In the present study, genotypic correlation coefficients were higher in magnitude than phenotypic correlation coefficients for all the characters, which showed that although which meant that environment played lesser role in governing the phenotype of the carrot genotypes studied. Results indicated that total yield per plot was positively and significantly correlated with plant height , root length, flesh thickness, leaf length , crown diameter and root diameter while days to 50% germination showed negatively significant association.
- Path coefficient analysis revealed that the maximum positive direct effects towards total yield per plot was recorded for flesh thickness followed by plant height, root : shoot ratio, root length, root weight, total soluble solids, number of leaves per plant and dry matter content. Negative direct effects on total yield per plot was recorded for days to 50% germination, and days to harvest. Thus, indicating importance of selection for bringing genetic improvement in yield.

Table: 5.1. List of promising genotypes for different characters studied in Carrot (*Daucus carota* L.)

Characters	Genotypes	Mean
Days to 50% germination	Madhuban	7.00
	CA-COHFNERI-1	7.67
	Pusa Rudhira	7.67
Plant height at harvest (cm)	Madhuban	111.47
	Durgapur-4- Red	95.83
	VRCAR -198	93.17
Leaf length (cm)	Madhuban	84.03
	Durgapur-4- Red	73.53
	VRCAR -198	71.10
Number of leaves per plant	Pusa Vrishti	12.67
	VRCAR-96	9.67
	VRCAR-85	9.53
Days to root harvest	Madhuban	85.00
	CA-COHFNERI-3	86.33
	CA-COHFNERI-2	86.33
Crown diameter(cm)	Nantes	2.08
	Pusa Yamdagini	2.09
	VRCAR-109	2.32
Core diameter(cm)	Nantes	1.02
	Pusa Yamdagini	1.09
	Pusa Rudhira	1.24
Root length(cm)	Madhuban	27.33
	Kashi Krishna	26.50
	Punjab Black Beauty	26.33
Root diameter(cm)	Kashi Arun	4.42
	Hisar Gairic	4.02
	VRCAR-96	4.00
Root weight (g)	Kashi Arun	125.20
	VRCAR-198	109.93

	VRCAR-96	109.20
Root : shoot ratio	Pusa Nayanjyoti	4.14
	Pusa Yamdagini	3.86
	Nantes	3.77
Flesh thickness (cm)	Kashi Arun	2.68
	Madhuban	2.27
	CA-COHFNERI-3	2.25
TSS (⁰B)	Pusa Nayanjyoti	7.00
	Pusa Yamdagini	6.97
	Madhuban	6.05
Dry matter content (%)	PC-161	14.23
	Pusa Rudhira	13.83
	VRCAR-96	13.45
Carotene content (mg/100g)	Pusa Nayanjyoti	26.61
	Kashi Arun	25.84
	CA-COHFNERI-2	25.83
Total yield per plot (kg)	Madhuban	6.00
	Durgapur-4-Red	5.97
	Hisar Gairic	4.87
	Kashi Arun	4.63

CONCLUSIONS :

- ✓ On the basis of overall mean performance of the genotypes, Madhuban, Kashi Arun, Durgapur-4-Red, and Hisar Gairic were found superior for total yield per plot and other important horticultural traits.

- ✓ For quality parameters like carotene content and total soluble solids Pusa Nayanjyoti and Pusa Yamdagini were found promising.

- ✓ Higher estimates of genotypic (GCV) and phenotypic coefficient of variation (PCV) were observed for root shoot ratio followed by plant height , total yield per plot, and carotene content.
- ✓ High heritability was observed for the characters carotene content , dry matter content, crown diameter, total soluble solids, days to harvest, plant height, root shoot ratio, days to 50% germination, no. of leaves, root length.

- ✓ The highest genetic advance as per cent of mean (genetic gain) was recorded for the trait root : shoot ratio, plant height, carotene content and total yield per plot.

- ✓ Positive and significant correlation of total yield per plot was observed with plant height, root length, flesh thickness, leaf length , crown diameter and root diameter.

- ✓ Path coefficient analysis revealed that the maximum positive direct effects towards total yield per plot was recorded for flesh thickness followed by plant height, root : shoot ratio, root length, and root weight. Thus, indicating importance of selection for bringing improvement in yield.

LITERATURE CITED

Ahmed N, Singh S R, Ranjan J K, Srivastava K K, Kumar D. and Yousuf S. 2019. Assessment of Genetic variability, character association, heritability, and path analysis in European Carrot (*Daucus carota* L.). *Indian Journal of Agricultural Sciences* **89:**1140–44.

Ahmed N and Tanki M l. 1992. Variability, heritability, and genetic advance in Carrot (*Daucus carota* L.). *Haryana Journal of Horticultural Science* **21:**311-13.

Al-Jibouri H A, Miller P A. and Robinson H F. 1958. Genotypic and environmental variance and covariance in upland cotton crosses of inter specific origin. *Agronomy Journal* **50:**633-37.

Allard R W. 1960. *Principles of Plant Breeding*. John Wiley and Sons Inc., New York. 485p.

Alves J C, Peixoto J R, Vieira J V. and Boiteux L S. 2006. Heritability and genotypic correlation among leaf and root traits in carrot, cultivar Brasilia progenies. *Horticultura Brasileira* **24:**363-67.

Amin A and Singla J. 2010. Genetic variability, heritability and genetic advance studies in Carrot (*Daucus carota* L.). *Electronic Journal of Plant Breeding* **1:**1504-08.

Anand V. 2001. Genetic evaluation and correlation studies in some cultivars of European carrot. M .Sc. Thesis. Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, India. 78p.

AOAC. 1970. Official Methods of Analysis of the Association of Official Analytical Chemists (Ed. William Horewitz). Benjamin Franklin Station, Washington, D.C.

AOAC.1990. Official Methods of the Analysis of the Association of Official Analytical Chemists (Ed. William Horewitz). Benjamin Franklin Station, Washington, D.C.

Asima A, Kumar S P. and Parveen W K. 2013. Genotypic variation for quantitative and qualitative traits in Asiatic and European Carrot (*Daucus carota* L.*). Indian Journal of Plant Genetic Resources* **26:**151–54.

Anonymous. 2018. *Indian Horticulture Database*. Published by National Horticultural Board, Ministry of Agriculture, Govt, of India. pp. 152-59.

Banga O. 1976. Carrot (*Daucus carota* L.) (Umbelliferae). In: Evolution of Crop Plants (Simmonds, N W (eds). Longman Publisher, New York, USA. pp. 291-293.

Begum S. 2018. Morphological, nutritional, and molecular characterization of rainbow carrots (*Daucus carota* L.) and their phylogenetic assessment. M. Sc. Thesis. Department of Biotechnology and Crop Improvement, University of Horticultural Sciences , Bagalkot. 179p.

Bhagchandani P M and Choudhury B. 1980. Correlation and path coefficient studies in carrot. *Indian Journal of Agricultural Science* **50:**663-66.

Bhatia M K, Baswana K S. and Dharamveer D. 2002. Correlation and path analysis in Carrot (*Daucus carota* L.). *Haryana Journal of Horticultural Sciences* **31:**227-29.

Brar J S and Sukhija B S. 1980. Variability, heritability, and genetic advance in Carrot (*Daucus carota* L.). *Journal of Research*, *Punjab Agricultural University* **17:**442–43.

Burton G M and De Vane E H. 1953. Estimating heritability in tall Fescue (*Festuca arundineacea*) from replicated clonal material. *Agronomy Journal* **45:**478-81.

Dewey D R and Lu K H. 1959. A correlation and path analysis of components of crested wheatgrass seed production. *Agronomy Journal* **51:**515-18.

Dhillon H S, Dhillon T S. and Devi R. 2016. Quality characterization in carrot (*Daucus carota* L.) Germplasm. *Indian Journal of Ecology* **43:**330-2.

Dod V N, Kale V S, Nagre P K. and Wagh A P. 2013. Genetic variability correlation studies in Carrot (*Daucus carota* L.). In: National Symposium on Abiotic and Biotic Stress Management in Vegetable crops, held at IIVR, Varanasi India, 9 April 2013. pp. 32-33.

Gill H S and Kataria A S. 1974. Some biochemical studies in European and Asiatic varieties of carrot. *Current Science* **43:**184-85.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research*. 2nd ed. John Wiley & Sons Inc, New York. 427p.

Gupta A J and Verma T S. 2007. Studies on genetic Variability and selection parameters in European Carrot.*Haryana Journal of Horticultural Sciences* **36:**166–68.

Gupta A J, Verma T S, Bhat R. and Mufti S. 2012. Studies on genetic variability and character association in temperate carrot. *Indian Journal of Horticulture* **69:**75–78.

Harland S C. 1939. *The genetics of cotton.* Janathan Cape, London.

Hussian K and Ahmed N. 2007. Genetic divergence in Carrot (*Daucus carota* L.) genotypes using multivariate methods. *Haryana Journal of Horticultural Sciences* **36:**356-58.

Jadhav, P S. 2009. Performance of carrot (*Daucus carota* L.) genotypes under Marathwada conditions. M. Sc. Thesis. Department of Horticulture, College of Agriculture, Marathwada Agricultural University, Parbhani. 121p.

Jain Y P, Dod V N, Nagare P K. and Kale V S. 2010. Genetic Variability in Carrot (*Daucus carota* L.). *Asian Journal of Horticulture* **5:**514–16.

Johnson H W, Robinson H F. and Comstock R E. 1955. Estimates of genetic and environmental variability in soybeans. *Journal of Agronomy* **47:**314-18.

Kaurav A. 2017. Genetic Studies of Yield and Yield Attributing Traits in Carrot (*Daucus carota* L.). M. Sc. Thesis. Department of Horticulture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur. 74p.

Kaur P, Cheema D S. and Chawla N. 2005. Genetic Variability, heritability, and genetic advance for quality traits in Carrot (*Daucus carota* L.). *Journal of Applied Horticulture* **7:**130–32.

Kulkarni C C, Manikanta D S, Poleshi C A, Cholin S S, Raghavendra G, Ambika D S. and Patil B B. 2019. Character Association Studies by Correlation Estimates of Diverse Carrot Germplasm Lines Evaluated under Tropical Climate. *Journal of Pharmacognosy and Phytochemistry* **8:**1453–58.

Kumar A, Pal A K. and Kumar S. 2011. Genetic variability, correlation, and path analysis in Asiatic carrot. *Indian Journal of Horticulture* **68:**433-37.

Kumari A, Kumar M. and Kohli U K. 2008. Genetic parameters and character association in garden pea (*Pisum sativum* L.) cultivars. *Vegetable Science* **35:**160-64.

Kumar N, Nigam A. and Pathak A K. 2021. Studied on genetic variability, heritability and genetic advance in some cultivated genotypes of carrot (*Daucus carota* L.) under two different seasons. *The Pharma Innovation Journal* **10:**324-35.

Kumar R, Kanwar M S, Dogra B S. and Kansal S. 2010. Genetic evaluation of European carrots (*Daucus carota* L.) in mid-hills of Himachal Pradesh. *Crop Improvement* **37:**73-9.

Liang G H and Walter T L. 1968. Heritability estimates and gene effects for agronomic traits in grain sorghum, sorghum vulgate pers. *Crop Science* **8:**77-81.

Meghashree J R, Hanchinamani C N, Hadimani H P, Nishani S, Ramanagouda S H. and Kamble C. 2018. Genetic variability studies for different attributes in carrot genotypes (*Daucus carota* L.) under Kharif Season. *International Journal of Current Microbiology and Applied Sciences* **7:**3419–26.

Meghashree J R. 2018. Seasonal response of carrot (*Daucus carota* L.) genotypes for yield and quality parameters. M. Sc. Thesis. Department of Vegetable Science, Kittur Rani Channamma College of Horticulture, Arabhavi. 207p.

Mugniev A F. 1991. Correlation and their importance in breeding carrot. *Vestnik Sel's Kokhozyaistvennoi Nauki Moskva* **3:**318-28.

Nagaraja B. 1988. Variability, Heritability, Correlations and Path Analysis in Carrot (*Daucus Carota* L.). M. Sc. Thesis. Department of Horticulture, University of Agricultural Sciences, Bangalore. 119p.

Nicolle C, Simon G, Rock E, Amouroux P. and Remesy C. 2004. Genetic variability influences carotenoid, vitamin, phenolic, and mineral content in white, yellow, purple, orange, and dark orange carrot cultivars. *Journal of the American Society for Horticulture Science* **129:**523-9.

Poleshi C A . 2016. Morphological, biochemical, and molecular characterization of carrot (*Daucus carota* L.) genotypes under tropical region. M. Sc. Thesis. Department of Biotechnology and Crop Improvement. 155p.

Poleshi C A, Cholin S, Manikanta D S. and Ambika D S. 2017. Genetic variability for root traits in carrot (*Daucus carota* L.) evaluated under tropical condition. *Annals of Horticulture* **10:**224-27.

Prasad A and Prasad L. 1980. Genotypic and phenotypic variability in a collection of carrot varieties. *Progressive horticulture* **11:**21-25.

Priya P A and Santhi V P. 2015. Variability, character association and path analysis for yield and yield attribute in Carrot *(Daucus carota* L.). *Electronic Journal of Plant Breeding* **6:**861–65.

Rai N and Yadav D S. 2007. Carrot. In: *Advances in Vegetable Production.* Research co. Book center Publisher, New Delhi. 669p.

Rana M K. 2008. *Olericulture in India*. Kalyani Publishers, New Delhi. 363p.

Robinson H F, Comstock R E and Harvey P H. 1949. Correlation and path analysis in egg plant (*Solanum melongena* L.). *Indian Journal of Agricultural Research* **42:** 232-34.

Robinson H F, Comstock R E. and Harvey P H. 1951. Genotypic and phenotypic correlation in corn and their implication in selection. *Agronomy Journal* **43:**282-87.

Ross J A and Kasum C M. 2002. Dietary flavonoids: bioavailability, metabolic effects, and safety. *Annual review of Nutrition* **22:**19-34.

Rubatzky V E, Quiros C F. and Simon P W. 1999. *Carrots and related vegetable Umbelliferae*. CABI publishing.

Salunkhe D K and Kadam S S. 1998. *Handbook of Vegetable Science and Technology*. Publisher Marcel Dekker Inc., New York. 7-9p.

Singh B, Pal A K, Pandy S. and Rai M. 2005. Correlation and path coefficient analysis in Asiatic Carrot (*Daucus carota* L.). *Vegetable Science* **32:**136-39.

Singh D, Dhillon T S. and Singh R. 2020. Characterization for different traits in Asiatic and European type carrot (*Daucus carota* var. *sativa* L.) germplasm lines. *International Research Journal of Pure and Applied Chemistry* **21:**26–32.

Singh R, Sukhija B S. and Hundal J S. 1989. Correlation and path coefficient studies in carrot. Journal Research of Punjab Agricultural University **26:**581-84.

Surles R L, Weng N, Simon P W. and Tanumihardjo S A. 2004. Carotenoid profiles and consumer sensory evaluation of specialty Carrots (*Daucus carota* L.) of various colours. *Journal of Agricultural Food Chemistry* **52:**3417–21.

Teli S K. 2016. Character association and path analysis in carrot (*Daucus carota* L.). *The Ecoscan* **9:**463-67.

Teli S K, Kaushik R A, Ameta K D, Kapuriya V K, Mali D. and Teli L K. 2017. Genetic variability, heritability and genetic advance in carrot (*Daucus carota* var. *sativa* L.). *International Journal of Current Microbiology and Applied Sciences* **6:**2336–42.

Tewatia A S, Dudi B S. and Dahiya M S. 2000. Correlation and path coefficient analysis in carrot at different dates of sowing. *Haryana Journal of Horticultural Sciences* **29:**217-20.

Thakur H. 2020. Genetic divergence in European carrot (*Daucus carota* L.). M. Sc. Thesis. Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni. 60 p.

Thakur N and Jamwal R S. 2015. Correlation coefficient and path analysis study in European carrot (*Daucus carota* L.). *Annals of Biology* **31:**97-100.

Thakur R. 2010. Variation and association studies for some horticultural traits in Asiatic carrot (*Daucus carota* L.). M. Sc. Thesis. Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. 94p.

Vashisht P. 2007. Evaluation of temperate carrots for yield and quality attributes . M. Sc. Thesis. Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, India. 117p.

Vieira J V, Silva G O D. and Boiteux L S. 2012. Genetic parameter and correlation estimates of processing traits in half-sib progenies of tropically adapted carrot germplasm. *Horticulture Brasileira* **30**:7-11.

Warshamana I K. 2005. Genetic parameters study for yield and quality traits in tomato. *International Journal of Chemical Studies* **3:**722-25.

Wright S. 1921. Correlation and causation. *Journal of Agricultural Research* **20:**557-85.

Yadav M, Tirkey S, Singh D B, Chaudhary R, Roshan R K. and Pebam N. 2009. Genetic variability, correlation coefficient, and path analysis in carrot. *Indian Journal of Horticulture* **66:**315-18.

APPENDIX-I

Mean metrological data during the study period (2020-21)

Month	TEMPERATURE		RELATIVE HUMIDITY (%)	RAINFALL (mm)
	MAX	MIN		
September	30.09	22.23	71.94	1.12
October	29.04	18.24	42.65	0.01
November	22.27	11.96	44.52	1.36
December	19.23	8.69	45.77	0.84
January	18.22	7.73	48.93	1.15

Source : Meteorological Observatory, Department of Soil Science and Water Management, College of Horticulture and Forestry, Neri, Hamirpur HP 177001

APPENDIX-II

Analysis of variance (ANOVA) for various horticultural traits in carrot

Source	Mean sum of squares		
Character	**Replications**	**Genotype**	**Errors**
	2	**22**	**44**
Days to 50% germination	1.406	14.241	0.830
Plant height at harvest (cm)	40.028	712.744	53.046
Leaf length (cm)	40.607	540.717	47.961
Number of leaves per plant	0.492	8.797	0.547
Days to root harvest	44.652	34.831	0.531
Crown diameter(cm)	0.005	1.133	0.002
Core diameter(cm)	0.220	0.274	0.089
Root length(cm)	1.761	31.153	2.379
Root diameter(cm)	0.221	0.940	0.104
Root weight (g)	290.590	1036.812	276.264
Root : shoot ratio	3.880	2.667	0.848
Flesh thickness (cm)	0.013	0.560	0.081
TSS (^{0}B)	0.018	1.749	0.009
Dry matter content (%)	0.013	5.494	0.004
Carotene content (mg/100g)	0.078	184.008	0.039
Total yield per plot (kg)	0.200	8.637	0.716

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

Title of the thesis	**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh.**
Name of the Student	Deeksha Rana
Admission Number	NH-2019-42-M
Major Discipline	Vegetable Science
Minor Discipline	a) Genetics and Plant Breeding b) Plant Pathology
Date of Thesis Submission	
Total pages of the Thesis	82
Number of words in abstract	294
Major Advisor	Dr. B.S Dogra

Abstract

The present investigation entitled "**Genetic divergence studies in Carrot (*Daucus carota* L.) under low hill region of Himachal Pradesh"** was conducted during rabi season, 2020 at the Experimental Farm of Department of Vegetable Science, College of Horticulture & Forestry, Neri, Hamirpur, HP. The experimental material consists of twenty-three genotypes of carrot and the experiment was laid out in randomized complete block design with three replications to assess the nature and the extent of various genetic variability parameters and the association among the traits for yield and its component characters. Analysis of variance showed highly significant differences among all genotypes for all the characters. On the basis of overall mean performance of the genotypes, Madhuban, Kashi Arun, Durgapur-4-Red, and Hisar Gairic were found superior for total yield per plot and other important horticultural traits. Higher estimates of genotypic (GCV) and phenotypic coefficient of variation (PCV) were observed for root : shoot ratio followed by plant height, total yield per plot, and carotene content. High heritability accompanied with high or moderate genetic advance as per cent of mean was recorded for the characters *viz*., carotene content, dry matter content, crown diameter, total soluble solids, days to harvest, plant height, root : shoot ratio, days to 50% germination, number of leaves per plant, root length, total yield per plot, leaf length, flesh thickness, root diameter, and root weight. Positive and significant correlation of total yield per plot was observed with plant height, root length, flesh thickness, leaf length, crown diameter and root diameter. Further, path coefficient analysis revealed that the maximum positive direct effects towards total yield per plot was recorded for flesh thickness followed by plant height, root : shoot ratio, root length, and root weight. Thus, indicating importance of selection for bringing improvement in yield.

Signature of the Student
Name: Deeksha Rana
Date:

Countersigned

Signature of major advisor
Name: Dr. B.S Dogra
Date:

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

BRIEF BIO- DATA

Name : Deeksha Rana

Father's Name : Shri. Gurbaksh Singh

Mother's Name : Smt. Mamta Rani

Date of Birth : 26-08-1996

Permanent Address : VPO- Ganu, Tehsil- Ghanari
District- Una , H.P – 174319

E- mail : deeksharana519@gmail.com

Sex : Female

Marital Status : Unmarried

Nationality : Indian

Educational Qualifications :

Certificate / degree	Year	Board / University	Marks (%)	Class/grade
10th	2012	CBSE	87.4	First
12th	2014	CBSE	84.6	First
Graduation	2019	DR. Y.S Parmar University of Horticulture and Forestry, Nauni, Solan (H.P)	83.2	First

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Dated: **(Deeksha Rana)**